# The Ragpicking DMI Design: The Case for Green Computer Music

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## ABSTRACT

This article introduces the idea of sustainable development of DMIs, discussing how fundamental concepts like e-Waste, Ragpicking and Green Computing can be (re)used to minimize or eliminate where possible the environmental impact of DMIs. The arguments and fundamentals for this initiative are presented, as also some examples to illustrate our ideas. Our intention is to contribute to the reflection by the Computer Music community on the subject.

## CCS CONCEPTS

**• Social and professional topics → Computing industry**; **• Applied computing → Arts and humanities**; **Law, social and behavioral sciences**.

## KEYWORDS

e-Waste, Digital Musical Instrument, Ragpicking, Green Computing, Computer Music

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## 1 INTRODUCTION

Electrical and electronic equipment (EEE) has become an essential part of everyday life. Its availability and widespread use have enabled much of the global population to benefit from higher standards of living. However, the way in which we produce, consume, and dispose of e-waste is unsustainable [19]. In 2019, the world generated 53.6 million metric tons (Mt) of e-waste, and only 17.4% of this amount was officially documented as properly collected and recycled. There was an increase of 1.8 Mt of recycled material since 2014, but the total e-waste generation increased by 9.2 indicating that the recycling activities are not keeping pace with the global growth of EEE disposal. This is no different in the context of digital music instruments (DMI), especially due to their prototyping culture where the design and construction of a (new) instrument usually is part of the exclusivity of the music performance. Once the musical piece or performance season is finished, the question remains: what to do with the equipment?

Such problems are related to greening of technology, i.e. enhancing environmental sustainability by making the entire product life cycle of technologies and products greener, including research, manufacturing, use and disposal. Computing has also established its share to contribute to saving the environment under the concept "Green Computing". In simple terms, Green Computing involves reducing the environmental impact of technology: that means using less energy, reducing waste and promoting sustainability. Green computing aims to reduce the carbon footprint generated by the Information Technology (IT) and related industries. Energy-efficiency and e-waste are two major techniques involved in green computing. The first one involves implementation of energy-efficient central processing units (CPUs), servers and peripherals as well as reduced resource consumption. The second one means the proper disposal of electronic waste.

We are now concerned with such ideas of sustainable development in Computer Music, more specifically related to development of DMIs. Thus we are interested in how some fundamental concepts like e-Waste, Ragpicking and Green Computing can be (re)used to minimize or eliminate where possible the environmental impact of DMIs. In this paper we firstly present some arguments and fundamentals for this initiative. Then, we discuss three main areas that require our attention in that matter: a) recycling waste; b) innovative repurposing of discarded materials; and c) use of sustainable material and/or a sustainable source. Some examples are presented to illustrate our ideas and initiatives.

## 2 GREEN INITIATIVES: FUNDAMENTALS, MOTIVATION AND SOME EXAMPLES

In this section, we summarize some initiatives related to ways of doing things while saving the environment. Such initiatives appear in a large number of aspects in our lives – such as recycling, energy-efficient devices, clean energy sources, eco-friendly vehicles,


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green buildings, etc. – but we are mainly focusing on fundamental concepts like e-Waste and Ragpicking.

E-waste is any electrical or electronic equipment that has been discarded. This includes working and broken items that are thrown in the garbage or donated to a charity reseller. Often, if the item goes unsold in the store, it will be eventually thrown away. E-waste is par-ticularly dangerous due to toxic chemicals that naturally leach from the metals inside when buried. Green computing [16], on the other hand, is a broader concept overreaching the environmentally re-sponsible and eco-friendly use of computers and their resources. In practical terms, green computing aims to find approaches of design-ing, engineering, manufacturing, using and disposing of computing devices in a way that reduces their environmental impact.

The environmental impact issue can be addressed from different angles and by different players. It echoes from the manufacturing lines to the consumer misuse of the product, overarching questions of design, the efficient use of raw materials, logistics (i.e shipping), sustainable disposal, cultural-biased bad practices, and so forth. It is a complex problem that should be handled collectively. In order to really make a difference, this issue should be in the centre of all aspects related to product design and usage, favoring durability, maintainability, reuse, repurposing, recycling, and all the different aspects of energy efficiency – to manufacture, to use, to dispose.

It is all about counterbalancing the user's convenience and practicality with ecological awareness and collective reflections: should we unconditionally replace audio cables with wi-fi transmissions despite knowing they require more energy to run and are dependent on batteries, which are very difficult to recycle? Here, an important mention to LE Audio and Bluetooth 5.2 must be made since it incorporates the efforts of transmitting high-quality audio with the minimum amount of energy [52]. Is the user-centred design still the way forward if that means detrimental consequences to environmental (and collective) interests?

Culturally-wise, we ought to rethink the social pressure to acquire the latest version of a product without questioning ourselves the real demand for it. Specifically, we must beware of the aggressive marketing campaigns heavily based on novelty used by computing device manufacturers. The same applies to developing a new piece of software from scratch even if there is an open-source option available, wasting resources and energy. It is important to bear in mind that before the industrial revolution, recycling and repurposing discarded objects used to be the norm. As mentioned by Compagnon [9], the ragpickers of Paris in the 19th century used to collect rags of old linen for the manufacturing of paper. However, with the rise of education and the abundance of the press production, the demand for paper exploded. The ragpicker was both the disturbing night prowler of the French capital and the indispensable agent of the progress of society; from the hygiene of the streets of Paris to the administration of waste. But not only old linen was a valuable item for recycling at those times: bones were collected and used to manufacture buttons and dominos. Furthermore, still according to Compagnon, "boiled, they would provide gelatin. Burnt, they were reduced to animal black used for filtering and dis-coloring beet sugar syrup [. . . ] one also obtains phosphor to manufacture the inflammable ends of matches" [6]. Nevertheless, from the end of the Second Empire, paper began to be made with wood fibre and, in 1883, the city mayor Eugène Poubelle decreed that the garbage would be placed in recipients, which would eventually be named after him: "la poubelle". Costalonga et al. [13] point out that the physicality of DMI may play a significant role in the user experience (UX). The authors go on by suggesting that designers should invest in a durable design using good quality materials that evokes desire in the users – in place of the usual, profitable and disposable toyish design. In fact, they even state that an augmented instrument approach should be preferred since musicians may lose the subjective feeling of actually objectifying the sound when using just a computer interface to make music. In addition, it can be quite frustrating having to deal with updates, fixing, compatibility, and the overall uncertainty of commercial continuation of digital instruments or software environments. Acoustic instrument does not have a due date and it will not become obsolete with the next year's release. Such credibility is an important value to improve the UX design of DMI and interfaces. The environmental aspect in a product development is a key factor to its design, costs, and consumer validation [2, 39, 42]. A modular design, for instance, allows a defected or obsolete part to be replaced when it is required, providing a longer lifecycle for the device and potentially reducing electronic waste. An example of such an approach is Project Ara [27], which was a modular smartphone project under development by Google. Under its original design, Project Ara was intended to consist of hardware modules providing common smartphone parts, such as processors, displays, batteries, and cameras, as well as modules providing more specialized components, and "frames" that these modules were to be attached to. This design would allow a device to be upgraded over time with new capabilities, without requiring the purchase of an entire new device. However, by 2016, the concept was revised, resulting in a base phone with non-upgradable core components, and modules providing supplemental features. Google stated that Project Ara was being designed to be utilized by "6 billion people": 1 billion current smartphone users, and 5 billion future phone users [1]. That said, the project has been dropped and no commercial product came out of it. Why is that? The reasons behind Project Area deflection and ultimate interruption is unclear, but one could argue that the decisions were taken due to the fact that marketing in the electronics industry is mostly driven by novelty. Fastest, clearest, and lightest are common words to sell NEW generation features of products, turning rather recent projects into obsolete devices (and their parts might occasionally become fanciful again after several years). Even some renowned academic gatherings highlight the "newness" appeal of musical expression interfaces. The hard question here is: What is the role of "newness" in driving design?

On that matter, it is clear that backtracking compatibility and the use of general accepted peripheral interfacing standards may extend the life cycle of a musical electronic product. For the last decade users have been dealing with all sorts of peripheral interfacing standards, such as USB 2/ 3/ 4 and their multitude of connectors, Thunderbolt using Displayport and TypeC connectors, Firewire 400/800, and so on. Many of such are used with limited support by the computer industry. In other words, one may be forced to upgrade a perfectly fine audio interface just because he needs to update the computer and can not find one with a Firewire port for instance.

The technical solution for the aforementioned compatibility problem may reside in one of many adapters produced somewhere, thousands of miles away from the consumer markets. Such adapters are inexpensive and have free shipping, but this may not be entirely true. While buying an adapter seems to be a better financial and more sustainable decision in comparison to buying a new audio interface, one must consider that cargo ships are the biggest and most polluting machines out there. The transport of maritime cargo emits 90,868 tons of C02 per hour, which means 796 million tons C02 in a year. That is more than the whole emission of a country as big as Brazil. A single ship pollutes the equivalent of 50 million cars, that is, 15 of these ships are equivalent to all cars in the world [43–45]. Also, developed countries with a thriving economy and rigid emission control policies have no influence what-so-ever in emissions of the countries that are manufacturing their state-of-the-art computers and musical devices. This is more than turning a blind eye to the problem, we are just playing dumb!

Sometimes it seems we act as if there were plenty of time to change our ways. We make our decisions based on immediate solutions, such as financial cost, not to solve, but to postpone the necessity of solving problems. For example, the decision that most Brazilian drivers face when refueling is, more often than not, purely based on the financial cost of refuel, not taking into account sustainability when choosing between petrol or ethanol (renewable, sustainable and usually less polluting). The social well-being and the economic growth of a country should not depend solely on the production lines, industries, and intensive farming. The global resources are limited and, as designers/makers, it is our due to rethink our practices in order to contribute to sustainable development of technology for music and artistic production in general.

## 3 THE MUSICAL INDUSTRY WASTE

Many electrical items can be repaired or recycled, saving natural resources and the environment. If you do not recycle, electrical equipment will end up in landfill where hazardous substances will leak out and cause soil and water contamination – harming wildlife and also human health. Some musical instrument retailers make efforts to conform to the Waste Electrical and Electronic Equipment Directive regulations (WEEE), meaning that if one purchases any electrical and electronic equipment (EEE), the retailer will dispose of equivalent equipment free of charge on a like-for-like basis.

Some classes of musical instruments tend to generate more waste than others. Worn parts such as old strings, picks, batteries, and tubes will certainly need to be disposed of some day, as well as, blown speakers, frayed wires, trashed amps, unwanted enclosures, and fried electronics [20].

According to Music Industry of 2020s Rank [47], the top 10 manufacturers are respectively: Harman Professional, Shure Inc., Fender Musical Instruments, Yamaha Corp USA, Steinway Musical Instruments, inMusic, JAM Industries, Gibson Brands, QSC, and Hal Leonard Corp. Some of these companies are, in fact, a conglomerate of independent brands with different views and approaches to the sustainability issue.

On the top of the list there is Harman Professional, a Samsung Company. Harman claims to monitor the water consumption, energy usage, waste production, and greenhouse gas emissions of its factories. From 2018 to 2019, their absolute emissions decreased by six percent and the waste generation was cut by two percent. In 2016, they met the first goal to reduce energy usage by ten percent worldwide. Is this enough? They still emit 468 metric tonnes of carbon dioxide equivalent (CO2e), plus 38,002 metric tonnes of CO2e (location based), plus 21,909 metric tonnes of CO2e (business travel). Their production processes consume 90,302 MWh and generate 10,657 metric tonnes of waste.

Bear in mind that greenhouse gases do not all warm the planet equally. For example, methane does not stay in the atmosphere as long as CO2 does. But for the first two decades after its release, methane is 84 times more potent as a greenhouse gas, according to the Environmental Defense Fund. “CO2e” simplifies by converting the warming impacts of other greenhouse gases — like methane — into CO2 terms [25]. To put in perspective, according to the United States Environmental Protection Agency (EPA), 1 metric ton of CO2e is produced by driving from San Francisco to Atlanta in an average car. In other words, the 60,000 (plus) tonnes of CO2e produced by Harman is equivalent to 60 thousand road trips between San Francisco to Atlanta, or 2,5 times around the world. No initiative regarding recycling waste, repurposing of discarded materials, or making use of sustainable material and/or a sustainable source were reported in their website or shareholders reports [28].

Shure Inc., is even more shy in their efforts towards a sustainable music industry. Likewise Harman there are no initiatives regarding repurposing of discarded materials or making use of sustainable material and/or a sustainable source, but at least the UK branch claims that all Shure products are in compliance to European directives such as “Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS)” and the “Registration, Evaluation, Authorization and Restriction of Chemicals (REACH)”. The UK branch is also registered with national recycling schemes (WEEE)[49]. World-wide efforts however are limited to having fitted in 2015 some rechargeable Li-ion Battery Roars into Wireless Mic Technology praising the environmental upside of their decision. Previously, they had also announced a redesign in its packaging to be more environmentally friendly, eliminating mylar coating and full-color graphic printing from the cartons to increase the recycle-ability of the packaging [31].

Fender (3rd in the list), along with other guitar manufacturers such as Gibson (8th), Martin Co. and Taylor, seems to be more environmentally conscious, at least regarding changes in logging practices for the woods used to make musical instruments. In 2010, together with Greenpeace, they formed the “Music Wood Coalition” that encourages private landholders in Alaska to apply for certification by the Forest Stewardship Council (FSC), which would entail adopting logging practices that would safeguard the survival of the region’s remaining ancient forests while continuing to produce high quality wood. The initiative is starting with Sitka spruce, commonly used as the soundboard for acoustic guitars and pianos and considered the heart of the instrument [21]. Out of this group, Martin Guitars deserves a special mention.

Martin Guitar claims to be a leader in environmental stewardship and to be, not only committed to creating high-quality eco-friendly and sustainable guitars, but a greener workplace for their employees [30]. In fact, Martin is the first in the Musical Instrument Industry to receive B Corp Status, given to businesses that meet the highest standards of verified social and environmental performance, public transparency, and legal accountability to balance profit and purpose. The brand as a whole invests in a myriad of sustainable projects around the globe including their own Biannual Wood Summit which gathers global environmentalists to discuss sustainability in sourcing raw materials. Martin Guitar have supported their commitment to the environment by choosing the Rainforest Alliance as their certifying body to achieve Forest Stewardship Council® (FSC®) Chain-of-Custody certification. They also source a majority of their tonewoods by actually visiting the plants to ensure their sustainable FSC certified wood is up to standard. Overall, Martin Guitars state that close to 80 percent of the wood they use has some level of FSC certification when it comes in the door. In addition, they have programs in place at the factory to recycle string waste, sound holes, sawdust, and more. Over 85% of their guitars are built from sustainably sourced wood [8].

Another guitar manufacturer which stands out in its efforts to provide a sustainable environment and recycling initiatives is Canada's Godin Guitars, a group consisting of several guitar brands: Godin, Seagull, Norman, Art & Lutherie and Simon & Patrick. All their guitars are manufactured in North America by local specialized workers in 5 factories in Québec, Canada and one in New Hampshire, the USA, therefore completely avoiding the widespread use of third-party Asian manufacturers in this field. Most of the wood used in their guitars comes from local (North American) forests, and the company has an active recycling policy regarding wood scraps which are used in a variety of products, down to saw blade dust which is sold to farmers to be used in stables [36].

Yamaha Group also seems to have established mature policies towards a sustainable future by understanding the significance of protecting the natural environment and maintaining biodiversity, and by promoting the reduction of environmental burden through measures such as sustainable procurement of timber and lowering greenhouse gas emissions [12]. Yamaha is known to produce a myriad of different instruments including pianos, percussion instruments, woodwind instruments, acoustic guitars and electric guitars. So, they use a significant amount of wood. With this in mind, the Yamaha Group established the "Yamaha Group Timber Procurement Policy," which, according to Yamaha " indicates the direction of our timber usage in order to better conserve this precious resource, as well as ensure its availability for continued use in the future." On top of that, Yamaha went on to establish the Yamaha Supplier CSR Code of Conduct, which basically stipulates certain practices regarding the harvesting and trading of timber resources to be followed by their suppliers [52]. With respect to the various product groups, Yamaha perform product life cycle assessments (LCA) that cover all product life cycle stages, including material procurement to production, transport, use, and disposal to identify what aspect of a product group life cycle has the largest environmental impact and to tackle environmentally friendly design from multiple angles [11].

Big companies, such as those mentioned above, have the resources to invest in those types of policies. As presented, some choose to do more than others based on their values and commitment to society, after all, there is little or no detrimental effect to their brand image if they decide not to embrace such initiatives. Nevertheless, due to their size, even a small step in the right direction will have a big impact on the absolute numbers. It is still far from ideal and, more importantly, far from the reality of the small luthiers and from the makers community. So, the question is: how can the small ones embrace the sustainable way of producing DMIs?

## 4 RECYCLING WASTE

Some musical instruments parts present natural degradation due to time and usage. What to do with this waste? Is it biodegradable? Is it toxic? Can it be recycled?

Some parts, like guitar strings and metal amp chassis are easy to recycle and might even have marketable value. Back in 2010, Cleartone Strings and Guitar Center announced the first guitar string recycling program for used guitar strings. In 2016, D'Addario's put together its own program allowing guitarists to send or drop off used strings – of any brand – at participating locations, after which the company will either make a charitable donation or the sender can earn loyalty points. In 2019 Martin & Co. (Martin Guitar) announces their official partnership with D'Addario on the Playback string recycling program. This seems like dealing with a very small part of the problem, but it is estimated that more than 1.5 million lbs. of instrument string metal could be put into landfill every year. Up to this point, D'Addario claimed to have recycled 6 million strings.

Cables are e-waste to be! It will certainly break at some point and it will need to be replaced, meaning more energy and material to produce a new one. Despite the fact that most cables do not end up being recycled, at least they are recyclable, and it is economically desirable to do so. That is not the case with single-use batteries that, although recyclable, it is not a straightforward process [48]. Recycling battery components is a complex and expensive process due to the chemistry involved, so recycling is an afterthought and manufacturers do little to simplify the retrieving of precious metals. The recycling business is small compared to the vast battery industry, and to this day, only lead acid can be recycled profitably [51]. Besides the need to require batteries, wi-fi transmission also requires significantly more energy than cabled systems.

Fried circuits, amps, and speakers would certainly let you exercise your craftsmanship by turning it into a fine keyring or a nice coffee table (repurposing) but it also holds commercial values, especially reverb units. Even if no one wants it, the scrapyard pays for the scrap metal. That metal is chopped up, melted down, and turned into new steel. Circuit boards and non-functioning electronics are recyclable as well. A circuit board has all kinds of precious metals—like gold and silver—and harmful metals like lead and cadmium.

Recycling is often something not to take solo. It requires specialized machinery and access to big volumes of material to be financially viable. Cities and towns eventually hold an eWaste day to raise awareness but, honestly, what usually happens is that the material is trashed into a container and shipped off to developing countries where someone might try to get the metals out of it. Therefore, recycling may not seem to be for the individual DMI maker, but surely they can keep an open mind for the use of recyclable material, for instance, in 3D printing.

Most filaments used in 3D printing are not sourced from recycled materials. There are initiatives that propose the use of recycled filament made of recycled plastic coming from different materials, such as its standard PLA or ABS, and rarer materials like HIPS and ASA [15, 26]. Recycled filament is made the same way as regular filament, but with raw materials sourced from recycled plastic, either from bottles or other recyclable scraps. These scraps are then loaded into expensive machinery, which grinds them into small plastic pellets. Just as regular filament is made, the pellets are heated and cooled to form a particular shape, known as filament.

## 5 REPURPOSING

Machado [34] defends that the appropriation that art makes of the technological apparatus contemporary with it differs significantly from that made by other sectors of society, as the consumer goods industry. He considers that, in general, appliances, instruments and semiotic machines are not designed for art production, at least not in the secular sense of that term, as it was constituted in the modern world – from the 15th century onwards. The fact that artists use devices that were not originally designed for Art makes more interesting and complex the discussion about when something becomes an artistic object or not [40].

Repurposing can be viewed as a different type of recycling. It is less about the material and more about its use, or original purpose. Something that is not working anymore for its intended original use can be ideal for another purpose. Repurposing an item can be done by modifying it to fit a new use, or by using the item as it is in a new way. The practice is not limited to physical items and, once more, open-source code can be seen as an example.

Component harvesting from old consumer goods is a sustainable way to get parts for the prototypes. Outdated electronics can be scavenged for motors, gears, and other interesting mechanisms, as well as component-level electronics that include resistors, capacitors, and inductors. Analog Outfitters, for instance, is an American company specialized in building amplifiers from repurposed Hammond organs, but also make the Scanner (Figure 1), which repurposes the vibrato and reverb units from old Hammond organs, and a MIDI controller from repurposed keyboards. The company began as an amp repair company before branching out with their own line of guitar amps. Highly rated by pro guitarists including, their quirky line of heads and combos is big on vintage values and boutique appeal, all tube and no frills. Their biggest distinguishing feature is the use of reclaimed parts from vintage Hammond organs, principally the transformers and casework, making each amp a unique piece of 'upcycled' history[22].

The "up-cycling", as the company calls it, goes beyond the electronics. They reuse the wood, the copper wiring, the amplifiers, and even the tubes whenever it is possible. Hammond used redwood, mahogany, walnut, and a lot of premium woods – some of which it is not available anymore. These premium woods are used in our wooden enclosures. The thing to remember about a (tube) guitar amp is that the output transformer is the most important part of the whole amp. The output transformer takes the energy created by that amplifier and couples it to the speaker. If the coupling device is not good, then the tone will not be good as well.

**Figure 1: The Scanner is an unusual electromechanical effects unit built from reclaimed Hammond organ parts, via official social media (Instagram @analogoutfitters).**

Building amps from repurposed materials is not simple or cheap so the quality of the "raw material" is a key factor for the success of it. For instance, organs from the 70's have no "up-cycling" value because the wood that they used was particle chipboard and the amps were transistor based reinforcing the importance of building or using good materials in the initial design as discussed by Costalonga et. al [13].

Another example comes from Detroit. In 2014, Wallace Detroit Guitars [23] was founded claiming to literally build guitars from Detroit history. They use reclaimed wood from Detroit abandoned buildings to build fine guitars (Figure 2). Most of the wood comes from the Architectural Salvage Warehouse of Detroit, a local nonprofit that functions as an unusual lumber yard. The pine that comes out of houses that were built between 1860 and 1930 is generally pine from old-growth forests and it is quite different from pine grown in modern forests. The reason that matters is that the growth rings you get from the old forests are much tighter than the growth rings you get from a modern forest, bringing an interesting performance characteristic to it.

Another company repurposing musical itens is Guitar Wrist [24]. They make bespoke jewellery (Figure 3) from used guitar strings and the profits go to the artist's charity of choice.

These hand-made items have both an emotional and physical connection to the Artist and fan. Their renowned artist's base includes names such as Judas Priest, Guns n' Roses, Waterparks, Joe Perry (Aerosmith), Iron Maiden and others. The Project Campus Vivo [14] delivers culture in the form of machinery art to the small academic community in the Brazils countryside. To entertain and to enchant the audience, computer engineering students use their technical skill in favor of the art to build Computer Automated Cultural Artifacts (CACA). As a keystone of the project, the students mostly use repurposed electronic components in their projects.

Figure 4 shows the students scavenging electronic components to be used in the interactive multimedia installation Memories Tree [38], as shown in Figure 5.

Figure 6 shows the first prototype of the project RoboMus [6, 7], which aims to develop an open framework of software and hardware

**Figure 2: Wallace Guitars uses reclaimed wood from abandoned Detroit buildings and houses, via official website (https://wallacedetroitguitars.com/)**

to robotic musical instruments. The prototype was developed over the mechanism of a reproposed printer.

One application of repurposing in computer music is reported in an exploratory research on the possibilities and on the elements that may be relevant for making use of consumer mobile devices as tools for musical activities, related in a PhD thesis by Luciano V. Flores at LCM-Ufrgs[17]. In his work, Flores has identified a problem he named "device repurposing problem", related to how to carry out the interaction design of a system for musical activities which involves non-specific mobile devices, that is, devices not originally designed for musical tasks. The answer lies not on adapting the device, but on finding unique and multiple (i.e., alternative) ways to manipulate data and musical information by using the features that the devices already provide. In a previous work [18], various models or paradigms of musical interaction were identified and formalized as patterns for the design of musical interaction with everyday mobile devices. His thesis has extended the preliminary patterns creating an infrastructure, composed of concepts and principles, interaction design patterns, and tools, to support the design of interactive musical systems which involve consumer mobile devices.

**Figure 3: Rings made from used guitar strings by Guitar Wrist, via the official website (https://www.theguitarwrist.co.uk/).**

**Figure 4: Students building CACA with repurposed and recycled electronic components.**

## 6 USE OF SUSTAINABLE MATERIALS AND/OR A SUSTAINABLE SOURCE

Where does the electrical energy that powers your computer when you are coding come from? What about the filaments of your 3D printer? Does your computer manufacturer use recycled materials or make sure they come from sustainable sources? Would you pay

**Figure 5: Memories Tree Interactive Multimedia Installation.**

**Figure 6: RoboMus first prototype.**

more for these models? When you want to create a new e-mail, do you consider the energy source of the data centers that hosts all those practical services attached to it (e-mail, cloud, messengers, etc.)? What about music streaming service or that delicious Colombian coffee that you drink all night long to boost your creative impulses? Any idea how it comes from Colombian fields all the way to your mug? Ok, maybe that last one was a bit too far, but it illustrates how we choose not to pay attention to such matters if it is beneficial to us somehow. It does not matter if lithium mining activities consume 65 percent of Chile's Salar de Atacama water forcing the local farmers to find water somewhere else. Afterall, your smartphone battery needs juice for another hour. We have not been educated to think about it! We just live with it, after all, there is so little we can do about it, right? Maybe you have been fortunate enough to be born in a rich country that provides you with economical means to fund that progressist development - it is a true pity that Congolese children working in Cobalt mines have not been as fortunate.

The energy footprint of the IT sector is already estimated to consume approximately 7% of global electricity [10, 29]. Some of the world's largest data centers can each contain many tens of thousands of IT devices and require more than 100 megawatts (MW) of power capacity—enough to power around 80,000 U.S. households [37]. Articulating and measuring the so-called cloud's environmental impact is difficult. It basically requires taking apart the constituent parts of the data center itself. Starting around 2006, power-usage effectiveness (PUE) has been the metric of choice for the data-center industry. PUE is a ratio created by the Green Grid Association, a consortia of IT industry professionals. It's a fairly simple measurement of a data center's total power usage to the power usage of its actual IT equipment. It is more a metric of efficiency than of environmental impact one. It only looks at the internal operations of the data center—not, say, where its energy comes from or how much energy they are using and what that looks like proportionately. For instance, Google is happy to report that its data centers account for only 0.01 percent of global electricity use [3], but fails to inform how much of it actually comes from renewable sources.

Since 2010 Greenpeace has been calling on major Internet companies to power their data centers on renewable energy. They release a series of reports [10] about the energy use of these companies and this has been a transformative experience. In 2010, they reported that Facebook data centers were running on 50 to 60 percent coal, just by buying energy from the grid. In 2011, Facebook became one of the first major tech companies to commit to operating on entirely renewable energy, in no small part because of Greenpeace's campaigning. In their last report (2017), Greenpeace reported that Facebook used 67% of clean energy (Figure 7).

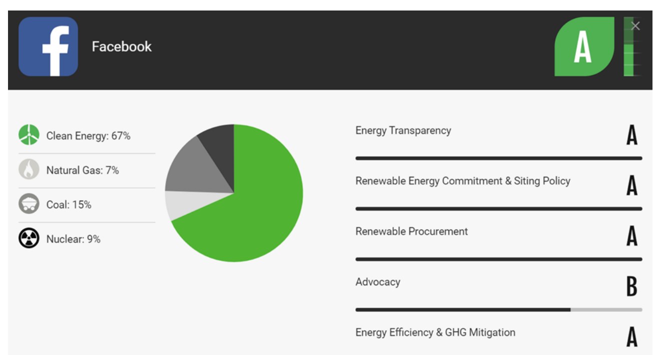


**Figure 7: Facebook energy profile according to GreenPeaces ClickClean Report.**

Since this work focuses on the music industry, what does the Greenpeace report say about music streaming services? The report gives an overall grade to the Companies that takes into account Energy Transparency, Renewable Energy Commitment, Efficiency and Greenhouse gas mitigation, Renewable energy, Procurement, and Advocacy. Therefore, usage of clean energy is not enough to guarantee a good grade (i.e. Spotify). All the policies must be at the right place to get an "A score" (Table **??**).

| | Grade | Clean Energy | Natural Gas | Coal | Nuclear |
|---|---|---|---|---|---|
| iTunes/Apple Music | A | 83% | 4% | 5% | 4% |
| Google Play/YT Music | A | 53% | 14% | 15% | 10% |
| Amazon Music | C | 17% | 24% | 30% | 26% |
| Spotify | D | 56% | 14% | 15% | 10% |
| SoundCloud | F | 17% | 24% | 30% | 26% |

Power-management is not a novelty in computing, but energy efficiency is. Do we develop software thinking about energy efficiency? The most widely implemented architecture for power management is the Advanced Configuration and Power Interface (ACPI). It has evolved together with Intel architecture, the hardware platforms based on the most widely available commodity CPUs and related components. Although ACPI is an important de facto standard with reasonably broad support from manufacturers, it provides only a mechanism by which aspects of the system can be controlled to affect their power consumption. This enables but does not explicitly provide energy efficiency, since energy efficiency is a matter of optimization: the system should consume the minimum amount of energy required to perform any task.

It is important to understand that performance and energy efficiency are not mutually exclusive. Traditionally, systems have been designed to achieve maximum performance for the workload bit even when achieving maximum performance, any resources that can be deactivated, or whose individual performance can be reduced without affecting the workload's best possible completion time or throughput, constitute energy optimization. The most strategic aspect of energy-efficient computing will be the evolution of application software to facilitate system wide energy efficiency. This is only possible combining application interfaces to the system software supporting the development of new energy-efficient applications coupled with an operating system that offer support and fine control to the compatible system hardware. Software developers must be aware of the possibilities in this area and make the most of it.

Another aspect DMI makers should be aware of is the choice of prototyping material. Prototyping is an inherently wasteful process. It is a trial-and-error process with no certainty of success that may lead to continuous rebuilding leaving a trail of waste behind. Although many consumer products are made from petroleum-based plastics, they do not necessarily have to be prototyped with plastic, especially in early-stage prototyping. Robust parts can be machined from wood or molded from natural wax. Paper and cardboard can also be great prototyping materials. They can be cut easily (less energy) on a laser cutter and assembled into prototypes [32]. Wood, in particular, is a great material for prototyping musical instruments, especially tonewoods. Not only is it biodegradable but also it is found that, from the CO2 emission and time consumed viewpoints, wooden prototyping technology is better than resin prototyping technology [50]. Reforestation of tonewoods, such as rosewood, ebony, and mahogany is an important aspect to be considered as well. The challenge, in terms of sustainability, is that trees take a long time to grow, sometimes 200 or 300 years. Also, it is not possible – at least not on a significant scale – growing these tropical trees in greenhouses.

As mentioned before, 3D printing is also a popular prototyp-ing tool, and fortunately there are eco-friendly materials available for extrusion-based printers. Companies such as Clean Strands (cleanstrands.com) offer starch-, hemp-, corn- and even beer-based 3D printer filament that will minimize your carbon footprint when you make plastic parts. Bear in mind, however, that computer-controlled prototyping tools are convenient, but they also use a lot of power. 3D printers use high-powered heaters to melt filament; laser cutters use high-wattage lasers to cut. To curb the excessive power usage, one should consider using traditional tools such as rulers, scissors, knives or hand saws to process material.

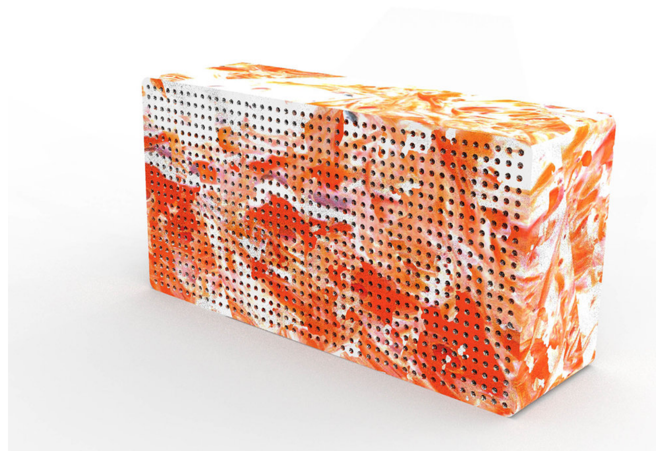

**Figure 8: Earth-friendly sustainable portable speaker handmade from plastic bags and powered by 100% repurposed e-bike batteries, via Gomi[33] press and images website (https: //www.gomi.design/press)**

A good example of sustainable source selection comes from Brighton-based design studio Gomi [33] that has created a portable bluetooth speaker (Figure 8), as well as other products, using plastic waste that is deemed non-recyclable by local councils in the UK. Each Gomi speaker features a rectangular body formed from colourful marble-effect plastic. The equivalent of 100 plastic bags in non-recyclable – or flexible – plastic go into the body of each speaker.

## 7 FINAL CONSIDERATIONS

Throughout this paper, it has been mentioned several examples of both products and initiatives that tackle the sustainable aspect of producing new technology, especially music related. Our intention is to invite the Computer Music community to reflect on the subject. A sustainable development of DMIs is a step to minimize or eliminate where possible the environmental impact of DMIs. Although apparently small, it is an actual initiative towards a Green Computer Music.

Fortunately, this is not an isolated concern, we are not alone. There are other works (see for example [35]) that have expressed this same concern.

Green computer music represents a change in priority in our activities. We are convinced such initiatives benefit the environment and that's why we have discussed and illustrated three examples of attitude changes concerning our research and development activities – recycling waste, innovative repurposing of discarded materials, and the use of sustainable material from a sustainable source. In this final section, we will summarize and highlight some attitudes that could contribute to a more sustainable design of Digital Musical Instruments.

1) Propose that undergraduate and new graduate students start by building copies of existing DMIs. By rebuilding DMIs, one gets to know the complexities of previous designs and the contexts in which they were done, but also becomes aware of possible lack of documentation, inviting one to become aware of the effort already made in the field and eventually provide better documentation to one's own designs. An example of such initiative is reported by Tom et al. [46];

2) Build novel DMIs by only using existing, used parts. Suggesting to students to only use secondhand material is a way to make them aware of waste and also of the value of existing tools that might not qualify as the newest of most advanced, but that may still be used to full advantage in novel designs (against marketing of novelty). Several initiatives related to that were reported in Section 5. If not possible, favor the use of recyclable material (software included) and renewable material as discussed in Section 4.

3) Propose that students create and document designs that will be re-created/implemented by other students, allowing them to understand the importance of documentation [4]. Here, we use the term "documentation" in the same sense proposed by Parnas [41]: a well-organized and precise documentation, written before and during the development (NOT written after the development), allowing many benefits like better communication about requirements, more useful design reviews, easier integration of separately developed modules, more effective testing, and more efficient corrections and improvements – but mainly easier reuse of old designs. In large-scale, collaborative projects, DMI documentation and replicability are essential features since they reduce effort and waste when recreating DMIs [5].

So far, the Computer Music community has been focusing on aspects of DMIs related to sound production, sound processing, control interfaces, and so on. Often, it is not concerned with other requirements like registering design decisions and their documentation, usage of reusable components, adoption of sustainable materials, devices repurposing. However, going forward, our community will need to deal not only with such requirements but the whole environmental impact of our work as well.

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