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Experimental-numerical correlation of the dynamic behavior of the Portuguese guitar

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A B S T R A C T

The Portuguese guitar is a pear-shaped plucked chordophone particularly known for its role in Fado, the most distinctive traditional Portuguese musical style. The acknowledgment of the dynamic behavior of the Portuguese guitar, specifically of its modal and mode shape response, has been the subject of a few researches. In this research, the experimental results of the dynamic behavior of the guitar, which were previously obtained, are correlated with a vibroacoustic finite element model of the guitar. The results of the correlation between experimental and numerical data are presented and the respective correspondence is discussed. The influence of the air inside the chamber on the computational results is shown to be crucial to characterize the low-frequency modes of the Portuguese guitar, whilst, for higher frequency modes, the geometry of the guitar assumes greater relevance. A comparison of the obtained results is also made with ones from the classical guitar, providing relevant information about the intrinsic differences between both, such as between their tones and other acoustical properties. These results represent a sustained base for future work on the Portuguese guitar, being as well an asset to the comprehension of its musical properties and qualities and may, furthermore, represent an advantage for its players and luthiers.

1. Introduction

Recently, guitars research studies have become popular in the scientific community. These studies typically present the dynamic behavior of the guitars using experimental modal analysis and/or numerical models, representing a strong asset to luthiers and their crave to produce better musical instruments. Studies can also be found regarding the influences of the guitar bodies on the modal shapes and dynamic behavior of the acoustic chambers. These theoretical and experimental works have shown that the materials and geometries of guitar bodies influence the vibration modes, the modal shapes and the dynamic response of the guitars [1–9].

For the Portuguese guitar, only a few studies are available in the literature [10–12] since its use is essentially confined to Portugal. Therefore, and in contrast to the classical guitar, there is little understanding of its effective dynamic behavior. The Portuguese guitar is a national star and it directly descends from the European cittern, possessing a pear-shaped feature of the resonance box, six double-string courses and a characteristic tuning. Furthermore, it requires a distinctive finger plucking technique. The two more common models of the Portuguese guitar are the Coimbra and Lisbon ones, which will differ between each other from their general dimensions, the intrinsic tuning and the arm-end decoration; the Coimbra version usually comes with bigger effective string lengths, a more resonant bass sound and a tear-shaped decoration near the tuning machine. For the Lisbon version, a more ornamented arm-end is used.

Regarding the few researches on the Portuguese guitar, Inácio et al. [10] performed experimental modal analysis on ten different guitars – both Coimbra and Lisbon ones -, having obtained the accelerance and the vibroacoustic frequency response for each. Tests were produced either with the sound hole opened or closed; this revealed that one of the lowest frequency peaks of both responses disappeared for the closed setup. Fig. 1 represents the results for one of the tested guitars, with the sound hole closed and opened. This phenomenon (which became evident in all the tested guitars) is associated with the Helmholtz resonance, and is usually found in air chambers with a hole to the exterior. With closed sound holes, there is no opening to the outside air and, therefore, the mode does not appear. This mode is one of the most relevant for the total sound radiation of the guitars and these results confirm the high dependence of the modal response of the guitar on the air inside the chamber and the respective sound hole. This result is a strong indicator that reliable models require not only the structural part of the guitar but also the air which is inside the respective chamber [6,13].

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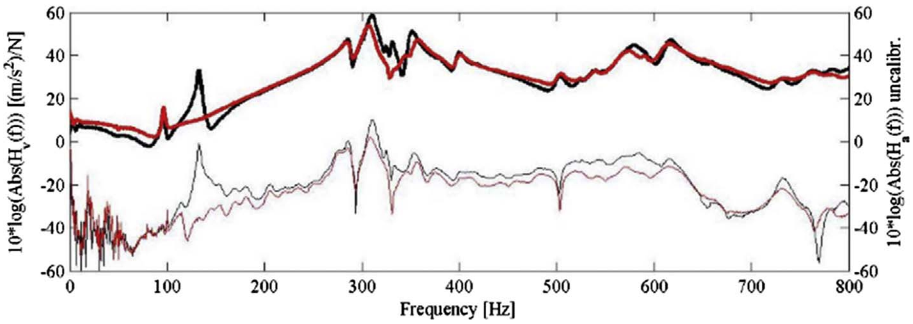

Fig. 1. Accelerance (H_a, top lines) and vibroacoustic (H_v, bottom lines) frequency responses of a Portuguese guitar: notice the disappearance of one frequency peak when the sound hole is closed [10].

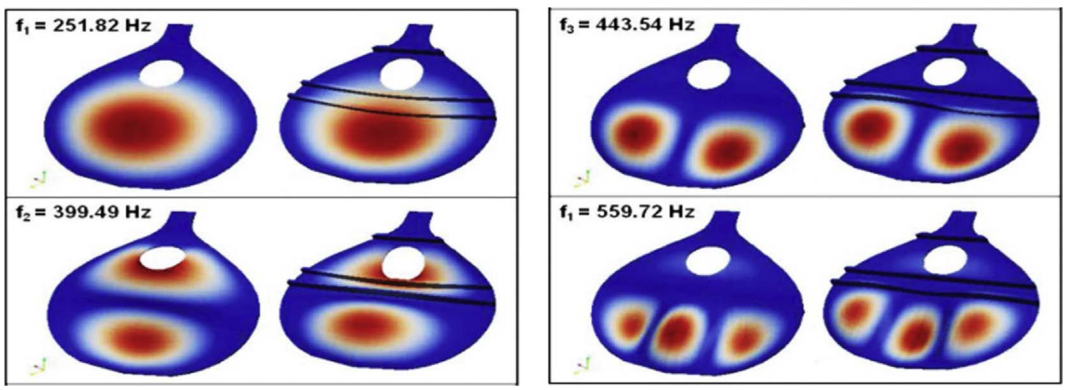

Fig. 2. Results of the FEM model for the first four structural modes [11].

Debut et al. [11] proposed a finite element model for the top soundboard (and its respective reinforcements) of a generic Portuguese guitar, using the CAST3M software and considering the materials as orthotropic. Results from this research are presented in Fig. 2, representing the first four modes identified by the developed model. In this model, the structural influences of the backplate and other parts of the guitar were not considered. The curvature of the top board is induced by the contact with the curved braces, promoting a pre-stressed condition for the analysis, since the board is originally plane. This implies that the obtained modes will differ from the ones from a plane board due to the induced curvature and to the pre-stressed condition.

There is currently no available literature which evaluates the computational behavior of the Portuguese guitar with its respective resonance chamber. Still, many authors have done similar researches for other types of guitars. For example, Paiva [14] produced a vibroacoustic model for the Brazilian guitar. The authors concluded that if the influence of the air inside the chamber was not considered, the obtained results would possess relevant mismatches with the experimental ones. With the inclusion of air, new modes appeared and others, that were already present in the structural model, became asymmetric. The influence of the internal reinforcements inside the guitar box was analyzed too, revealing that its disposal affects the higher frequency modes, whilst the low frequency ones depend more on the resonance chamber geometry. Elejabarrieta et al. [7] studied the influence of air inside the air chamber of a classic guitar using a coupled finite element model, and compared the obtained results with the experimental ones, describing, as well, each individual vibration mode. Other authors have done extensive research on the fundamental understanding of the dynamic behavior of guitars, such as Boullosa [3], Caldersmith [4] and Bécache [5].

Obtaining confident results for this type of computational guitar analyzes is quite difficult due to the complex geometries of guitars and the anisotropic characteristic of woods. Complex geometries arise from curved surfaces, purposeful asymmetry of different parts and difficulties on the identification of the exact position of reinforcements or the thickness of the soundboards and braces, for example. On the other hand, woods possess an anisotropic behavior due to the specific arrangement of cellulose on their layered cell walls [8]. Furthermore, woods have great importance on a guitar not only due to its acoustic influence, but as well to guarantee the necessary structural resistance over the time (especially on the high amplitude boards) and to respond to aesthetic requirements [15,16]. Usually, and to ease this type of analyzes, woods are not considered as anisotropic but as orthotropic materials. The most important parameters that characterize woods are the Young modulus, density and respective Poisson coefficients, stability with humidity, heat bendability and hardness, [8,15,17]. Damping takes special relevance as well, although it may be more difficult to evaluate and compare [15].

Although woods and their properties take special relevance in the created sound, it is the interaction between the strings and the soundboard the main mechanism behind this sound radiation [9,16]. In fact, strings alone do not radiate much sound, being the top soundboard the biggest responsible for this sound radiation [16]. The air chamber and the backplate radiate less sound [9,16,18], since they have no direct connection with the excited strings and because the player provides dampening to their movement [18].

The research presented here focuses on the generation of a coupled vibroacoustic model of the Portuguese guitar. This guitar has been experimentally tested before, where its effective modal shapes and related frequencies were obtained. The vibroacoustic model is based on a three-dimensional model of the Portuguese guitar, which is analyzed using a commercial finite element software. The external acoustic field of the guitar was not considered on this research, but will be suggested for future researches.

2. Methodology

2.1. Experimental modal analysis

The experimental data used during this project were obtained from a previous national project report [21]. The main goal of this research was to thoroughly characterize the experimental geometric shapes and