Considering Virtual & Physical Aspects in Acoustic Guitar Design

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ABSTRACT
This paper presents a new approach for designing acoustic guitars, making use of the virtual environment. The physical connection between users and their instruments is preserved, while offering innovative sound design. This paper will discuss two projects, *reAcoustic eGuitar,* the concept of a digitally fabricated instrument to design acoustic sounds, and *A Physical Resonator For a Virtual Guitar,* a vision in which the guitar can also preserve the unique tune of an instrument made from wood.

Keywords
Virtual, acoustic, uniqueness of tune, expressivity, sound processing, rapid prototype, 3D printing, resonator.

1. BACKGROUND
Each acoustic instrument made of wood is unique. Each piece of wood is different, leading to uniqueness of tune of the acoustic sound that is created. Both uniqueness and expressivity are the most important characteristics of the acoustic instrument. Digital instruments lack the uniqueness but usually allow more sound flexibility [1], by offering digital sound processing or synthesis [2].

Digital keyboard instruments have been significantly more successful than bowed or plucked instruments, which suffered from lack of expressivity and uniqueness of tune. On the one hand, the digital instrument can add new interfaces, controllers and sound abilities to the musical experience. On the other hand, there is a significant cost for modeling the captured information into a pre-defined digital structure. Besides the processing problem, it usually leads to decreasing or canceling the uniqueness of tune and expressivity of the instrument.

The main approach to deal with the expressivity problem lies in the field of sound processing, instead of synthesis. One option to this approach is to capture expressive signal and modify some parameters while preserving the expressive behavior [3].

We come to suggest a different approach. We believe that significant work can be done by combining benefits from both of the worlds (digital and physical) – preserving the values of acoustic instruments while applying digital control to their structures.

1.1. Acoustic, Electric and Virtual Guitar
The design of a guitar is influenced by its cultural context. For thousands of years lutes and afterwards guitars evolved: starting with ancient instruments that were made out of natural chambers (turtle shells, gourds), through fine handmade wooden chambers [4] to electrically amplified guitars. *Carfoot* [7] presents and analyzes the huge changes in guitar in the 20th century; electric guitars, which use electricity in order to amplify instead of chambers, evolved at mid century and were a part of the musical revolution of *Rock & Roll* and its distortion sound.

The guitar has been influenced by electrical technologies. It is to be expected that digital technologies will now take a significant part in the guitar evolution. While sound design has been conventionally done using digital software, expressive digital instruments are starting to appear as well. The *Line 6 Variax* [5] guitar gives a variety of preset sounds, from classic acoustic and electric tones to sitar and banjo. It allows the player to plug into a computer and customize a chosen tone. Expressive playing and sound flexibility is enhanced with the digital guitar. Another example is Fender's *VG Stratocaster* [6], a hybrid electric and digital guitar.

Carfoot uses the term *virtual* instead of *digital*. If *digital* defines the type of process being done, *virtual* refers better to an experience's context. Like *virtual reality,* the virtual sound created in digital environment imitates real life experience. This experience feels like a natural experience to our senses, but it was created with a computer model of that real life experience. In sections 2 and 3 we present our approach using the virtual sound experience in order to create a new physical guitar (a conceptual work). In section 4 we present a different vision in which the guitar can also preserve unique tune of a material (a work in progress).

2. COMBINING VIRTUAL AND PHYSICAL IN GUITAR DESIGN
3D design, sound design and digital music software are becoming common and easier to use. Their combination is leading to the possibility of designing, simulating and printing objects according to pre-required acoustic behavior.

Gershenfeld [8] presents a future realm in which personal 3D printers become as common as color printers. *RedEye RPM* [9] is a rapid prototyping company that creates guitars using digital manufacturing technology. Synthetic materials, such as carbon-fiber epoxy composites, could be used instead of wood in guitar soundboards [10]. *Blackbird Guitars* created the *Blackbird Rider Acoustic* [11], a commercial guitar digitally designed and made from composite materials. This kind of new material enables a significant decrease of the chamber's size while preserving the instrument loudness.

3. reACOUSTIC eGUITAR

Three perspectives are fundamental to the sound experience created by a musical instrument: the listener, the performer and the instrument constructor [12].

The vision of *reAcoustic eGuitar* invites players to become creators of their acoustic instruments and their sounds with endless possibilities for the sounds to be re-shaped. Players will customize their own sounds by assembling different small chambers instead of using a single large one. Each string has its own bridge; each bridge is connected to a different chamber. Changing the chamber size, material or shape will change the guitar's sound.

Designing sounds digitally allows the player to share the experience of the constructor. This might lead in a change of relationship between players and their instruments. Today rapid prototype materials have a broad range of qualities. Players can now take part in designing their own acoustic sounds, by modifying the physical structure of their instruments, revealing the characteristics of new materials (see Figure 1).

We created a simple chamber in rapid prototype process. This chamber adds a significant amplification to a single string (see Figure 2)[1], even without optimizing acoustical parameters as membrane thickness and sound box size.

In the *reAcoustic eGuitar* vision digital technology will be used to design the acoustic guitar structure (see Figure 3 for a design suggestion). It presents a novel sound design experience between users, their objects and the digital environment.

Re-designing the guitar according to the characteristics of rapid prototyping materials could lead to sound innovations. Open source and shared files environments could create a reality in which a player downloads or designs his own sound cells, and plugs them to his instrument (see Figure 4).

Starting from virtual sound, getting the desired virtual shape and then printing it, the *reAcoustic eGuitar* offers a new user experience for the guitar player.

The main disadvantage of the *reAcoustic eGuitar* concept lies in the rapid prototype process itself. The process is expensive and doesn't preserve uniqueness of tune as wood does. Perhaps in a few years, 3D printers will become less expensive and more accessible so this idea can be reconsidered.

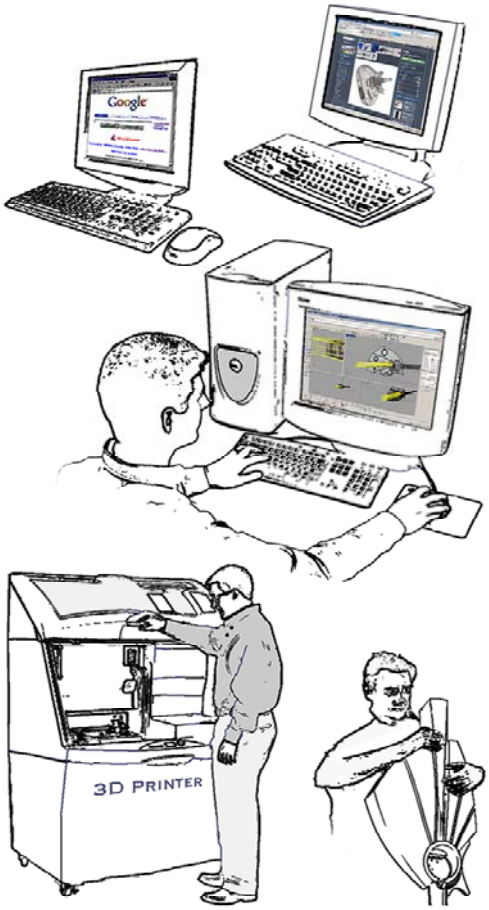

Figure 1: Constructing principles: Searching, downloading, modifying, printing and assembling the chambers.

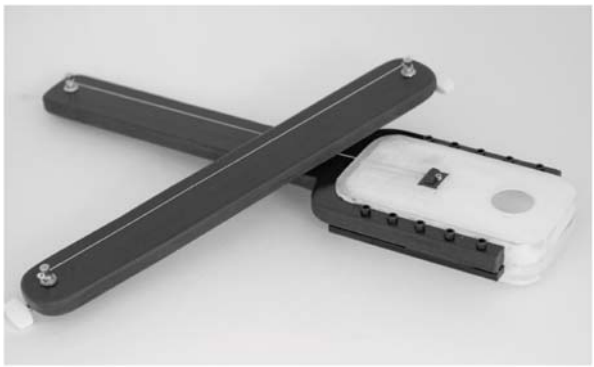

Figure 2: The 3D printed chamber connected to single string on a wood structure vs. string on a wood structure without a chamber.

[1] 3D printed chamber from *3D Systems InVision HR 3-D* is presented in ambient.media.mit.edu/projects.php, January 27, 2008.

Figure 3: *reAcoustic eGuitar*, a design suggestion.

Figure 4: Examples of different chambers.

4. A PHYSICAL RESONATOR FOR A VIRTUAL GUITAR

The former project led to a new vision*, A Physical Resonator For A Virtual Guitar.* It is a concept of combining the values of the virtual guitar with the uniqueness of the wooden acoustic guitar's tune. By doing so we can achieve expressive playability in a unique tool that also enables the player to design the required sound with the computer.

The uniqueness of a musical instrument influences more than just its sound. By differing itself from other instruments, it assumes an individual economic value and stabilizes a unique relationship with its owner. The structure of the wood is the main reason for the acoustic instrument's unique behavior. The grain of the soundboard [13], the wood's humidity, the exact thickness and more influence how it transfers different frequencies. Luthiers [14,15] used their experience in order to tune the instrument by making modification to the wood until it gave the required results.

A Physical Resonator For A Virtual Guitar focuses on the influences of the chamber on the sound of the acoustic guitar. The chamber's main parameters are the shape and material [14,15]. The structure and shape can be virtually designed on a computer and be used as a virtual chamber. The material will not be synthesized or modulated. In this way we will get a hybrid chamber – part of it is physical (the guitar's resonator) and part of it is virtual (see Figure 5).

A replaceable slice of the material (the guitar resonator) will be connected to the guitar bridge using mechanism that enables easy replacement. Piezo sensors will capture the frequencies being developed on the guitar's resonator. The signal will be transferred to a digital signal-processing unit (DSP). The DSP will modify the sound by simulating different chambers shapes and sizes, thickness and surface smoothness.

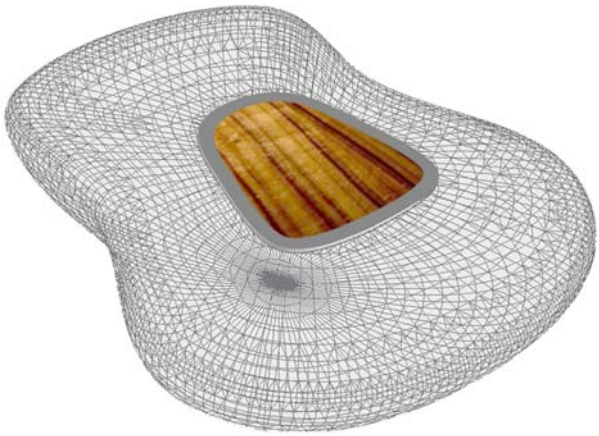

Figure 5: Physical resonator in virtual shape.

By combining the virtual with the physical, we believe we can preserve both worlds' values. More than that, the new approach of the physical resonator can play an important role in continuing the traditional relationship between players and their unique instruments. The digital part can be replaced and updated; the resonators can be collected and saved. A player could take one guitar body with many resonators, instead of a lot of guitars.
The use of a physical resonator is not limited to wood. The resonator can also be created in a rapid prototype process; similar to the concept presented in section 3.

5. CONCLUSION AND FUTURE WORK

We believe that the future of the guitar lies in the connection between digital sound design and acoustic experience. Digital processing can create new options for sound design, where the acoustic part of the instrument will give the expressivity and uniqueness of tune. The *reAcoustic eGuitar* concept is based on rapid prototype techniques and 3D printers. This process is expensive and not accessible to the majority of guitar players. There is not enough knowledge and experience of using rapid prototype for creating acoustic instruments. However, we believe that this may be more feasible in the future.

The *A Physical Resonator For A Virtual Guitar* is a work in progress. We believe that by creating a chamber that is part virtual and part physical, we will preserve expressivity and uniqueness of tune in digital sound design innovations. We intend to develop a working model for *A Physical Resonator For A Virtual Guitar.* This process will be divided into different parts - from mechanical solution for the replaceable resonator through development of piezo sensors system that will be able to capture the resonator vibration in different locations. We also intend to develop a DSP unit that will implement the digital modeling of the structure.

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