DEVELOPING A NUMERICAL PROTOTYPING TECHNIQUE FOR COMPOSITE MATERIAL STRINGED INSTRUMENTS USING TOPOLOGY OPTIMIZATION

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The increasing scarcity of high grade lutherie wood and growing customer awareness have motivated instrument makers to look for synthetic alternatives. Fibre reinforced composite materials are a good candidate to substitute for wood, while also increasing the design domain of the instrument's mechanical properties. By combining natural fibres, such as flax, and carbon fibres to replace wood in a stringed musical instrument part, the span of the possible mechanical properties of the part is far greater than what is possible with wood.

However, the current design of common stringed instruments is the results of decades of trial and error by skilled artisans, thus achieving a viable design using fibre reinforced composite materials is not a trivial task. To facilitate the integration of synthetic composite materials in the lutherie industry, a numerical prototyping technique was developed to generate composite material designs from the vibrational behaviour desired by luthiers. As the guitar is by far the most manufactured stringed instrument and its soundboard is the part for which the design has to most influence on the sound of the instrument, the prototyping method is focused on this part.

The guitar soundboard can be divided into two key components, the top plate, and the braces: the top plate is typically a constant 2.5 - 3.5mm thickness wood board and the braces are 5 - 12mm thick strips of wood glued in key places to reinforce the soundboard and to influence the sound produced by the instrument. To find the optimal design of a synthetic composite material meeting the vibrational behaviour expected by a luthier, the top plate is taken to be a fixed layup of reinforced composite material and the optimization problem is solved for the 2D topology of the braces, which are a second layup of reinforced composite material with a core material.

The optimization solver uses the Solid Isotropic Material with Penalization method, where the optimal material distribution is represented by a density function varying between 0 and 1 with intermediate density being penalized by an exponent. The objective function consists of a Reissner-Mindlin finite element plate model solved for its natural modes of vibration. The optimization criteria can either be finding a design with a given fundamental frequency of vibration, maximizing, or minimizing the frequencies of the natural modes of vibration of the soundboard.

To manufacture the soundboard corresponding to the optimal topology result, the density field is transformed into a 3D mesh and sliced to generate a 3D printing file. The 3D printed parts are then used as the core material with which the soundboard braces are manufactured and combined with the top plate. The braces are manufactured using the vacuum assisted resin transfer moulding process, the carbon fibres are draped on the 3D printed core then infused. An example of the design to manufacturing process is shown on figure 1, the optimization criteria used was the minimization of the total displacement under the tension of the guitar strings.

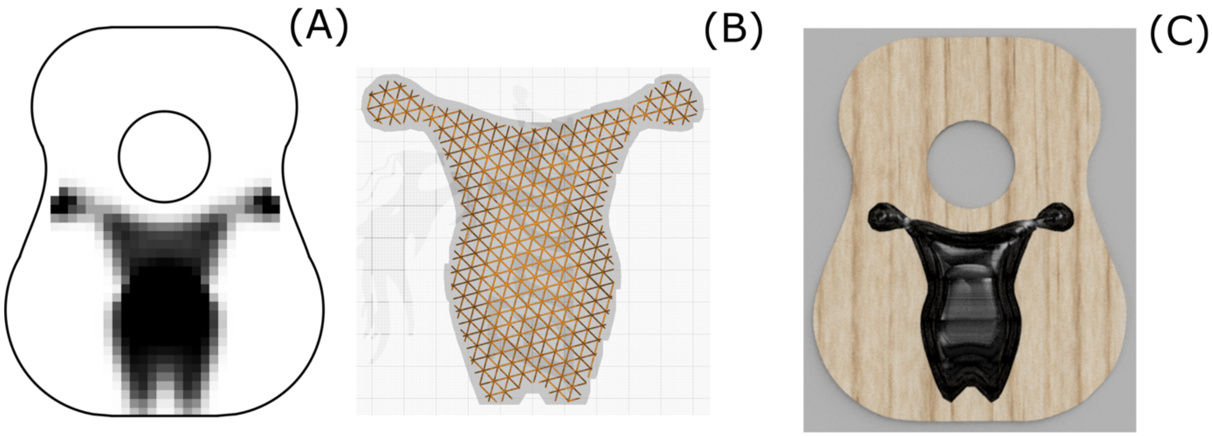

Figure 1: (A) Topology optimization density field with guitar outline, (B) Visualization of the 3D printing gcode of the exported mesh for the soundboard braces core, (C) Render of the underside of the finished flax fibre soundboard with carbon fibre bracing built with the 3D printing core (not shown).