Glass World: Music, Sound Sources, and Space

by Austin Henry

Abstract

This work reviews the history of glass instruments and how they function, analyzes glass music, and identifies some of the qualities that make it unique. As glass instrumentation is not very common, this topic demands explication in contemporary music scholarship. This work will expound the compositional context of six glass instruments. This review contributes to the body of research on the topic of glass music with a new survey on composition techniques utilizing glass sources, as well as the resulting compositions.

Key Words: Glass, Composition, ADSR, Cloud-Chamber Bowls, Zymo-Xyl, Glass Harp, Glass Armonica, Verrophone, Glass Pan Flute, Physical Modeling, Helmholtz, Tubes, Plates

Glass Music History

Glass was invented in Mesopotamia in approximately 3600 BCE (Corning Museum of Glass, 2011). 'Singing' glasses have been traced as far back as 12th century China. It is unknown what year singing glasses were invented. The earliest European writings that mention glass music date back to 1492. Modelled after singing glasses, the glass harp was invented by Richard Pockrich in 1741 (GlassDuo, 2020). The more water in each glass, the lower the pitch produced when performed. These glasses draw comparison to bells. Both instruments share anatomical terminology in reference to their glass bodies: mouth, head, shoulder, waist, neck, and lip. Bell tone is produced by an inside hammer strike, as opposed to glass harp tone, produced by a wet finger. Finger playing is functionally a 'catch/slip,' the style of striking a violin bow. Each glass has a specific resonant frequency, allowing the player to control 'which bell is struck' (Zeitler, 2009).

Figure 1. The Glass (H)armonica, (Corning Museum of Glass, www.cmog.org)

Invented by Ben Franklin in 1761, the glass armonica (*Figure 1*), also known as glass harmonica, produces sound via the friction of fingertips on a moving glass bowl (Corning Museum of Glass, 2011). Foot movement moves the bowl in a similar musical mechanical function to that of piano and harp foot pedals. Inspired by the glass harp, the fluid circular motion of the glass allows the player to hit multiple tones at once, creating resonant textures. Wolfgang Amadeus Mozart's *Adagio and Rondo K.617* and Ludwig van Beethoven's *Eleonore Prochaska* score utilized the sounds of the glass armonica to build tension and mystery.

Figure 2. Glass Harp
(Szafraniec, www.glassharp.eu)

Drawing inspiration from the glass harp (*figure 2*), early on glass armonica players sometimes rotated the glass instrument body through a trough of water during performances, as opposed to dipping their hands into water to wet their fingers. Players opt to no longer use this method. Glass interaction with water caused pitch to oscillate, affecting performance. Dipping a finger into the water to continue playing can be compared to a vocalist taking a breath while singing (Zeitler, 2009). This need to breathe 'breathe' is a barrier to continuous playing. Performers and composers play within this restrictive space creatively.

Sometimes the glass armonica is played with a mallet, producing an almost pure tone. The high pitched and fast-moving textures conjured by finger friction on the circling glass are absent in mallet performances. There is no friction, and therefore no need for glass movement when mallets are used. In Phillip Glass's *Music Box*, a glass armonica is struck with a mallet. The wheel starts moving halfway through the piece. Both the mallet and hand play the instrument. The mallet sound is unaffected by the finger playing the glass armonica.

Figure 3. Glass Pan Flute
(Fuchs, www.panfloete-glas.ch/)

The glass pan flute has no documented date of genesis. Pan flute constructor Martin Fuchs credits making his first glass pan flute in 1981 (*Figure 3*). This pan flute holds 16-24 glass pipes of different lengths. Pipes are curved in length from longest to shortest: lowest to highest pitch. Thinner pipes have a firmer tone. Thicker pipes have thicker ends, holding a lighter and more dynamic tone, as more mass equates to louder amplitude. This pan flute is tonally akin to a traditional bamboo pan flute, but as expected is airy and light in tone, like most glass instruments (Fuchs, 2020).

Invented in 1983 by Sascha Reckert (Hilmer, 2018), the verrophone (*Figure 4*) is comprised of long glass tubes open at one end, held in a curved wooden frame matching tube length. The shorter the tube, the higher the pitch. Tubes are close to each other, allowing multiple notes to be played in one strike. Long industrial tubes and a large frame allow the verrophone to project to an audience of up to 1000 persons with no amplification. The verrophone projects far, with a precise attack of tone when mallet-struck, making it easier to implement into the orchestra than other classical glass instruments. When played with sticks instead of mallets, the attack is higher in pitch and less prominent, ringing out. When hand played, the sound draws comparison to the glass armonica, and string-like tension of the violin (Glassharfe, 2020).

Figure 4. The Verrophone
(Bertomeu, www.glas-musik.de)

The late Harry Partch created the cloud-chamber bowls in 1950 (*Figure 5*), from 12-gallon glass Pyrex jugs, cut in half with a kerosene-soaked string lit on fire (Dunn, 2000). Higher pitches were made with additional cuts to the jug. Once cooled in water, chamber bowls were arranged from the top of the 7-foot wooden rack, from highest to lowest pitch. Visually comparable to large hanging racks seen in retail store changing rooms, each rack holds 10 to 13 cloud-chamber bowls, 2-4 per non-uniform row. Cloud-chamber bowls are easy to break, and therefore one of a kind (Chesworth, 2002).

Figure 5. Cloud-Chamber Bowls, photo by Fred Lyon
(Szanto, www.corporeal.com)

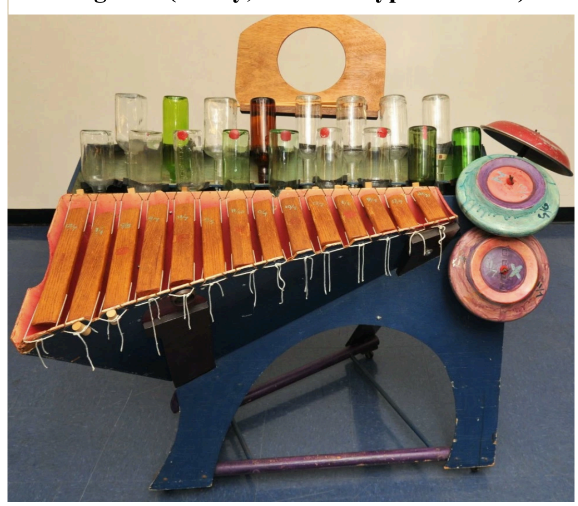
Partch took pride in repurposing Pyrex jugs, originally used in experiments with subatomic particles to create weapons at the Radiation Laboratory at the University of California, Berkeley. Repurposing materials analogous with destruction and turning them into creation, Partch's values lay on his sleeve (Dunn, 2000, p.42).

Studying ancient Greek scales and Hermann von Helmholtz's *Sensations of Tone*, he applied his knowledge, making micro-tonal instruments. Each cloud-chamber bowl holds a pitch never again to be replicated. Partch described the tone as "wonderfully alive," but bottoming out to a "dead end" at lower notes (Chesworth, 2002). Bowls are spread far apart, a design choice essential to cultivating *corporeality*, the Partch-coined term defined as "part dance, and part ritual theater" (Corey, 2017). Cloud chamber-bowl performers are active, moving from high to low bowls in a dance. The rack was designed seven feet tall to ensure performers engagement and exaggerated movement. The result of this design choice in performance is the visual illusion that the sound produced is a product of dance, rather than bowl strikes.

Notes on top of the bowls are unrelated to the pitches produced by bowl sides. Cutting bowl bottoms doesn't affect the pitches on bowl tops. Bowl top pitches are random, coming from however Pyrex decided to make their 12-gallon jugs (Corey, 2017). Percussive, but semi-tonal tops project notes one to two octaves above 'side' notes. Cloud-chamber bowls encompass the percussive and tonally random bowl tops, and the more consistent tone of the bowl sides. Never tuning bowls, Partch opted to arrange them by ear. The rich overtone series in overlapping notes sometimes creates a bell-like sound pattern known as *beating*, the oscillation between 2 frequencies in close proximity. The dynamic of the tonal pitch of the bowl sides and the random pitch of the bowl tops mirror the organic, usually found only in mother nature.

In 1963 Partch created the Zymo-Xyl, a series of empty glass alcohol bottles of different brands, representing notes, on a keyboard style rack. Each bottle of the same brand and drink is identical in pitch. When broken, bottles (keys) are easily replaced (Corey, 2017). There is less opportunity for human 'error' in designing this instrument than in cloud-chamber bowls. There is no bottle cutting needed. The room for humanity/corporeality in the Zymo-Xyl is in pitch choice. Partch arranged Zymo-Xyl pitches to ear. The small rectangular bottles are high in pitch, leaving less room for the oscillating overtones found in cloud-chamber bowls.

Figure 6. The Zymo-Xyl, Photo by Steven Severinghaus (Corey, www.harrypartch.com)



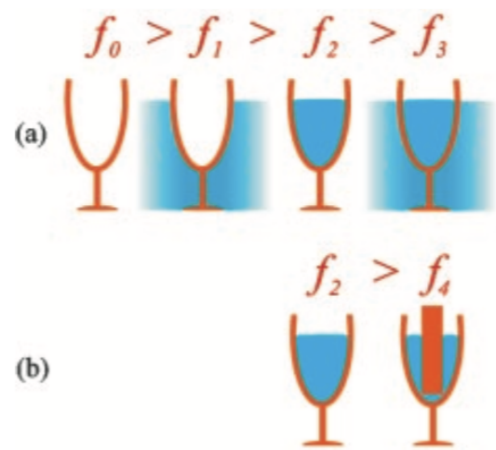
Homeless for much of his life, Partch seldom had access to professional equipment to build instruments (Chesworth, 2002). The gift of this limitation: Partch created completely unique instruments. The curse: these instruments are tough to learn how to play, write for and reproduce.

Glass Characteristics

Adding fluid to the glass structure can be considered adding mass. The more fluid added to the cup, the more work to be done to move the fluid (Wilson, 2017). In Chen's 2005 preliminary experiment with four glasses, the glass with the most mass had the lowest pitch. Of greater interest In Chen's four additional experiments, glasses were tested with the same mass regulations, but in different locations surrounding the glass. These four experiments were done with four glasses of slightly different thickness from 1.72 to 2.4 mm. Each glass interacted with water differently. Results were averaged to affirm reliability. Glasses of different thickness were tested to ensure that thickness wasn't a variable.

In the first of Chen's four experiments (*Figure 7*), glass one had water on the outside and nothing on the inside. When struck, this glass produced a lower pitch than the barren glass zero with no water on the outside. Glass two had water on the inside only, producing a tone of about 200 Hz lower than glass one. Glass three had water on the inside and outside, producing a tone only a couple Hz lower across the board. The fourth glass was the same as glass two (water on the inside only), with an added thin column inserted into the water (material not disclosed in the study). This rod vibrated about 100 Hz lower than glass two (Chen 2005, p. 335).

Figure 7. Variations on a theme by a singing wineglass, Image by Kuan-Wen Chen (Chen, 2005)



All mass contributes to frequency content. Within the confines of the experiment, the addition of the rod served functionally as if more water was added to the glass. The addition of the rod audibly lowered the frequency of the already mostly full glass. Adding water to the outside of the glass proved less successful at lowering frequency in comparison to adding water to the inside of a glass. The third glass had water on the inside and outside, but only registered at a slightly lower frequency. The most effective way to lower frequency is to add mass of any sort to the inside of the glass body being vibrated.

Alcohol, linseed oil, water, brine, and vinegar tests affirmed the hypothesis that the denser the liquid, the lower the frequency. This study also examined the correlation of water level in glasses, reporting in detail on how small water level adjustments can audibly alter frequency. Water level was found to be less correlated to frequency than expected. The slope of reliability was deemed semi-reliable, not pristine. Having water in a glass (as opposed to not) will lower frequency, but adding an ounce of water won't lower frequency much (Chen, 2005, p. 339).

A glass, string, or wind instrument is defined by its physical vibration. In the context of a glass instrument, one can visualize a mallet hitting glass. A string instrument can be represented by a plucked string vibrating. *Physical modeling,* the digital production of instruments, can go beyond this visualization. An example: a half-glass string, half-wooden string instrument, plucked underwater can be physically modeled using a synthesizer. The sounds of instruments that have never been heard before can be simulated in a digital setting. Numbers in a computer representing physical materials can be mixed, matched, and placed into new contexts.

One example of physical modeling software is Sculpture (*Figure 8).* From the industry-standard digital audio workstation Logic Pro X, Sculpture is a stock-synth example of this hodgepodge of sound modeling. This synth can blend sounds coaxed from wood, glass, metal and string, at any level of tension, body-size, location and altitude. Other popular physical modeling systems focus on instrument body shape: whether constructed in the form of a plate, string or tube, whether stiff or sound absorbent. *Modal synthesis* is based around the frequencies that resonate when each type of instrument body is energized, resulting in vibrations. In synth, instrument shape is defined by frequency, Q factor, resonance (narrow versus wide) and amplitude (Mantione, 2019).

Figure 8. Sculpture Synth, Logic Pro X (Apple, 2013)

Impulse models are modeled after traditional glass sources. The striking of an instrument transfers energy to it. The sound dies as the energy quickly loses friction and movement. The input leaves, output dissipating shortly after. In the context of a string, a *continuous model* is the ongoing transfer of energy between the bow and the body. Glass is not continuous. The impulse model of glass will take a sound, create an algorithm, and use the algorithm to produce a resonant frequency. The result of this resonant frequency algorithm will be a short decay after the 'source' is initially 'struck.' (Mantione, 2019).

An example of a more complex impulse model would be a hammer speeding up as it strikes an instrument. Parameter variation creates an aura of natural and human creation. Without variability sparked by short impulses, strikes in succession, picks, noise and the sidechaining of signals, glass modeling will sound dry and robotic. Stiffness and dampness are tools used to help recreate the tension of a glass instrument. The choice between wood, metal, glass, and string in synth mostly has to do with the vibrating attack of the instrument body, and how this attack dies off. Alternatively an instrument can be modeled to die off like glass, but if the attack sounds wooden, it won't sound like glass.

To think about glass instruments and how they work is to think about the various shapes of sources. In the *free tongues* format air runs through a continuous disk, is interrupted and then allowed to pass, creating a siren sound. In the context of the glass sphere, peak pressure must be emitted when the tongue opens. This high pressure and low wind combination creates a flat tone and loud high-pitched *partials,* sine waves that are part of the tone's complex audio harmonic (Helmholtz, 2009, p. 102). Glass rods and plates are used as source material in the context of many military and dance songs because of their blatant, sharp and sometimes abrasive quality.

Rods are placed between 2 strings and struck by hammers in the glass harmonicon and straw fiddle. The rod material affects the quality of tone. Metal allows essential tones in pitch to ring the longest and secondary higher tones to ring the loudest. Glass also rings out high frequencies- but these high frequencies tend to die off faster. Glass breaks easily and is softer all around. The mass of the glass body is much smaller than metal. In contrast, wood has a small mass and rough structure, creating imperfect tones that die away fast (Helmholtz, 2009, p. 71).

Cut into shapes from ovals to hexagons, plates vibrate in many different ways, often producing simple inharmonic tones. Multiple nodal points will help the plate ring true to one pitch. Glass plates decay rapidly. Points coming in to contact with multiple other points stifle source vibration. Bells hold inharmonic secondary tones, in more spread-out intervals than those of flat plates. In bells, even number nodal lines ignite vibration, for example: four, six, eight, ten. If a wall is thicker or thinner than the other, the entirety of the bell tone will become a warbled oscillating sound. 2 frequencies in close proximity (example: 303 Hz and 305 Hz) will be produced, creating frequency beating (Helmholtz, 2009, p. 72).

Firm and smooth spherical resonators resonate the most. Spheres need to withstand pressure and negate friction. A smooth surface equates to more air getting through: more resonance. The glass tube carries wind through to the sphere and resonates. Larger openings (more mass) create more resonance

(Helmholtz, 2009, p. 372-373). Six to ten cm tubes inserted into the external opening of a glass sphere can produce ‘A E I O U’ sounds. Air passes through, resonating in each tube based on length. Another method for producing vowels is to revolve a toothed wheel. The wheel mechanism vibrates via pressure put on each spring as it spins. The tone produced is a summation of how many teeth have struck the spring per second (Helmholtz, 2009, p. 117).

Continuous motion of teeth, measuring comparably in length to the spring equates to a U vowel sound. As shorter springs are used O A E I vowel sounds are pronounced. Vowels start from O as the spring gets slightly smaller, eventually getting to I at the shortest spring. The spring, although effective, is less effective than the reed. Higher partials are essential to the pronunciation of vowels. The reed, in combination with humans producing air, creates compound tones. The human element of creating airflow is essential to higher partials (Helmholtz, 2009, p. 118).

Helmholtz presents another possibility (crediting the thought process of Willis, 1831): the partials themselves, created from reed pipe interaction, are formulated from echoes. Willis believes that the high pitched partials are not directly created from extra human interaction with pipes. Instead, Willis credits the pulses of air that bring to fruition vowel sounds, to the resonance of the reed pipe. Pulses of air die off quickly in the tooth wheel context because they are not trapped in a pipe. High partial pulses of some sort might exist in the tooth wheel context, but they are not as prominent as the air coming from a human mouth. Furthermore, whatever high partial spring sounds do come from the toothed wheel, they escape (Helmholtz, 2009, p. 118).

Upon listening to recordings of Partch’s compositions for cloud-chamber bowls, it becomes clear that the instrument lends itself toward repetitive rhythmic patterns and fast-hitting glissando (sliding up and down) block chords. The timbre of the cloud chamber-bowls draw comparison to the lower notes of the Marimba, and the resonant oscillation of a church bell. As a bell of sorts, each bowl’s uneven circle creates frequency beating when struck. When listening to bowls being struck in succession, the effect is similar to water droplets; it feels as though each of the cloud-chamber notes are similar enough in frequency content to be trickling down from each other, but different enough to be going in a new melodic direction with every hit.

It’s easy to compare cloud-chamber bowls to the glass armonica. Neither of these instruments are mainstream nowadays. Both were tough to make and easy to break. Partch’s instruments have much less high frequency varying timbre over time in comparison to the glass armonica. This time-varying timbral movement is created by the glass armonica's circular motion. When one listens to Carl Leopold Röllig's *Quintet for glass armonica and string quartet in C minor*, the composition is slow and winding. This composition style derives from the glass armonica's weak attack and long release and sustain time.

Loud high pitched frequency content in the armonica touches upon frequencies that the human ear hears the best. The overtone series is uniform and clear. A decent amount of noise is created from the motion. The other mallet-struck glass instruments described hold lower frequencies. Most of the high frequency content is in the very brief attack. Keeping in mind this context of ADSR (attack, sustain, decay, release), it's easy to see why the glass armonica would be paired with a string quartet, and other glass instruments might be in a more percussive piece.

Glass Composition Analysis

The Fixed Stars, the Frontier to the Beyond by William Zeitler fades in with an oscillating glass armonica note. High-frequency noise builds up, dipping in and out in frequency and dynamics, creating the feeling of movement. This world full of motion, encapsulated in just the first note, is quickly overlapped by another. With the coming of the second note, tonal mid-high frequencies stack creating a loud, resonant and almost distorted tone: overlapping frequency 'beating.' This resonance echoes and reverberates, overpowering the white noise and lower frequencies in the armonica. The overlap between notes creates a weaving in and out chord-like motion. 'Chord-like' because there is little to no attack to define chords, just texture weaving in and out.

Abruptly transitioning from the pure tone and white noise, the saturated high frequency beating jumps out. When the note overlap is less prominent, and individual notes are given space, the frequency content is lower. This absence of note overlap, after the overlapping takes place, creates calm. The beating frequency content, and then the absence of it, is representative of many constants in nature: storm and then calm, tides coming in and out, moonrise and sun fall.

In brief pauses and quieter moments, the glass armonica rings out. This haunting echo allows each moment in the piece to become a valuable memory. Zeitler's composition choice of playing with dynamics, leading quiet moments into loud peaks, puts more emphasis on the quiet ones. This leaves the louder sections of this piece powerful, almost overwhelming. Zeitler deliberately chooses to have the last note of this piece be of simpler low frequency content. This choice to not end on the overlapping tension of the high-frequency beating was deliberate. Zeitler wanted to end the journey with calm.

Phillip Glass's *Music Box* begins with a catchy phrase played on the glass armonica with a mallet, evoking an almost cheery Christmas-song-like familiarity. This phrase is played the first time alone, then accompanied. Empty rhythmic pockets quickly fill up with consistent lower mallet hits on the verrophone, accenting both on and off beats. The low verrophone notes are consistent, defining the key and direction of the piece. The armonica dictates a simple repeating melody that includes the first phrase of the song, changing in slightly format from time to time. Passing tones come in, hinting at new melodic directions before they happen. The verrophone outlines lower chords, and the new melodic direction shifts. The glass armonica follows, leading the verrophone towards lower pitches.

After a pause, the first section repeats once more. The verrophone mallet sound brings to mind water droplets in a cave, echoing low and far away in contrast to the closer-sounding glass armonica. The armonica mallet sound brings to mind mysterious and mischievous solstice bells: high pitched, slightly tin-like and metallic sounding. The catchy armonica phrase that started the song speeds up in repetition in this new section, repeating twice as often as before. The phrase is fit into previously blank spaces in the piece. This doubling of repetition marks the movement of the glass armonica. A finger is placed on the glass body. It moves, creating the first smooth long note in the piece.

Notes wind in and out, every two to three beats. Shortly after the finger playing starts, a feeling of excitement begins to take hold, welcoming the newfound variation in the piece. 15 seconds later the glass armonica stops circling and the finger notes end. After a pause in the piece, the first section and phrase repeat, as if the song was starting for the first time. 20 seconds later, out of the blue, the finger playing restarts. A brief couple of notes are played, cut off by a pause again. The piece restarts once more exactly as if it were the first section, but with the glass harp replacing the verrophone. Mallets are reversed and the glasses are played with sticks. The pitch is higher and release slightly shorter, bringing to mind the tone of high piano pitches.

Music Box slows down to a halt, omitting the last note that made the phrase feeling complete in prior sections. What is left is tension. The song is seemingly 'incomplete.' The effect of this simple repetition and alteration of the first section of the piece, is the creation of an expectation. It's assumed that the piece will end how it started, with the first section. The last section was likely to repeat the pause from the first section, allowing the glass instruments to ring out in the space made. The pause was a constant presence in transitioning between sections. The lack of pause, last note being omitted, instrument change to glass harp, seeming decay of melody, and tempo grinding to a halt all defy this expectation. Although simple, very repetitive and structured, the way different parts of glass instruments were used to create space made small moments in this piece important.

Eleven Intrusions XI: Cloud-Chamber Music by Harry Partch starts with a single note being struck from the side of the bowl. This evokes a punctuating effect: bringing to mind funeral bells accenting important plot twists and scene changes in movies. After the monotone, slightly ominous and very mysterious words: “cloud-chamber music” are uttered by Partch, 4 more hypnotizing notes come into play, looping multiple times. The loud high pitched attack of these notes are fast and passing, leaving quieter, warbling, overlapping sustained tones and echoes behind. This creates a sense of space.

As the hypnotizing pattern becomes clear, it moves faster, building a tense and anxious atmosphere. It instantly dissolves. A low note repeats sporadically until a high pitched cloud-chamber bowl top is hit, acting as a signal; this pattern is over and now the next section of the piece will begin. What sounds like Partch’s adjusted guitar begins to glide up and down in pitch. Every beat or so, semi-percussive light cloud-chamber block chords (two to three notes) accent each gliding pitch movement of the adjusted guitar.

These new block chords are of high pitch and controlled sustain, never allowed to echo. As the adjusted guitar section continues, block chords lower in pitch, influencing the tonality of the composition more. These low chords are longer but very controlled in mallet performance. They are not loose in release like the performance in the section that starts this piece. Chords fade away and the adjusted guitar is given space to perform a solo. This performance is then cut off. Block chords quickly build-up, shifting from low to high frequency. The same high-pitched chord is then repetitively hit at a fast rate.

What sounds like a bass-marimba and cello appear. An American sounding folk song comes into play, completely unrelated to this piece thus far. The cloud-chamber bowls, and what this piece was up to this point, are nowhere to be found. The section is responded to with adjusted guitar, moving faster and loopier, taking melody fragments from the section before. Cloud-chamber bowls now begin to ring out in higher pitch, like bells again. They accent the first and fourth beats, faster than in the beginning. This composition choice creates a war-time, song-like, rhythmic bounce.

The melody is almost reminiscent of a warped version of the 1939 song *We're Off to See the Wizard* by Judy Garland and Ray Bolger. A marimba section is given, with accompaniment from a shaker, eventually built up with cello and adjusted guitar. This section is abruptly cut off again by a solo repeating note from the chamber bowls. A voice, cello and bass-marimba move slowly in pitch together, for the first and last time. A final lonely cloud-chamber note accents the end of the song, just as it did the start. Partch's choice to begin and end this way leaves the listener remembering the chamber bowls.

Glass Composition Creation

Beyond analysis, hands-on research is necessary. 400 glass hits were recorded by the author and arranged into a dozen songs. Two of these dozen songs, created in two different environments are this works' focus for brevity's sake. Song one was produced in a foley/sound design studio utilizing an empty wine bottle. Song two was produced in a home studio setting, utilizing a glass of water. Other sources were used to produce vibrations. Every part of the glass was hit with materials ranging from hand palms to fingers, to metal, plastic, and wood. Air was also blown into the glass.

In the first piece, the bottom of the 750 ML long transparent empty Pinot Grigio bottle was struck on a large padded metal chair covered in fabric, creating a low booming tone. This booming tone could be compared in pop music to a kick drum or low textured 808. A note on the perception of glass sounds: It's easy to categorize sounds into the confines of popular western instruments. A lot of sounds were heard as drums or tonal keys. If the goal was to compose an ambient nature-oriented piece, the compositional choices made with these samples might be very different. Hearing repetitive patterns in these sounds, the author's role as a pop composer influenced sampling and arranging in a traditional, more instrument-oriented way.

In the first composition 'glass clinking sounds' (the high pitched striking of the higher end of the Pinot Grigio bottle) made perfect percussive 'cowbell/hit hat' sounds. 'Clinking sounds' were used to fill in rhythmic pockets: rhythms in between every beat. The light dropping of a material (a penny, a drumstick, another bottle) on top of the glass bottle created a high pitched oscillating texture. When slightly time-stretched, the oscillation almost sounded similar to the winding of a clock, or a jittery grouping of hi-hats. This sample was used to lead up to an echoing 'snare' of sorts: the moderately loud hit of a drumstick on the middle of the wine bottle.

This full-spectrum sample (with a focus on midrange frequencies through 2.5K Hz) led into the complicated higher frequency content oscillating texture. This rolling texture led into the lower sharp attack echoing of the ‘snare’ just described. How this texture led into another (with the help of spatial effects like reverb and delay) brings to mind cloud-chamber bowls; refer to the ‘raindrop’ effect described in the Partch section of this work. Even though the rolling texture is on the first beat and the ‘snare’ is on beat four, the texture and spatial effects used create rhythmic groove, adding polyrhythms to these simple beats. Glass as a medium is easy to sample and alter into a rhythmic groove.

The main melody of this song is comprised of simple echoing block chords sampling the same ‘snare.’ This ‘snare’ was pitched down two octaves to unveil a texture comparable to a cross between the marimba, xylophone and a very staccato cloud-chamber bowl top, paired with lower frequency content from a bell. The four mostly-looping block chords are in the key of C#. Overtones make this simple chord progression slightly dissonant, adding interest factor. It’s important to note that this dissonance is not inaccessible, and makes the chord progression more meaningful and memorable.

At first glance at a graphic equalizer, the overtones in this sample seem so varied that most of the spectrum is taken up. A closer look at resonant Qs shows that notes are very simple, aligned to one tone. Peaks and valleys in the spectrum are uniform. Even patterns, and the numbers correlating to resonant peaks doubling, affirm this simple pitch. The larger array of frequency content is noise. This noise, produced by the glass sound source being hit with a wooden drum stick, makes the sample memorable. This noise is from the glass instrument body, not from the space the it was recorded in, as the glass was struck in a soundproof recording booth.

The second song was recorded in a home studio setting. A glass of water created the majority of sounds. Noise and reverb from the bedroom seeped into every sample recorded. Even though this glass of water is similar in size to the glass harp described in the history section of this work, how this glass of water was used to create sound was very different. The glass was not allowed to ring out in the same way that a glass harp does, as there was no mallet use. The structure of the glass was more uniform. The glass of water used had rectangular ridges, far less circular than the wine glasses that comprise the glass harp.

The water glass was flicked with an index finger. The result was a percussive sound. When pitched lower, the sound was deep, rich and very tonal. Pitching to C for sampling purposes proved difficult as the overtone series was complicated and time-consuming to analyze, but manageable. This sample was moderately noisy, as it was not recorded in a soundproof recording booth. The noise from the room made this sample stick out in the final arrangement. The low-frequency content was made more apparent when spectrally backed up by short high frequency noise.

The overtone series of this sound is more complicated (holding uneven peaks and valleys of varying numbers) than the sound of glass being struck in the first piece. The water in the glass created variability in oscillation, and more frequency content in general. Glass armonica players didn't continue to use water troughs to wet their glass, because of the water creating oscillation affecting otherwise very clear pitch. These same oscillations that glass armonica players avoid, add an interest factor to the piece. The sample sounds more full and can be used as a bass of sorts because of its rich overtone series.

This lowest octave filled in rhythmic pockets between the higher pitched 'percussion' sounding glass samples. These samples aligned themselves with the strong beats of the 4/4 meter. The low 'bass' octave filled in off beats, adding rhythmic bounce. This low octave often paused to make space for 'percussive' samples accenting strong beats. The 'bass' octave provides tonal foundation, filling in off beats and pausing often on strong beats, bringing to mind the low verrophone from Phillip Glass's *Music Box.*

The glass flicking sound became more percussive and less tonal when pitched higher. The lowest octave had bass to it, but shared qualities with the lowest notes of the cowbell or marimba. The second highest octave could be compared to the top parts of cloud-chamber bowls: higher-pitched and less consistent in tonality, but still adding to the melody of the song. It's important to note that this sample was tight in release and sustain, and not very reverberant. The highest pitch class used was purely percussive.

Another sound was made via placing an upper lip on the lip of the glass and then moving away from it. This plucking-like sound was mid to low in frequency range, but percussive. This timbral variation could be compared to a low snare or tight bongo drum. Lastly, water was flicked inside of the glass making another percussive sound, in turn adding more high pitched moving rhythms to the piece. The main low octave sound of glass being flicked on the outside tended toward a rhythmic loop with no notes overlapping. Basslines tend to not overlap, avoiding overlapping frequency 'mud.'

The overtone rich frequency content of this lowest octave was better suited for simple monophonic sampling. The medium octave added in rhythmically sporadic, overlapping and mostly-tonal clicks. This effect made the lowest octave of the glass sample more prominent, adding rhythmic interest. The raindrop effect mentioned in the Partch section of this work could describe how the less tonal, mid-range clicks led to more clicks. The lack of square rhythms added to the natural 'organic' effect, and the high-frequency noise helped make it more prominent. Each mid-range strike at the glass could be a raindrop.

Conclusion

Glass can be as percussive or tonal as the composer wants it to be, making it a one of a kind source. Glass history, characteristics, and music analysis laid the foundation for the new compositions created in this study, meshing Harry Partch's outsider music and western music tradition. These compositions emulated the textural, tonal and rhythmic variability of nature that Partch prized. Incorporating repetition and structure, these new pieces also built upon the sometimes sharp and pure, sometimes winding and overlapping music of classical glass instruments. The timbre and rich overtone series of glass can be used to create fleeting moments.

Cloud chamber bowls when struck from the side warble, but when top struck are percussive and random in tone. Glass armonica notes are drawn out, creating a slow and noisy motion-filled passing of time, each note reminiscent of valuable memories. Overlapping distorted notes represent ocean waves at their peak. The mallet struck verrophone cries out like rain, its low sharp attack dampening fast. When stick struck, the timbre is akin small high pitched bells ringing out ever so slightly- like a ghost. Performing glass with heavy control of sustain creates a percussive quality. If performed loosely the glass will ring. Two water glasses can be used in very different ways. The glass harp rings out in textured high frequencies, alien to the low bass octave created by glass flicks from the second new piece in this work.

Further research is necessary. Many glass shapes have been touched upon in this study and in others; most shapes have been spherical. Glass plate and underwater glass performance studies are the next logical steps in experimentation. Glass plates come in many shapes, holding nodal points interacting with one another to create pitches. The glass armonica and glass harp heavily incorporate water into performance. The study of underwater glass performance is a long time in the making. It's tough to imagine what underwater glass plate music might sound like. It's likely never been brought to fruition. From mallets to sticks, to hands and beyond, glass music holds endless possibilities. The beautiful thing about glass is that it's defined by how you play it.

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