ABSTRACT

The guitar is a classic instrument that’s been around for hundreds of years. The sound quality of a guitar can be attributed to the wood used to construct it. However, sound quality is more qualitative than quantitative. A more expensive guitar is not necessarily a better guitar.
Introduction

The guitar, which is “a stringed musical instrument with a long, fretted neck, a flat somewhat violin like body, and typically six strings, which are plucked with the fingers or with a plectrum” [1] is one of the most well known instruments in the world. Researchers believe that the guitar originated from the guitarra latina, an instrument invented in Spain in the early 16th century [2]. Those guitars were composed of four strings, tuned to the notes C-F-A-D [2]. Nowadays, guitars are made with six strings, and are tuned to the notes E-A-D-G-B-E.

The primary material used in making guitar bodies is wood, and the two main parts of the guitar that use wood are the neck and the body. Different species of wood can be used for each part, or the same can be used. The species of the wood greatly changes the sound and tone of the instrument. Some of the common woods used include Alder, Ash, Basswood, Korina, Mahogany, Maple, Poplar, Rosewood and Walnut. Woods of the same species cut from different trees (or grown in different regions) will sound slightly different, and have different weights, different densities, and so on [3]. Taylor Guitars is one of the largest and most popular producers of guitars. The three most popular models are the 114ce, 214ce, and 814ce. Table 1 shows a summary of the price, and wood types of these three guitars.

<table>
<thead>
<tr>
<th>Guitar</th>
<th>Price (USD)</th>
<th>Wood Type Used</th>
</tr>
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<tbody>
<tr>
<td>114ce</td>
<td>1,058</td>
<td>Back/ Side – Layered Sapele</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Top – Sitka Spruce</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Neck – Sapele</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fretboard – Ebony</td>
</tr>
<tr>
<td>214ce</td>
<td>1,328</td>
<td>Back/ Side – Layered Rosewood</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Top – Sitka Spruce</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Neck – Sapele</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fretboard – Ebony</td>
</tr>
<tr>
<td>814ce</td>
<td>4,498</td>
<td>Back/ Side – Indian Rosewood</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Top – Sitka Spruce</td>
</tr>
</tbody>
</table>
From Table 1, it can be observed that the top three most popular guitars made by Taylor all have a Sitka spruce top and sapele or rosewood backs and ebony or mahogany fretboards.

Taylor Guitar says that, "While the rich tones of solid wood remain unmatched, a layered wood construction can yield great sound in a beautiful, durable and affordable instrument. Such is the case with layered sapele, in which we use interior and exterior veneers of sapele with a core layer of poplar between them" [4].

There have been many recent developments in guitar technology over the years. One such example is layering woods for the neck instead of using one solid piece. This allows for more flexibility where guitars with better sounds using lower quality wood could be achieved. Other innovations include the use of materials that are not necessarily wood, but are carbon fiber or fiberglass, or graphite. For example, Adamas graphite-top acoustic is better protected against temperature and humidity changes compared to the traditional spruce top [5]. Thermowood is another innovation being used for making guitars. Essentially, the wood is baked in an oven to create a vintage, crisp sound [6]. Lastly, Acoustic Resonance Enhancement (ARE) is a new way of treating wood. It is similar to thermowood in that "new wood matured with this technology produces a tonal richness like that of well-used vintage instruments" [7].

**Guitar Anatomy**

In a guitar, the sound comes from plucking or strumming the strings. The strings are connected to the neck and the body of a guitar through the saddle and the headstock. Figure 1 shows a diagram of a guitar and its different parts.
The body is what resonates the sound of the strings being plucked or strummed. The generally accepted design is for the sound hole to be in the center of the body, as this makes it more symmetric and appealing. However, this actually structurally weakens the soundboard, or top of the body. One important part of the body is the heeljoint. “The heeljoint refers to the curved block of wood that is usually found on an acoustic guitar at the point where the neck joins the body.” Steel strung guitars with a ‘traditional’ neck joint have a wood block inside the guitar and the neck is joined to this block with a dovetail joint. The dovetail is carved into the inside face of the heel and secured to a matching cavity in the body block with glue.

The neck is what holds the fretboard of a guitar. It is connected to the heeljoint of the body and on the other end is connected to the headstock. This is one of the most important parts of the guitar because this is where the feel of a guitar and its playability are most observable. Another part of the neck is the truss rod. It is a metal rod that is placed inside, along the length of the neck. It is used to stiffen the neck of the guitar as well as to “counteract the force of the strings, which tends to bend the neck forward.” The truss rod can also be adjusted to bend the neck at a higher or lower angle from the heel joint. This can change the feel of the guitar by either increasing or decreasing the space between

Figure 1: Diagram of a guitar [8]
the strings and the fretboard. A higher space makes the guitar harder to play, however if
the space is too small, there is a risk of the strings hitting the fretboard and producing an
unpleasant buzzing sound.

Different woods are used for the body of the guitar. “The top of soundboard woods are
usually chosen for their strength and acoustic properties while the sides, or rims, and back
woods are chosen more for their appearance and ability to be steam bent into curves for
the sides” [9]. For the neck, the most commonly used wood is mahogany as it carves easily
and has good longitudinal strength. Taylor uses another wood called sapele, and according
to them, “it’s sometimes mistakenly referred to as African mahogany because it closely
resembles the West African wood khaya, which is commercially known as African

**Tonewoods**

Tonewood is wood that creates a certain sound or tone when struck. “If a guitar’s body
shape produces the sonic equivalent of a meal, think of tonewoods as the seasoning” [12].
There are many types of wood available in the world, however, tonewoods are special
because they create a sound when struck and resonate that sound well. “Because of the
dynamics of the guitar, tonewoods for faces need to be different than tonewoods for backs,
if the instrument is to have the best and most even sound” [13]. “Lighter woods like mahogany
are said to have a dry and woody sound. The denser Rosewoods have a rich and bell-like sound,
while the denser-still Ebonies and Blackwoods are said to impart a deep, piano-like sound to the
guitar” [14].

For the top, spruce is the most popular wood to use (Table 1). “As a guitar soundboard, or
top, Sitka spruce is the tonewood standard of the modern era. It’s used on 85-90 percent of
the guitars that Taylor makes. Its combination of strength and elasticity translates into a
broad dynamic range, yielding crisp articulation and allowing for everything from
aggressive strumming and flatpicking to fingerpicking. Sitka spruce is Bob Taylor’s
personal favorite for an all-around great guitar” [15]. There are two types of spruce woods
used: (1) European Spruce, when bent or stressed, will crack and break because it is brittle. However, it creates very good overtones and a more full sound. (2) American Spruce is strong and will not break when bent or stressed, however it creates less overtones and a warmer feel. This is good for music such as folk.

Usually the top of the body is a different wood compared to the back of the body. “The best guitar backs are made of high quality hardwoods such as rosewood, ebony, maple, walnut, koa, mahogany, or a number of other suitable body woods” [13]. In the case of Taylor, their three most popular models have either a sapele, or a rosewood back. Traditionally, Brazilian rosewood has been used because of its high quality resonance. “When struck, a properly cut sample rings like a plate of glass” [13]. This is a great quality for a guitar because it helps with the resonance and will allow the guitar to sustain the sound for a longer time. The alternative to Brazilian rosewood is Indian rosewood. This has the same properties as the Brazilian rosewood, but is not as good at resonating and sustaining sound. The reason for an alternative is the declining amount of Brazilian rosewood.

To obtain wood, trees must be cut down from the forest. In the case of rosewood, Brazilian rosewood is one of the best choices. Because of this, Brazilian rosewood has become more scarce and is on CITES Appendix I, which means that even finished products of this wood are not allowed to cross international borders [16]. This is the main reason that Indian rosewood has been used as a substitute. The sound is very similar and Indian rosewood is more available. Another example of woods used in guitar that is becoming scarcer is Ebony. Ebony is used mostly in the neck and on fret boards. “The issue isn’t rocket science: ebony trees (in the Diospyros genus) are generally small and slow growing. Demand for ebony wood is very high: it’s a high quality hardwood that’s very hard, very strong, and most of all, very black” [17]. Most of the world’s ebony comes from third-world countries and so it has been exploited to near extinction. Taylor uses Macassar ebony and African ebony in their guitars. To obtain this ebony, they have purchased “Crelicam, an ebony mill located outside of Yaoundé, Cameroon” [18]. This is to ensure “that ebony is legally, sustainably, and ethically harvested” [18].
Scientific analysis of sound

The sound of a guitar is produced in the strings. The body is what resonates the sound and the type of wood is what ‘colors’ the sound. The bridge, which connects the strings to the body (more specifically the top), “transfers the vibrational energy of the strings to the top plate” [19]. The top then vibrates and transfers the vibrations to the air inside the body of the guitar and out the sound hole amplifying the sound. “The top plate is made so that it can vibrate up and down relatively easily. On the inside of the plate is a series of braces. These strengthen the plate” [20]. It is also necessary to note that the body does not “amplify” the sound in the traditional sense of the word. For comparison, in electric guitars, the vibration from the string disrupts the magnetic field around the pickup, which is a series of magnets, and the pickup sends this disruption to the amplifier to create a louder sound that can be heard through speakers [21]. In acoustic guitars, “all of the sound energy that is produced by the body originally comes from energy put into the string by the guitarist’s finger” [20]. The body then does the equivalent of what an amplifier does by strengthening the sound inside the body.

One of the main factors that affect the acoustic properties of wood is its density. “The most important acoustical properties for selecting materials for sound applications, such as musical instruments and building interiors, are the speed of sound within the material, the characteristic impedance, [and] the sound radiation coefficient” [22]. The grain of the wood and its direction affects the speed of sound. In a guitar, characteristic impedance is important between the bridge and the body. The two mediums have different impedances to sound and a careful ratio must be made by changing thickness of each medium.

“Sufficient vibratory energy must be transmitted form the string to the soundboard to make the strings vibrate audibly, while the energy should not be transmitted too readily or too rapidly, causing the vibrations of the string to die down quickly and their sound to resemble that of a thud” [22]. The sound radiation coefficient refers to the dampening of a vibration in a body due to sound radiation. This is important in guitars for how long they can sustain a sound.
With these properties in mind, a difference can be measured between new guitars and aged guitars. Luthiers and experienced guitar players will say that vintage guitars have a better tone and sound quality because of the aged wood. "One bit of science [Luthier Alan Carruth] has brought to the attention of the lutherie community is that wood consists mainly of cellulose, lignin, and hemicellulose, and that all wood gradually loses hemicellulose—a soluble polysaccharide—to evaporation over a long period of time" [23]. This means that as wood ages, it loses weight and tensile strength over time, but the stiffness is not lost as quickly. “As long as the tensile strength remains sufficient to withstand string tension, there is a net gain in one of the most important features of tonewood: the stiffness-to-weight ratio, which is known as Young's modulus” [23].

**Primary Research**

One of the biggest opinion differences in guitars comes in how a guitar sounds. This is because each person hears things differently than the person next to them listening to the same thing. They will hear the exact same soundwaves, however their brain will interpret it differently and the sound will give them a different feel. The sound of a guitar, while it can be somewhat quantified in terms of decibels, is more qualitative. For this very reason, I went to a music store, Long and Mcquade located in Vancouver, BC, and tested out the three Taylor guitars mentioned earlier. I played each one for about 20 minutes and played the exact same thing on each guitar. Here are the results.

**Taylor 114E (899 CAD)**

The only difference that this guitar has with the Taylor 114CE is that it lacks the cutaway in the body that allows players to reach higher frets with more ease. “The 114e defies the logic of most starter guitars by providing a really great-sounding instrument that extremely well-built. Laminated sapele back and sides and a solid spruce top make for crisp and well-defined sound in this versatile mid-priced guitar” [24]. In my opinion, this guitar felt heavier than the other two models. Purely on aesthetics alone, I was not a big fan. The dots on the frets, as well as the design on the soundhole, looked like they were painted on or were stickers. The sound was not too powerful, but good for plucking softly. I was hoping to hear
the bright warm sound that is associated with Taylor guitars, however I found the sound to be slightly dampened and more ‘twangy’. I could not hear the overtones as much and the notes were sustained for only a short time before sounding dead. This guitar is good for beginners because it was the easiest to play.

**Taylor 214CE (1,399 CAD)**

It’s “a glossy, solid Sitka spruce top meets gorgeous Indian rosewood laminate back and sides, delivering an experience of sight, sound and touch that’s unmistakably Taylor” [24]. In my opinion, this was exactly what Taylor guitars should sound like. It was bright and warm, perfect for strumming and light plucking. This guitar would play nicely with folk music or slow jazz. The playability was really easy and I found that I lost track of time while playing it. The sound was very full and filled the little room I was in with no effort. There was a slight hint of overtones, but nothing too obvious. I really liked the aesthetics of this guitar’s neck due to the wood grain of the layered rosewood. Overall, this was my favorite of the three and it was the most reasonably priced.

**Taylor 814CE (4,899 CAD)**

This guitar’s ”balance, warmth and articulation are great for fingerstyle, it has enough punch as a strummer to front a band, and the top-end power will fuel lead runs without getting shrill. It’s a great choice for a gigging player looking for one guitar that can cover it all” [25]. Aesthetically, it had pearl inlays on the marbled fretboard. The colors of the guitar were very eye catching and looked vintage. The sound was full and filled the entire room effortlessly, meaning you didn’t need to strum or pluck the strings as hard as you would on the other two. The overtones were very obvious and the sound was sustained for a longer period of time. The downside to this was that the neck was not as smooth because of a finishing varnish on it and the action (space between the fret and the strings) was much higher. This made the guitar less playable and it did not feel as nice to play as the Taylor 214CE.

After trying these three guitars, my favorite guitar in terms of sound and playability was the Taylor 214CE, although aesthetically, the Taylor 814CE was the best. I am not an expert
when it comes to guitars, however I have been playing for more than ten years and so I think this qualifies the observations I made about each guitar.

One interesting thing that I noticed was that all the guitars sounded the same when plugged in. This is probably due to the guitar pickup system being the same in all three guitars. When plugged into an amp, all the guitars sounded exactly the same, so the qualitative observations I made about the sound were nullified.

**Technological Advances**

New and innovative technology is being released everyday and this holds true for guitars. These technologies can range from improving the sound system that allows a guitar to plug into speakers, new materials for strings, and most importantly, changing the way the wood used for guitars is treated.

One innovative way of changing the wood in a guitar has been mentioned earlier. Layered wood, or more commonly known as laminated wood, is used in many guitars (for example the Taylor 114CE and Taylor 214CE). The laminated wood is composed of a layer of an expensive piece of wood over layers of cheaper pieces of wood. This makes the guitar less expensive. According to Taylor, “One of the benefits of layered wood for guitars is extra resilience in the face of fluctuating humidity conditions” [4]. One drawback of layered wood is that it has a flatter sound and does not produce as much volume as compared to a solid piece. This is because it does not vibrate as well due to its layers.

Yamaha is also developing a technology called ARE or Acoustic Resonance Enhancement. This new technology is a way of treating wood to make it have a mature sound and the tonal characteristics of vintage wood. One of the biggest things the affects wood in instruments is heat and humidity. What Yamaha found was that, “Young wood gives an edge and hardness to the sound, but, as the years pass by, it becomes more and more difficult for changes to occur and it produces a good deep, rounded sound” [26]. The way that Yamaha discovered to create this sound in young wood was by controlling the
humidity, temperature, and atmospheric pressure. This treatment affects the grain of the wood. “The hardening in the direction of the grain and softening across the grain of the wood achieved by the ARE treatment improves the clearness of the sound, making it unmuffled, and produces excellent resonance by enhancing low range sustain and increasing the attack in the medium- to high-range frequency bands” [26].

Another innovation that is worth looking at is thermowood, which is a process that was developed in Finland. Thermowood is essentially wood that has been heat-treated to increase its strength properties. The wood is treated at low oxygen levels to prevent it from burning. “Temperatures for the actual heat treatment period range from 150 °C to 240 °C, the time of the period is 0.5 to 4 h” [26]. A company named ‘Sago’ is using this thermowood in their guitars because it gives it a more vintage sound and makes it more durable. According to Sago, “balance between strings and frets will increase. Thermowood processing keeps the body size stable in humid Japan, preventing deformation of your instrument at home or in a car, or even against spotlights and heat of the audience at a performance” [6].

**Summary**

The guitar is a timeless instrument that is only getting more popular as the years go by. This popularity can be attributed to its convenient size, its playability, and the great sounds that it produces. There are many types of guitars and they are all made with the same general blueprint in mind. The differences are based on the wood chosen for specific parts and the shape in which each one is built. Other notable instruments that have a similar build and style of play include: ukuleles, mandolins, basses, and banjos.

The science behind the sound of a guitar can be summarized into the wood’s density and the stiffness to weight ratio (also known as Young’s modulus), as well as how the sound acts and moves inside the body of the guitar. The factors of the speed of sound in the guitar, its characteristic impedance, and sound radiation coefficient, all play a large part in the acoustic properties. These are specific things that can be measured with scientific
instruments inside a lab. Many works of literature go more in depth on the specifics of sound in an instrument; however, I have found that the sound of a guitar is dependent on the ear and sound perception of the person listening. When describing how a guitar sounds, the terms used are more qualitative than quantitative. The average guitar player would not be able to tell you the acoustic properties of the wood in their guitar, but they can tell you that it “sounds warm” or “it creates a bright tone and produces loud overtones.” None of these descriptive qualities are quantitative and is all based on the guitarist’s perception of the sound. Within the guitar community, there are disagreements on whether a vintage guitar sounds better than a newer guitar because of its aged wood. There has been research done to support this, such as the increase in stiffness as wood ages, but the advancements in wood treating technology is making those arguments null. Treatments have advanced to the point new or young wood is “aged” and thus the sound it produces is vintage. These advancements are also affecting new guitars in that cheaper guitars are sounding better even with lower quality wood. A more expensive guitar does not necessarily mean that it is going to be better sounding or more playable than an expensive one, as per my observation between the Taylor 814CE and Taylor 214CE.

The guitar is a classic instrument that has undergone many changes over the years. There are always more improvements to be made to bring it to the next level. It is exciting to see where technology is pushing the boundaries of guitar making and the sounds it can produce. From thermowood to acoustic resonance enhancement, the future of guitars looks bright. As a guitar player, I believe that the current state of the guitar is perfect, but I am eager to see the developments being made and where it will take this instrument that has been around for hundreds of years.
Appendix A – Common Tonewoods

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Latin Name</th>
<th>Average Dried Weight (kg/m³)</th>
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<tbody>
<tr>
<td>Sapele</td>
<td>Entandrophragma cylindricum</td>
<td>670</td>
</tr>
<tr>
<td>Sitka Spruce</td>
<td>Picea sitchensis</td>
<td>425</td>
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<tr>
<td>Macassar ebony</td>
<td>Diospyros celebica</td>
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<tr>
<td>Brazilian Rosewood</td>
<td>Dalbergia nigra</td>
<td>835</td>
</tr>
<tr>
<td>Indian Rosewood</td>
<td>Dalbergia latifolia</td>
<td>830</td>
</tr>
<tr>
<td>African Mahogany</td>
<td>Khaya spp.</td>
<td>640</td>
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References


