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DESIGN, CONSTRUCTION, AND ACOUSTIC CHARACTERIZATION OF A FULLY FUNCTIONAL 3D-PRINTED GUITAR

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ABSTRACT

Crafting a guitar demands expertise and skill from the artisan in selecting the appropriate tonewood and working with it. Despite these efforts, the outcome remains highly unpredictable. The above is due to inherent variability in material properties and manufacturing procedures. In contrast, 3D printing, coupled with parametric modeling, enables precise control over structural characteristics, replicability, and quick prototyping. Furthermore, the printing process offers potential benefits, including reduced waste generation and the use of bio-based materials.

In this work, an interdisciplinary team of luthiers, designers, and scientists designed, constructed, and characterized a scaled-down, fully functional guitar with a modular design, enabling its fabrication in desktop 3D printers. Acoustic measurements were conducted compared to a mass-produced guitar, highlighting the need to improve certain key aspects of the printed one, such as sustain and low-frequency response. Despite that, the results pave the way for future studies to optimize materials and techniques to enhance the acoustic quality of 3D-printed instruments.

Keywords: *luthiery, 3D-printing, 3D-printed guitar*

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1. INTRODUCTION

The variability of wood's mechanical properties has been a significant challenge in consistently building musical instruments such as the guitar [1]. Considering this, additive digital manufacturing techniques emerge as an alternative to traditional instrument-making, allowing not only the replication of conventional models but also the development of new design alternatives that would be impossible to achieve with subtractive or manual techniques [2]. Regarding string instruments, preliminary studies have explored the FDM printing of functional violins and ukuleles [3-5].

This work presents a functional 3D-printed guitar model, designed as an assemblable modular structure and manufacturable using desktop 3D printers. The model has undergone acoustic studies to compare specific timbral properties with those of a low-cost, mass-produced wooden guitar. The sound production when playing open strings has been analyzed, and the instruments' frequency content and time response have been compared.

2. GUITAR DESIGN

At the beginning of the research, specific fundamental characteristics were established for the 3D-printed guitar model:

1. It had to be manufactured using desktop 3D printers with an approximate build volume of 220 mm × 220 mm × 220 mm. This decision aims to facilitate the instrument's fabrication in different work environments.

2. IIt needed to be easily assembled, minimizing the use of adhesives.

3. It had to be functional and capable of standard tuning, like a traditional acoustic guitar.

All these characteristics align to create a replicable model in manufacturing and assembly, making it accessible to audiences interested in instrument fabrication. Based on these requirements, a modular, thread-assembled design was proposed, inspired by an 1886 Torres model [6] and Latin American instruments with a *golpeador*. In these traditional chordophones, the section of the soundboard that covers the upper bout is overlaid with a rigid and dense wood.

Given the limited printing dimensions, the proposed design corresponded to a 1/4-scale guitar with a vibrating string length of 480 mm (see Fig. 1).

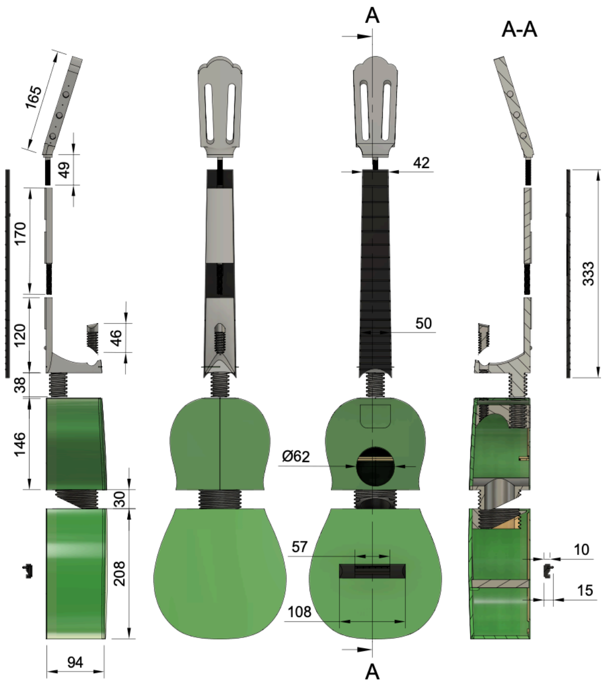

Figure 1. Main Dimensions of the Proposed 1/4 Guitar Model. The vibrating length is 480 mm.

3. MODEL SLICING

The slicing process was carried out using the open-source software Orca Slicer. The aim was to impart orthotropic properties to the printed components through specific printing parameters. To achieve these properties, printing directions were assigned following the grain orientation of the wood traditionally used in guitar making. For example, in the soundboard case, printing patterns were designed to align the primary strength direction to the strings, following the fiber orientation found in traditional soundboard construction. Fig. 2 shows details of the printing directions in the soundboard and bridge.

(a)

(b)

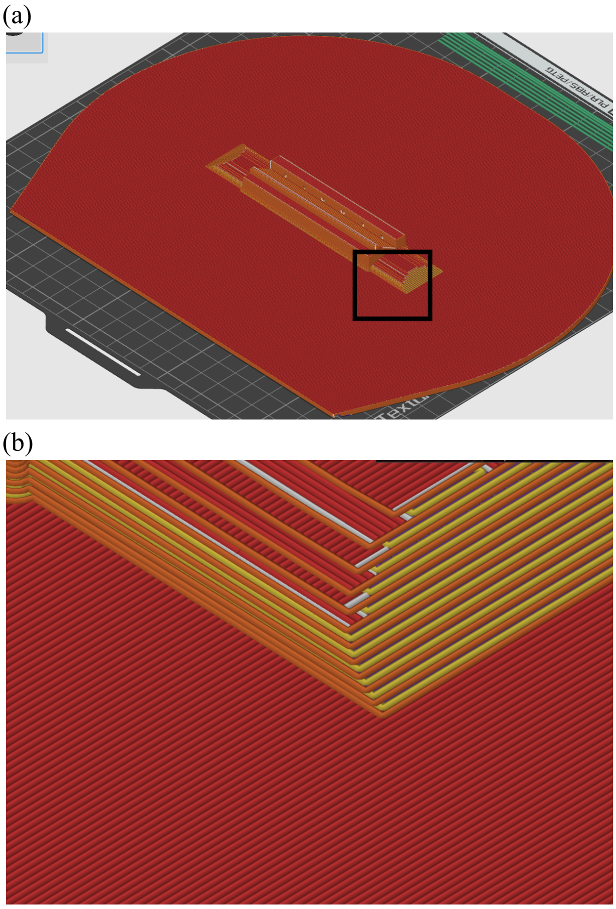

Figure 2. Printing orientation of the soundboard and bridge (a) View of the soundboard with the bridge attached. (b) Close-up showing details of the preferred orientations.

4. INSTRUMENT MANUFACTURING

PLA+ was used for manufacturing. Preliminary material characterizations were performed and elastic modulus measurements were conducted using tensile tests. The printing patterns corresponded to 100% infill of (a) longitudinal fibers "L" (aligned with the tensile direction) and (b) transverse fibers "T" (perpendicular to the tensile direction). Using a Type IV specimen, the tensile tests followed the ASTM D638 standard. The equipment used was an Instron testing machine, and the tests were conducted at a speed of 50 mm/s. The measured density was $\boldsymbol{\rho}$ = (1039 ± 214) kg/m³, with elastic moduli of $\mathbf{E_L}$ = (2.05 ± 0.03) GPa and $\mathbf{E_T}$ = (1.83 ± 0.04) GPa.

The printing time with a Bambu Lab X1 Carbon Combo printer was approximately 50 hours, while the assembly time was around 5 hours. The assembly process required post-processing of components, including support removal, thread cleaning, and minor adjustments.

Figure 3. 3D-Printed parts of guitars.

Finally, approximately 1 kg of filament was used. Fig. 3 shows various printed components. The tuning pegs and strings used are traditional. The guitar was strung with high-tension strings. Finally, Fig. 4 shows a fully assembled guitar.

Figure 4. Fully assembled printed guitar.

5. ACOUSTIC CHARACTERIZATION

For the acoustic characterization of the 3D-printed guitar, certain timbral attributes were compared with those of a reference guitar. The study involved recording the sound produced (a) when plucking each string individually in open position and (b) when strumming all strings open simultaneously.

The reference instrument was a 3/4 guitar (540 mm vibrating length), made of wood, mass-produced, and low-cost. This instrument was chosen for being the closest in price and size to the 3D-printed guitar.

The recordings were conducted in a semi-reverberant room, with the strings manually excited at L ~ (vibrating length)/3. A Dayton EMM-6 microphone was positioned 10 cm from the soundhole of each guitar, and a Focusrite Clarett interface was used for signal acquisition. The sound produced by each guitar was analyzed in both the time domain and the frequency domain.

In the time domain, the decay time was studied following the approach used in [7]. The RMS envelopes were obtained, and in the decay region, a function of the form $A_0e^{-t/\tau}$ was fitted. In this function, τ is the exponential time constant and corresponds to the time at which the signal amplitude has decayed to 36.8% of its maximum value. The results are shown in Fig. 5. It can be observed that while the decay constants for the strings tuned to E4 (~330 Hz) and D3 (~147 Hz) are practically the same, the strings tuned to A2 (~110 Hz) and E2 (~82 Hz) exhibit significantly longer decay times in the reference guitar. Despite the previous results, when evaluating the decay of the instruments when strummed with open strings, the decay times were practically identical.

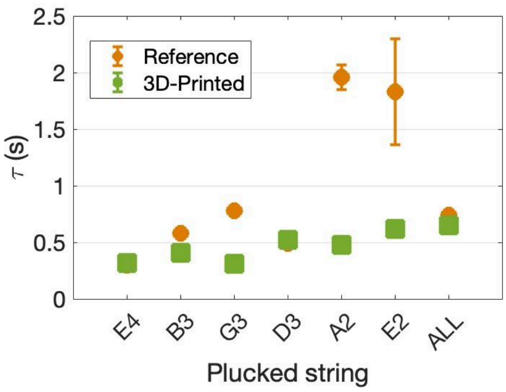

Figure 5. Time decay constant for open strings

In the frequency domain, the Power Spectral Density (PSD) was analyzed for each case. In general, the most significant differences appear in the low and mid-frequency ranges. In the low frequencies, the reference guitar exhibits a stronger response between 100 Hz and 200 Hz, whereas the 3D-printed guitar shows areas of greater response in the mid-frequency range. Figs. 6–8 show examples of the PSD obtained for the E2, E4, and all open strings cases.

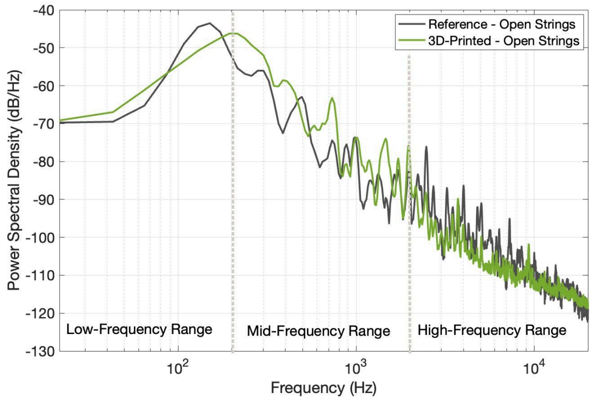

Figure 6. PSD for all open strings strummed.

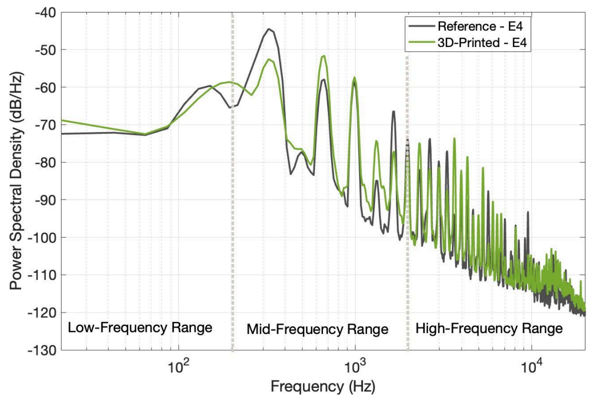

Figure 7. PSD for plucked E4 string.

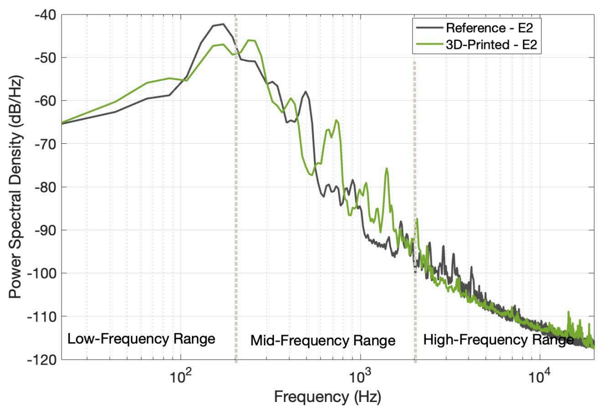

Figure 8. PSD for plucked E2 string.

6. CONCLUSIONS

Details on the design, slicing, and fabrication of a fully functional 3D-printed modular guitar were presented. The manufacturing time for the model is approximately 55 hours in a desktop machine, requiring around 1 kg of PLA+ filament.

The results demonstrate the feasibility of producing functional, low-cost instruments with rapid prototyping capabilities. This opens possibilities for both the construction of study guitars made from alternative, low-cost materials aimed at beginners and the development of scientific research using instruments built in a more controlled way compared to traditional wooden guitars.

Acoustic analyses generally show shorter decay times than those observed in wooden guitars, highlighting an area for improvement in future versions of the instrument. Additionally, a weaker low-frequency response is observed when compared to the reference instrument, which should also be addressed in the next stages of research.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] R. Viala, V. Placet and S. Cogan: "Simultaneous non-destructive identification of multiple elastic and damping properties of spruce tonewood to improve grading," *Journal of Cultural Heritage*, vol. 42, pp. 108-116, 2020.

[2] A. Zoran: "The 3D Printed Flute: Digital Fabrication and Design of Musical Instruments," *Journal of New Music Research*, vol. 40, no. 4, pp. 379-387, 2011.

[3] The Hovas, "Hovalin V5," Hovalabs. [Online]. Available: https://www.hovalabs.com/blog/hovalin-five/. [Accessed: 11-Feb-2025].

[4] OpenFab PDX, "Modular Fiddle," OpenFab PDX. [Online]. Available: https://openfabpdx.com/modular-fiddle/. [Accessed: 11-Feb-2025].

[5] P. Qian, N, Xiaoyu, L, Liangzhi, M. Junjie, Y. Shumeng, C. Zhuo, L. Jonghyun and F. Shengxue, "A comparison on sound quality of PLA 3-D printing ukulele and single board wooden ukulele," in *Proc. of Meetings on Acoustics*, (San Diego, California), p. 035007, 2019.

[6] R. Courtnall. *Making Master Guitars*. London: Robert Hale, 1993.

[7] S. Gonzales, M. Rau, C. Espinoza, G. Longo, F. Antonacci and A. Sarti, "Sound synthesis of geometric and material changes in archtop guitars: towards the timbral design of musical instruments" in *Proc. of Inter-Noise24*, (Nantes, France), pp. 6294-6303, 2024.