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Review

Water-Driven Music Technologies through Centuries

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Abstract: Water-driven music technology has been one of the primary sources of human leisure from prehistoric times up until the present. Water powered, along with air pressure organs, have been used throughout history. One of them was an organ of fountains located inside a formal garden. Throughout ancient mythology, several different gods have been linked to music in many civilizations, in particular, Minoa, Mehrgarh, and Gandhara. Water deities were usually significant amid civilizations located next to a sea or an ocean, or even a great river like the Indus River in Pakistan, the Nile River in the Middle East or the Ganga River in India. These fountains performed a wide range of songs from Classical to contemporary Arabic, and even included other worldly music. The study of water-driven music technology demonstrates the diachronic evolution and the revelation that ancient people had impressive knowledge of the engineering needed for water exploitation and manipulation. This revelation is still both fascinating and intriguing for today's water engineers. This paper also shows the relationship between water in nature and music, and furthermore, how nature has inspired composers throughout history. This research shows the sustainability of different kinds of water-driven musical instruments, not only through their use in past centuries, but their relevance in music therapy and other purposes of today. This study is useful for researchers in the fields of history, music, engineering and sustainable development.

Keywords: sustainability; water-driven music; fountains; socio-culture; water organs; musical instrument; water history

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1. Prolegomena

Life's as kind as you let it be.
-Charles Bukowski (1920–1994), Hot Water Music

Water as a music tool can probably be referred to as the last oracle of Pythia Nikandra, by Plutarch, a Greek biographer and essayist (ca 2nd century BC). However, it was said that it was merely a construction of fanatical Christians, and not credited to those early Greek writings, but designed only to impart a climate of defeat unto the Greeks after Julian (ca 4th century AD, [1]):

"Tell the king that the sophisticated hall has fallen to the ground. Phoibos no longer has his house, nor his mantic bay, nor his talking spring; the talking water has dried up."

Early Christians used the Greek Septuagint [1] as their Bible, because most of the quotes in the New Testament come from the Septuagint, particularly in Paul's writings. Many passages in the New Testament cannot be properly understood without the Septuagint as their base, e.g., "Before the creating of the land, and before the creating of the deep, before the fountains of water came forth (Proverb 8:24)."

According to ancient mythology, several gods were linked to the music of most civilizations through the centuries. These included, e.g., Menrva in Etruscan, Enki in Mesopotamian, Apollo (Orpheus) in ancient Greek and Roman, Saraswati in Hindu, Hathor in Egyptian, Kui in Ancient Chinese, Huehuecóyotl in Aztec, and Hillon in Celtic. In addition, according to Greek mythology, all of the ancient writers appealed to the Muses (the goddesses of music, Figure 1) in the beginning of their work. Homer asks the Muses both in the Iliad and Odyssey to help him tell the story in the best way, and still today, these Muses are symbols of inspiration and artistic creation [2]. In addition, some musical instruments are known to be used since prehistoric times such as the lyre since ca 2000 BC. Besides, the Minoans, the Indus valley civilization, Babylonians, Greeks, Romans, and the American Indus all had gods and goddesses for the water irrigation of crops as well as water purity [3]. Temples and the construction of water delivery systems were often built to honor these gods and certain elements were incorporated into them to honor that god. In addition, gods and/or goddesses were associated with making rain when faced with severe droughts [4]. Water deities were usually more important among civilizations where a sea or an ocean, or a great river was more prevalent in their culture.

Figure 1. The Muses on a Roman sarcophagus (ca 2nd century AD).

The relationship between the study of nature and music is present in many ancient civilizations [5]. The Grecian Pythagorean philosophers were the first who explicitly investigated musical sounds in mathematical terms [6]. Since then, nature and water have been used as inspiration by many composers. Rock paintings dating from prehistoric times located along bodies of water which served as transportation routes, made a natural echo-based sound and in its own right was considered a "musical instrument".

The instrument hydraulis, the forerunner of the modern organ, was invented by Ktesivius in Classical Alexandria. Such a well preserved model made of pottery was found at Carthage in 1885. The instrument used water to supply a constant flow of pressure to

the pipes. The keyboard mechanism had a device by which the instrument was supplied by air. Essentially, the air that flowed into the pipes that produced the sound came from a wind-chest connected by a pipe to a dome; air is pumped to compress water, and the water rises in the dome, compressing the air, and causes a steady supply of air to the pipes [7]. Thereafter, several musical instruments based on water have been developed.

The word innovation raises a problem of great importance in the history of water-driven technology. The surface tension of water has high flexibility and a fast response to imposed vibrations, even with transients as short-lived as a few milliseconds. Therefore, water is able to translate many of the sinusoidal periodicities in a given sound technology. Musical fountains are deemed suited for both amusement parks as well as large appropriate outdoor and indoor areas.

The principal objectives of this paper are to review water-driven music technology in several parts of the world throughout the centuries and to provide information on the current status of water for developing musical intermediate events. The information presented in this paper can be used by researchers in the fields of history, music and sustainable development.

2. Methodology

This is a review paper mainly based on two methods for collecting information. The first method was to (by) visit and explore selected (various) relevant places around the world. The second covered by reviewing many relevant references describing water-based music technologies in these places. In addition, some photos were taken directly in the spot, though the majority of them were collected through literature review.

In this review, the evolution of water culture issues and water-driven music hydro-instruments was adopted through the extended history of the human being since the prehistoric times. The tools adopted for the research included visits to historical sites and museums, comments, consultations, correlation, and exhibitions available in cyberspace.

As a whole, this review paper is organized in six main sections as follows: the first section is introductory; the second briefly explains the paper methodology; the third describes from the prehistoric to medieval times (ca 3200–1400 AD); the fourth deals with the early and mid-modern times (ca 1400–1900 AD); the fifth covers the contemporary times (1900 AD–present); and the sixth addresses the discussion of major issues and provides concluding remarks.

The paper provides information on water-driven music technologies through centuries and attempts to increase attention for the majority of the world regions. It includes 10 co-authors from four out of five continental of the planet and from several disciplines and regions of the planet. The disciplines include archaeology, hydrology, history, engineering, life sciences, artists, musicians, composers and environmental sciences.

3. Prehistoric to Medieval Times (ca 3200–1400 AD)

3.1. Prehistoric Times

The Indus Valley Civilization, situated in a resource-rich area, is notable for its early application of city planning and sanitation technology. Indus Valley construction and architecture, called 'Vaastu Shastra', implies a thorough understanding of material engineering, hydrology, music (melodies) and sanitation. There are a number of evidences of different water and music instruments, including the guitar, piano, santoor, pressure bagpipes, drums, flute, whistles, doyra, pungi, water pot, bhel, dabhli, harp, sarangi, jhola and gurka, found on terracotta figurines, pictographs and seals.

In addition, the people of Mehrgarh in current Pakistan also showed the ability to make various kinds of water music instruments from mud or clay in the shape of animals like turtles, animals, and birds, as presented in Figure 2a–c.

Figure 2. Water flutes in the shape of a turtle (**a**), elephant (**b**), and a bird (**c**), as well as a water pot musical instrument of ancient times (**d**); Mehrgarh and Mohen Jo Daro (**e**), and water pot in use (**f**) [8].

The water flute has two holes on both sides of the shell and one hole at the mouth. To make different sounds, the musician controls the sound by placing fingers on the holes and giving air pressure through the mouth. Accordingly, they used to make a water flute in the shape of an elephant. This elephant flute had four holes at the belly and one hole at the mouth. The four holes at the belly were used to make different sounds by using the fingers. Furthermore, they used one hole at the neck and one also at the tail of the birds.

The Gandhara civilization existed in the region now known as northern Pakistan and Afghanistan, since the mid-1st millennium BC. Although the Gandharan people have been historically known since the Achaemenid Empire, and more specifically during the reign of Cyrus the Great (558–28 BC), it was not widely known until the pilgrimage of Xuan Zang in the ca 7th century AD, at the tail end of that civilization [8].

The musical instrument known as a water pot was used in the Punjab, Khyber Pakhtunkhwa and Balochistan regions in Pakistan since the prehistoric Mehargar, Indus valley and Gandhara civilizations. A water pot is a receptacle used for the storage of water and has been used as such for thousands of years. It has a wide belly with about a four-inch opening at the neck. It is used as a musical instrument only when completely dry. It is played with the flat palm of one hand, trapping and releasing air in the water pot, producing a booming sound, and with the other hand, softly striking its outside either with a finger-ring, a coin or a pebble. To produce a greater boom, a sheet of inner auto-tire tube rubber is tightly tied onto the neck of the water pot that is beaten with the hand like a drum. To enhance the sound further, it is accompanied by a "Chillum" (the base of a hubble-bubble or a water pipe) into which water is poured, proportionate to sound desired, and is beaten with a soft shoe sole producing a sharper and higher pitched boom. Played together with a Chatralay Sitar, the sound becomes transcendental (Figure 2).

3.2. Historical Times and Far East Civilizations

3.2.1. Early Chinese Dynasties and Empires (ca 770 BC–220 AD)

The Chinese people wrote most of their music based on the five-note, or pentatonic scale. Each of the notes corresponds to one of the five elements "water, earth, metal, wood and fire".

3.2.2. Classical and Hellenistic Periods

Music was widely present in ancient Greek society, from marriages and funerals to religious ceremonies, theatre, folk music and the ballad-like reciting of epic poetry. There are significant fragments of actual Greek musical notation as well as many literary references to ancient Greek music and much of the Greek art we know depict musical instruments and dance. The word music derives from the name of the Muses, the daughters of Zeus who were patron goddesses of the arts.

Hydraulis: Greek musical instruments included stringed, wind, and percussion. By far the most popular were the lyre, aulos (usually double), and syrinx [9]. The Hydraulis (or Hydraulos = aulos of water or water pipe) is a keyboard instrument and is the forerunner of the modern organ. It is an invention born from the climate of an advanced way of urban life in ancient Alexandria. The Hydraulis, based on the Ktesivius' piston-type pump used for its air supply, became the first known musical instrument Harmonium, which is considered as the first organ [10]. It was invented in the 3rd century BC by Ktesivius, one of the most famous engineers of the time [11]. As the name indicates, the instrument used water to supply a constant flow of pressure to the pipes. Two detailed descriptions have survived: that of Vitruvius and that of Heron of Alexandria. These descriptions deal primarily with the keyboard mechanism and with the device by which the instrument was supplied with air. A well preserved model in pottery was found at Carthage in 1885. Essentially, the air to the pipes that produces the sound comes from a wind-chest connected by a pipe to a dome; air is pumped in to compress water, and the water rises in the dome, compressing the air, and causing a steady supply of air to the pipes (http://en.wikipedia.org/wiki/Water_organ).

The hydraulic consisted of two air-supplied Ktesivius' pumps, the "pnigeus" (by which the air pressure was regulated), the keyboard, and the musical pipes (Figure 3). The first instrument operated with compressed air, which passed through a water tank to balance its pressure. The sound came out of a series of tubes of different height. It had a strong and sharp sound and was initially used in horse-race shows, when performing military music and during church ceremonies. Later, other parallel series of tubes were added so that the result was polyphonic. The loud and charming sound of the hydraulic made it very dear and it quickly won its place in temples, theaters, horse races, and also in the imperial court of the Romans. Later, in the chaos of barbarian raids, water was abandoned and forgotten in the West. However, it remained in the yard of Byzantium in a sophisticated form, but without the use of water. Here, it acquires the importance of a state symbol and remains the privilege of the emperor. According to the experts, a hydraulic syringe was a large device, like Pan's Syringe (Panflautos or Aulous of Panos), which consisted of a series of cane tubes, graded according to their length, into which the performer blows. High and constant air pressure was kept in the lumps of its lumens and then provided as needed. Under the aulous, there was a water reservoir at the bottom of which there was a hollow hemisphere, called the drowning. In this drowning, water came from the base holes and air from the top pipes. These tubes were above the hollow hemisphere and ended up outside the tank. One pipe, which was included from outside, waved and communicated with the compass (compass–plunger). The compass was a piston pump that blew the air from the top tube by pressing on the choke. The air was then led to the watertight space above the reservoir and below the aulous. Located at the bottom of the aulous, there were the tongues. Each tongue was perforated and pushed in with the help of the button (hook) to open a passage to the mouth of the corresponding tube. The compressed air was thrown into the lumen, and the instrument sounded. When the

key was pressed, the tongue was returned to its position by means of a spring mechanism, interrupting the air flow and the aulous ceased to sound. It is noteworthy that the air was produced by people (teenagers or slaves) who were banging or jumping up and down on the bellows while the performer played the instrument thus revealing his craftsmanship on the keys.

(**a**) (**b**)

Figure 3. The Ktesivius' Hydraulis: (**a**) from useum at Dion in north Greece (with permission of A.N. Angelakis) and (**b**) a reconstruction of hydraulic organ (adapted from [11] see also: (http://www.youtube.com/watch?v=atT7Tjpn5js)).

After the Greeks, this pioneering acoustic and technological structure was eagerly adopted by many, reaching the Romans and then the Byzantines. In the 7th and 8th centuries the Hydraulis was now called an "Organ" and flourished in the Byzantine Empire and in all of its major manufacturing and production centers, such as Constantinople. There was a memorable incident where the Byzantine Emperor Constantine the Copronymus sent a church organ to the Emperor of the Franks Pepin the Short, father of Charlemagne, as a gift in 757 AD. Shortly afterward, in 812 AD, the Byzantines gave a second organ to Charlemagne itself. In the 10th century, the Windsurfing English Instrument was built at the expense of the church, with an unusual size and 26 bellows that required 70 people who played 40 notes, with 10 aulous for each.

A mosaic of the ancient city of Zliten in Libya, ca 2nd century AD, located at the Archaeological Museum of Tripoli, Libya, shows musicians playing the ecclesiastical organ (hydraulis) along with other Roman musical instruments.

The salpinx was a brass trumpet used for military calls and was played in the Olympics. A number of sources mention this metal instrument (with a bone mouthpiece). In the Aeneid, Virgil makes numerous references to the salpinx, most notably having to do with Aeneas' comrade, Misenus:

> Son of the god of winds: none so renowned,
> The warrior-trumpet in the field to sound,
> With breathing brass to kindle fierce alarms,

And rouse to dare their fate in honourable arms.
He served great Hector, and was ever near,
Not with his trumpet only, but his spear.
http://www.youtube.com/watch?v=aZa6oAdNMEA

The Delphic Hymns: the Delphic Hymns are two musical compositions from Ancient Greece, which still survive in substantial sized fragments. Both had been written for a performance at the Athenian Pythaides in 128 BC [12]. In the first verse, the singers call on the Muses (goddesses of music and dance) to leave their home on Mount Helicon and to join them in the song in honor of Apollo. This part has been translated by Brown and D'Angour [13]. Pöhlmann and West [12] divide the hymn up into ten short sections, with frequent changes of key. As in the First Delphic Hymn, the song opens by calling on the Muses to come to Delphi to join the song in honor of Apollo.

3.2.3. Roman Period (ca 67 BC–330 AD)

The lyre, kithara, aulos, hydraulis and trumpet all found their way into the music of ancient Rome. During that time, they did not add much to the principles of the various water musical instruments. However, the Romans did improve the instruments by increasing their scale only through using Greek knowledge.

Mechanical singing birds: In the 1st century AD, in Alexandria, the Hero of Alexandria invented the world's first steam-powered engine, the aeolipile. In his treatises "Pneumatica" and "Automata" he also described over one hundred machines and automata, which included mechanical singing birds [14]. In his treatise on "Pneumatica", Hero outlined his own designs for several different types of artificial birds that could move and sing in response to flowing water that pushed air through small tubes and whistles concealed within his carved birds. The pneumatic birds designed by Hero of Alexandria are shown in Figure 4. From these basic designs, the interest and intrigue surrounding mechanical birds, and automatons in general, only grew as the centuries passed. Hero of Alexandria is considered the "father of robotics" [15]. Today such devices are also used as toys, for entertainment events and door bells.

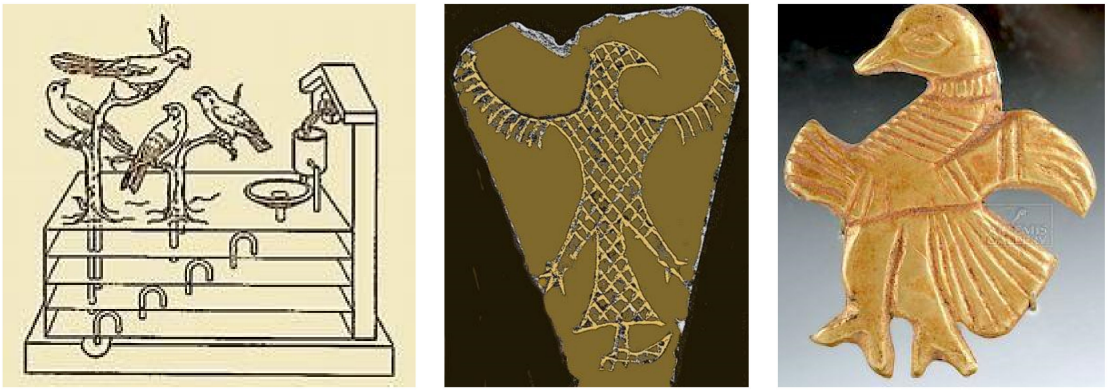

Figure 4. The pneumatic birds designed by Hero of Alexandria, dancing eagle and bird figurine, Indus Valley Civilization.

4. Early and Mid-Modern Times (ca 1400–1900 AD)

4.1. The Renaissance Times

During the long history of mechanical musical instruments, one device is famed above all others; the water powered organ of the fountain in the formal gardens of the Villa D'Este, in Tivoli, 30 km northeast of Rome. With water pressure created in an aeolian chamber, this instrument's sound became so magical that the visiting Pope once believed it to be the work of the devil. Despite this, political changes and simple decay destined it to a short life. However, in recent decades, through a combination of both craftsmanship and scholarship,

Rodney Briscoe created a modern interpretation of the instrument connected to the original aeolian chamber to sound out across the gardens again.

Mr. Briscoe worked closely with Dr. Leo Lombardi at the villa to uncover details of the original organ of 1570, but the details in the construction of the new organ were solely left up to him. Therefore, the organ was constructed in a traditional manner, while the materials used were upgraded to the more modern stainless steel and bronze, instead of the more usual wood and leather (Figure 5). This modernization protects the mechanism from the ravages of damp, humidity and splashes of water. The organ plays automatically, with the notes operated by a barrel. The air pressure is created by the original renaissance system of chambers and pipes located in the back of the fountain. This was only cleaned, but otherwise, remained original. Each tune lasts for around 50 s and the sequence is preceded by a fanfare blast.

(**a**) (**b**)

Figure 5. The Villa d'Este water organ, reconstructed in a traditional manner: (**a**) the recreated organ and (**b**) the fountain houses with the recreated water organ.

The tunes themselves are period compositions, chosen by Patrizio Barbeiri, a professor of music at Rome University. The first barrel contains: Cortege—Anon 1557, Ciacoona—Francesco Mannelli, who was born in Tivoli in 1595, Aria della Folia do Espagna—Bernardo Pasquini and Canzone—Agostino Soderini. Tivoli is a traditional playground for Romans wishing to escape the summer heat from as far back as Emperor Hadrian's day. The Villa d'Este was commissioned and built by Cardinal Ippolito d'Este. Born in 1509, he was the son of Lucrezia Borgia and the grandson of Pope Alexander VI. He was the only Cardinal who could say that he was the grandson of the Pope, and according to legend, he never missed an opportunity to revel in its beautiful music.

Ippolito d'Este (year) was a bishop at the age of two, an archbishop at the age of 10, and a cardinal at thirty. At the age of forty-one, he almost became Pope. The papal throne was wrested from him by Julius III. Julius immediately sent him away by naming him the Governor of Tivoli and could not leave the province he governed, therefore, he no longer represented a threat to the stability of Rome. Julius thus imprisoned him in Tivoli, and the cardinal spent the last twenty years of his life there. He devoted his time to the gardens, and during this time he commissioned several more musical devices.

The organ itself was constructed by Frenchmen Luc Leclerc and his nephew, Claude Vernard. This hints at a thriving pan-European industry of these musical devices, since there would have been no point to import experts from far away France unless they had special knowledge or experience building them. Work on the organ was completed sometime between 1569 and 1572. Interestingly, on a visit to the gardens, Pope Gregory had to ensure that demons were not involved in the production of the music, therefore, he could

not listen or enjoy it until the system was confirmed to be only mechanical. The instrument was vandalized in 1582 and later fell into ruin when Cardinal d'Esme abandoned the villa in 1586. It may have been restored sometime between 1609 and 1615 but records on any further use are unclear. There are suggestions that remains of the instrument that were capable of playing, were still visible in the organ fountain until the early 20th century. It is remarkable that a traditionally constructed instrument could have remained intact in such a humid and hostile atmosphere [16].

4.2. Others/Innovation in Water Music Instruments

Glass Harmonica

Musical instruments which are made of glass are probably just as old as glass making itself. In the 18th century, there is evidence of a concert composed by Christoph Gluck using dozens of drinking glasses tuned with spring water [17–19]. Benjamin Franklin invented the glass harmonica in 1761 after hearing a set of glasses in Cambridge (Figure 6). The tones may be turned into music by playing different glasses filled to differing levels with water. The volume of water and the shape of the glass determine the pitch, which enables the user to play a little melody [20–30]. There were also some attempts to add a keyboard to the glass harmonica. In the 19th century, Marianne Kirchgessner tried to add a keyboard based on Mozart's version. In 1956, organist Biggs added a keyboard to the glass harmonica and gave a concert to celebrate the 250th anniversary of Benjamin Franklin's and 200th anniversary of Mozart's birthdays. There are also some interests to keep the glass harmonica alive by conducting glass musical festivals [19].

(**a**) (**b**)

Figure 6. Glass harmonica: (**a**) the instrument and (**b**) in operation.

5. Contemporary Times (1900 AD–Present)

5.1. Nature and Water as Inspirer in Composing (Case Jean Sibelius, Finland)

Nature and water have inspired many composers such as Jean Sibelius (1865–1957) who is internationally the most well known Finnish composer. According to Murtomäki [31], Sibelius is one of the most important writers of symphonies and tone poems not only in the 20th century but in the entirety of all musical history. As a national composer, Sibelius was particularly talented with his ability to capture Finnish legends, its history and its landscapes in his music. For Sibelius, nature was poetic, even a mystical force: "In the twilight Janne (Jean) amused himself by lying in wait for fairy-tale creatures in the thick of the forest" [31].

Sibelius loved Finnish landscapes and nature. In his Sixth Symphony, he said: "[It] always reminds me of the scent of the first snow." The forests surrounding his residence Ainola often inspired his compositions. On Sibelius´ ties to nature, he wrote:

"Even by Nordic standards, Sibelius responded with exceptional intensity to the moods of nature and the changes in the seasons: he scanned the skies with his binoculars for the geese flying over the lake ice, listened to the screech of the cranes, and heard the cries

of the curlew (Numenius arquata) echo over the marshy grounds just below Ainola. He savoured the spring blossoms every bit as much as he did autumnal scents and colours".

In fact, the first genuine composition of Sibelius dates back to his childhood, when he wrote "Waterdrops for violin and cello" which is considered the ideal chamber music repertoire for music colleges and amateur musicians, alike [31]. In 1911, as a special "natural instrument" in Hvitträsk, Kirkkonummi, west of Helsinki, he identified the first reported Finnish rock painting dating back to the Stone Age [32]. These paintings were made ca 7000–3500 years ago on vertical rock surfaces. The nearby lake served as an important waterway and any sound echoed around the sites. By 2018, 122 rock painting sites were confirmed to be located in Finland [33].

Reznikoff [34] has explored the relationship between pictures and echoes at prehistoric painted rocks in Finland (Figure 7a), France, and Norway, which obtained positive results, particularly in France. In Northern Finland, Rainio et al. [35] found out that several echoes could be heard directly by the rock paintings of Värikallio (ca 3000–500 BC). A depiction of a drummer was identified in the paintings giving a clue of significant sound rituals. In painted caves, or a more resonant location, the more paintings or signs are found [34].

(**a**) (**b**) (**c**)

Figure 7. Others: (**a**) the relationship between the pictures and echoes at prehistoric painted rocks in Finland has been explored (Photo T. Katko); (**b**) embedded holes in the organ Zadar's seashore organ in Croatia; and (**c**) the wave organ by Frank Schulenburg.

5.2. Zadar's Seashore Organ

Zadar is a coastal city in Croatia that suffered massive damage during the Second World War. After reconstruction, the city's seaside had been hastily repaired for utility rather than aesthetics, leaving residents staring at a boring concrete wall. Croatian architect Nikola Bašić saw an incredible opportunity to build something miraculous using this blank canvas [36,37]. Therefore, he designed a massive, ocean-powered organ. The steps along the water hide a system of pipes, resonation tubes and vents that create lovely harmonies at random. Whenever waves lap against the steps, air is pushed through the "instrument" and produces sound as the air passes through the tubes (Figure 7b).

5.3. Wave Organ

The Wave Organ, another musical water organ, is an acoustic sculpture built on the shore of San Francisco Bay in 1986 by the Exploratorium. By using a network of pipes, the wave organ interacts with the waves of the shore of the bay and conveys their sound to listeners at several stations [38]. Depending on the level of the tide, the voices produced are different. The structure incorporates stone platforms and several benches where visitors are able to sit near the mouths of pipes, listening (Figure 7c).

5.4. Hydraulophones

Hydraulophones are essentially pipe organs that use water instead of air to produce sounds. Unlike the Waterphone, hydraulophones can be played melodically like a piano. However, instead of using keys, hydraulophones offer a row of holes similar to a flute that players cover with their fingers, forcing water through the instrument to create music [39–44]. Many hydraulophones are marked with Braille so that players can recognize the various holes to plug and produce the notes they want without having to worry about trying to see through all that splashing water (Figure 8). Hydraulophones also provide children with unstructured and open-ended creative play opportunities through sound and water [44].

(**a**) (**b**)

Figure 8. Hydraulophones: (**a**) in a church and (**b**) in a public concert.

5.5. The Lalitsa

The lalitsa is a wind-blown Greek musical instrument, a type of a vessel flute, widely used in folk music (Figure 9a). It is usually made out of clay or ceramic, in the shape of birds, fish, cockerels or little pitchers. It is a vessel flute, much like the floghera, though lalitses themselves have no finger holes. When its circular body is filled in with water, it gargles and sounds like birds chirping. It can also be played without water, in which case, its sound is similar to whistling. The lalitsa may also be called water blower, cuckoo or nightingale and can produce various tones (like the ocarina) or just one tune [45].

(**a**) (**b**) (**c**)

Figure 9. Other water musical instruments: (**a**) the lalitsa [45]; (**b**) a waterphone musician [46]; (**c**) water drums (photo by A.N. Angelakis).

5.6. The Waterphone

Richard Waters developed the waterphone in the 1970s, acquiring a patent for the unusual instrument in 1975 [47]. It is also called the Ocean Harp or the AquaSonic Waterphone, and it looks like a flying saucer and its alien appearance is more or less accurately rendered in the otherworldly sounds it makes. The instrument's unearthly wailing evolves in an organic way because a chamber built into the base is filled with water [46]. Players can change the pitch or produce strange reverb-like textures by tilting the waterphone, which sloshes the water around inside. With such an eerie sound, the waterphone lends itself to suspenseful soundtracks, scoring films such as "Poltergeist," "Let The Right One In" and several "X-Files" episodes. The instrument is used mostly to create spooky atmospheres rather than melodies. Since its haunting tones are reminiscent of whales, some have even used the waterphone to call to the marine mammals (Figure 9b).

5.7. Water Drums

Water drums are an old percussion musical instrument, traditionally played in African tribes. The water drum has two parts. The bottom half of the water drums are filled with water while the top half of the water drum is placed open end down on top of the water [48]. Water drums are a category of membranophone which are characterized by filling the drum chamber with some amount of water to create a unique resonant sound. Water drums are used all over the world (Figure 9c). Water drums are used in Iroquois, Navajo, Cherokee, Creek, and Apache music [49]. They are very common in Native American music and are widespread in North and South America. Nowadays, the application of water drums has increased worldwide by famous singers and composers. Mohammad Reza Shajarian (1940–2020), the greatest and most famous Iranian musician, applied water drums in one of his tiny desk concerts (Figure 10). With two Grammy Awards nominations, Shajarian was and is an idol in Iran and around the globe. He was hailed as one of National Public Radio (NPR)'s 50 Great Voices of all time and he believed in using new and innovative instruments (e.g., water drums) in Persian classical music [50].

Figure 10. Mohammad Reza Shajarian (the singer) is using water drums in one of his tiny desk concerts [50].

5.8. The World Greatest Dancing Fountains in Burj Khalifa Downtown Dubai

The Dubai fountain is the world's tallest performing fountain (https://youtu.be/MELNJRJMK-Q). The world's biggest dancing fountains are located right outside the Burj

Khalifa, the tallest building in the world, which is right next to the Dubai Mall, the biggest of its kind in the entire world. At over 275 m in length, equivalent to over two football pitches, the Dubai fountain is situated on the 12 ha Burj Lake and performs a selection of different melodies. The fountain has a unique design comprising five circles of varying sizes and two arcs and features powerful water nozzles that shoot water up to impressive heights. Over 6600 wet super lights and 25 color projectors create a visual spectrum of over 1000 different water expressions, while 50 color projectors provide a full spectrum of color with a total output of 1.5 million lumens. The fountain performs a range of different songs from classical to contemporary Arabic and includes other music from around the world. When operational, the fountains have over 83 m^3 of water in the air at any given moment.

5.9. Water Research and DJing

Research and music are activities that one chooses out of passion, which is the most important trait d'union between two worlds that seem very different at first glance. Nonetheless, there are some examples of people who have realized the important benefits held in both fields, such as the great guitarist and astrophysicist Brian May, and the 90s techno DJ Ramirez alias Alex Buelvas who is also a physicist (https://en.wikipedia.org/wiki/Brian_May; https://it.wikipedia.org/wiki/Ramirez).

If you stroll around university backyards, you can meet some students who perform as DJs in their free time and study for more "formal" professions. However, there is also someone who started DJ performances after a M.Sc. in Chemical Engineering and a Ph.D. in Wastewater Treatment, as Luigi Falletti alias DJ Colouring, author of this short contribution, who did his first performance as DJ in Italy in 2011 and then three years later performed in Ibiza just some weeks before presenting a paper at the World Water Congress in Lisbon. Now, research in wastewater treatment and DJing continue passing from mixers that stir moving bed biofilm reactors to mixers connected with CD-players and loudspeakers, dealing both with filters that separate particles and with filters that cut bands of frequencies to give particular effects to house and techno music tracks.

Many thousands of tracks are indeed inspired by water. Searching on www.beatport.com (which is a site where a lot of DJs buy music), there are more than 90,000 titles that contain the word water, river, sea, ocean or rain. There are even three titles that contain the word wastewater. Certainly, rock lovers know "Smoke on the water" by Deep Purple, nineties dance lovers know "It's a rainy day" by Ice MC, electro dance lovers know "Sex, love and water" by Armin van Buuren and hardstyle techno lovers know "Ocean" by TNT.

Both research and DJing require hard work and continuous revision. Behind a very great DJ set, there are a lot of numbers: the speed of every music track (which is measured in beats per minute, bpm) and its adjustment to the value of the previous track, the starting point of the subsequent track at the end of a harmonic progression, music tones of two tracks that give better mixing effect, and in some, the combinations correspond to precise frequency ratios (https://en.wikipedia.org/wiki/DJ_mix; [51]). If a DJ starts producing new tracks, they have to deal with algorithms of electronic music production software [52] from morning until night. However, nothing is more important than the number of people who dance and move to your music. Because music is a sort of universal language that transmits sensations to people, as much as water is present in every living being.

5.10. Water and Modern Sounds

In his revolutionary book" Blue Mind", Nichols [53] points out the benefits of being in, on, under, or simply near water. He combines cutting-edge neuroscience with personal stories from a variety of people with different backgrounds and positions. Through these he shows how proximity to water can improve "performance, increase calmness, diminish anxiety, and improve professional success".

The human body, itself, made up mainly of water, receives and transfers external sound and music impulses in the brain not only just by hearing and seeing, but also by other mechanisms (e.g., neurologic). These impulses are processed in the brain, and then

can create emotions, feelings and sensations only to be interpreted as being caused by those sounds and musical wonderment.

The water-induced effects in the aforementioned processes is most achieved and most enhanced while playing or listening to instruments that vibrate or resonate (e.g., sound bowls) underwater, while the listeners are floating or wading near the sound source.

When a human being creates sound and music, the physical and emotional interactions become very complex. The more the producer of sound and music sings and moves, the more profound the part of water inside their body will have in the overall effect on those listening [54].

The Finnish rock band Miljoonasade ("Million Waterdrops") have played their instruments underwater (https://www.youtube.com/watch?v=GzBhg6kXbaQ). It has been reported that the underwater atmosphere is audible in the final result [55].

Accordingly, in the modern sound bath, both bathers and music devices are floating in water (Figure 11). Sound making bowls are played in the water as close as possible to the bathers to maximize the vibration effect. This kind of a bath combines soothing and calming elements such as warm water, feeling of weightlessness, and vibrations in both water and air. This tradition originates from Tibet [56].

(**a**) (**b**)

Figure 11. Modern sound bath [56]: (**a**) both bathers and music devices are floating in water and (**b**) the bather is playing the music device.

5.11. Contemporary Artists' Use of Water in Sound Art

In this section, we focus on some of the contemporary artists who use water in their sound art. One of the examples of the relation of water and modern music is a water fountain designed by Gerhard Trimpin a sound artist, kinetic sculptor and German musician. In his invention, drops of water, timed in complex rhythmic fugues, dripped into glass receptacles [57]. There are also some other examples of modern art and water-driven music technologies such as the funnel wall and submerged turntable [58,59]. The funnel wall was designed by Annette Paul, Christoph Roßner and André Tempel Dresden, Germany. This wall, all covered with funnels and gutters, is one of the strangest and most enjoyable attractions in Dresden's student district (Figure 12). When it rains, this colorful drain system turns into a charming musical instrument and the funnels and pipes, which grace the building, play "rain-music". The funnel wall was inspired by Rube Goldberg Machine, converting the mere patter of rain into a spectacular orchestral symphony [58].

Figure 12. The funnel wall in Dresden, Germany [58].

Another example application of water and music in modern art is the submerged turntable designed by Evan Holm. In this device, you can submerge a record player and still hear what is scratching just below the surface (Figure 13). Holm says: "There will be a time when all tracings of human culture will dissolve back into the soil under the slow crush of the unfolding universe. The pool, black and depthless, represents loss, represents mystery, and represents the collective subconscious of the human race. By placing these records underneath the dark and obscure surface of the pool, I am enacting a small moment of remorse towards this loss. In the end, however, this is an optimistic sculpture, for just after that moment of submergence; tone, melody, and ultimately song is pulled back out of the pool, past the veil of the subconscious, out from under the crush of time, and back into a living and breathing realm." [59].

Figure 13. The submerged turntable designed by Evan Holm [59].

Tomoko Sauvage, the Japan-born musician and artist, has been exploring sonic properties of water in different states for over ten years. The title of one of the artist's projects water bowls comes from the name of the "natural synthesizer" (Figure 14). Through the sounds coming from water bowls, the artist investigates the sculptural properties of music and spiritual potential of vibrating matter. The 'natural synthesizer', which the artist uses as an instrument in her performances, is made out of ceramic bowls filled with fluids, light and an underwater amplifier. From the microphones submerged in water, the artist uses hydrophonic feedback flowing both with water waves and within airy bubbles released from the porous ceramic surfaces [60].

Figure 14. Tomoko Sauvage is playing water bowls in her concert [60].

Jana Winderen is a Norwegian artist who pays particular attention to audio environments and to creatures which are hard physically and aurally for humans to access such as inside ice, deep under water, or in frequency ranges inaudible to the human ear (Figure 15). Her activities include site-specific and spatial audio installations and concerts, which have been exhibited and performed internationally in major institutions and public spaces [61].

Figure 15. Jana Winderen is recording the ocean's voice [61].

6. Discussion and Conclusions

Water is a sound source in itself, where even a tiny drop of water can produce a big effect in music. Water is an incredible and engaging system that through rivers, fountains and the sea can inspire musicians to create motion and emotion [62]. In addition to being an inspiration for composers, nature and natural formations have served as a "natural water instrument" since ancient times.

The variety of interpretations, combined in respect to water and music, may serve as the ultimate proof of the diversity of human natures, different attitudes, approaches and interpretations of water as presented by individual musicians and artists. Studying how water is interpreted in music (the imitation of its sound and flow, allusions to the openness of the sea, applying texture reminiscent of water, using rhetoric figures, etc.) helps to realize the multi-faced nature of human relation with water serving as a catalyst for human creativity.

The composer George Frideric Handel wrote water music for a water pageant on the Thames but included no fanfare for fountains when the piece was first performed on King George I's royal barge in 1717. It is called wave movements, in which ocean wave patterns were translated into musical notation, but that delivery is performed by a conventional orchestra. Though some listeners may know the sound of water from the singing or whistling of shower heads and faucets, hearing the hydraulophone is a far different experience [63].

Nature and natural formations such as vertical rocks along water bodies connected with echoes have served as a "natural water instrument" since ancient times. The use of water instruments for musical purposes have been developed through technological progress in contemporary times (1900 AD–present). Zadar's seashore organ, hydraulophones, waterphone, and the world's greatest dancing fountains in Burj Khalifa downtown Dubai

are some examples of the use of water instruments for musical purposes in contemporary times. At first, some instruments had hunting applications. For example, they were used mostly to create spooky atmospheres rather than melodies. Since its haunting tones are reminiscent of whales, some have even used the waterphone to call to marine mammals. However, nowadays, most instruments are used as entertainment. As an instance, unlike the waterphone, hydraulophones can be played melodically like a piano. Other aspects of employing water for musical aims may be observed in some creations such as The Dubai fountains and seashore organ in Zadar.

The musical water fountain is loosely based on the fountain located in front of the famed Bellagio hotel and casino. It takes input from any sound source and the sound breaks it down into different "sequences", then they use the output to turn on various solenoid valves. Each of the different ranges will correspond to a different valve which then comprises the musical water fountain to operate to the beats and rhythms of the song.

Applications of water-driven music technologies in sound art well show a linkage between modern art and use of water as an inspiration element of the nature. In this paper, we discussed examples of the use of water in sound art such as water fountain, funnel wall, submerged turntable, water bowls, and recording nature's voice. Future studies can provide more information on the relationship among water, musical instruments, postmodern art and sustainable development to enhance our knowledge about these fields.

This review provided valuable insights into the art of water-driven music technology developed in several regions of the world (e.g., Balkan Peninsula, China, Finland, India, Italy, Pakistan, UAE, and the USA). The examples that were briefly described above prove that water-driven music technology has remained an important medium for the entertainment of people since antiquity. A chronological continuation of water-driven music technology among various regions of the world throughout centuries is shown. In the cases where there are indications of contact between civilizations, the similarities of such technology are obvious (e.g., Greeks, Egyptians, Indus Valley and Mesopotamians). In addition, they could "build bridges" with neighboring civilizations [64]. In other cases, where there is no contact (e.g., Mediterranean and Chinese), technological similarities should be considered as accidental [65]. This paper demonstrates that people have developed a variety of sophisticated techniques using water-driven music. These ancient hydro-technologies and practices applied from past civilizations are imperative technological knowledge for any new scientists dealing with water-driven music systems and for new musical bands who are interested in the link between water and music [66–69]. This paper contributes to developing ideas and new water-driven musical technologies as a music therapy strategy for sustainable development purposes.

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