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Residual Orchestras: Notes On Low Profile, Automated Sound Instruments

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The paper deals with strategies and techniques for building and using "residual orchestras", that is, ensembles of low cost music instruments that can be controlled by the computer. First, the notion of "residual" is discussed as a keyword for the project. Then, the physical computing scenario is introduced, as it is the main reference for all the discussed projects. The inspiring "punk" philosophy is presented, and basic values and principles for design and implementation are discussed, in particular "refabrication", softening, flexibility. A design/ production pipeline is presented that takes into account the three different layers in residual orchestras: physical, physical computing, computation. Finally, some projects that have been realized are shortly discussed.

Keywords
Physical computing, Music instruments, Hardware hacking.

INTRODUCTION

The definition of music instrument is much more complex than it might appear at first glance. A vast, still on-going, debate among scholars has been prompted by the seminal classification by Hornbostel and Sachs (1961, see Kartomi 2001). By taking into account also electronic and digital music instruments (Lysloff and Matson 1985; Jordà 2002) it is possible to propose a minimal definition, that considers a music instrument as a device capable of generating sound once a certain amount of energy is provided. Three elements are relevant in its construction: the physical body, an energy source, and a control interface that allows fine-tuning of the latter, so that the physical body can respond properly.

In fact, in all tradition, music instruments are accurately crafted to match a certain desired output. In order to do so, they require an important amount of resources: be them related to construction (time, materials) or to control (again, time to master their usage). During the 20th Century, automation, as the control of a certain production pipeline operated by some autonomous technological agent, has followed an analogous path: in order to be accomplished, it has typically required many resources and resulted in expensive technologies (Groover 2007). Bu the raise of Informatics has partly changed this scenario, as personal computers made available to a very wide audience the use of computation (Davenport and Short 2003). But, until recent years, affordable computation has still remained isolated from the physical world.

This paper is intended as a discussion of some principles and experimentations that lead to various projects of automated, low cost sound/music instruments that can be defined "residual orchestras". "Orchestras" because, rather than focusing on a single instruments, each project deals with many sound generators. The meaning of the adjective "residual" here includes various semantic hues. Quoting the Oxford Dictionary, "residual" means "remaining after the greater part or quantity has gone". As I will discuss, a residual orchestra maybe made up of debris and re-cycled objects. But "residual" may also refer to "remaining after the removal of or present in the absence of a causative agent": in residual orchestras, objects are reused and redefined with respect to their previous statuses and functionalities. "Residual' also indicates what remains in terms of errors from an experimental of arithmetical procedure. Residual orchestras necessarily and happily exploit the serendipitous behaviors of the objects they are made of, leading to unexpected (at different granularity) results. Finally, when associated to soil or other deposit, "residual' stands for "formed in situ by weathering". Residual orchestras are the product of a sort of technological percolation, in which the resulting technical solutions emerge or stem from empirical experimentation.

The main ratio at the basis of residual orchestras is to couple advanced computational control technologies with low cost, re-used/recycled objects. Such an approach can be shared with communities of non-experts that may be involved –by designing and creating instruments- in the rather abstract practice of algorithmic composition.

SCENARIO: PHYSICAL COMPUTING

Personal computers have indeed prompted a sort of decentralization and democratization of computation. On the other side, the digital revolution has led to a drastic de-materialization of various practices. Considering the realm of electronic music, suffice it to say that the electronic music studio -that since its inception in the '50s required an environmental dimension simply to contain the hardware equipment- since the last decade has collapsed into a single computer. With a contrary motion, in more recent years experimental electronic practitioners have rediscovered and re-actualized through "physical computing" hardware hacking practices firstly explored in the analog domain (Collins 2006, Ghazala 2005).

The so-called "physical computing" (O'Sullivan-Igoe 2004) is an explicitly alternative scenario to the traditional digital scenario, the latter being based on a configuration of a processor unit (the computer) and highly standardized input/output devices (respectively keyboard/mouse and screen/loudspeakers). Physical computing proposes to uncouple computation (as a process) from computers (as objects) by moving the former into the "real world". Its motto is "making things talk" (Igoe 2007): collections of heteroclite objects can therefore be put into mutual communication and in communication with human agents by means of low-cost, programmable, mobile hardware devices capable of mediating bidirectionally between the analog and the digital domains: the so-called "microcontrollers". Microcontrollers are small boards that can act as computers (they can be programmed) but that also feature the capability of reading and generating electric signals. In this way, they are able to read information from the physical world (e.g. from sensors) and to control other physical objects (provided that these objects have some electric operability, e.g. motors, actuators).

Three features seem to characterize physical computing. First, the model of embodiment at its basis differs from the one implied by the classic configuration in the "multimedia" computer, in which the body is reduced to an eye-ear-finger pointing/receiving device (O'Sullivan-Igoe 2004). Secondly, physical computing proposes a very general approach to the technological re-appropriation of the world. For example, it is one of the factors that have catalyzed the revitalization of the DYI electronic hacking movement (as evident by taking into account the projects that include microcontrollers on instructables.com or by exploring the dorkbot.org community). Finally, physical computing reassigns to real-world objects (i.e. hardware) some typical properties of the software, because the system of relations between objects is mediated by the power of computation. Thus, it is possible to define another aspect that differentiates physical computing from the purity of the classic digital scenario: heterogeneity. The latter is not only a property of the hardware (i.e. involving physical objects of different natures), but also of the software, that often results from the interaction of multiple languages/paradigms/programs.

THE "PUNK MUNARI" FRAMEWORK

The physical computing scenario is strongly coupled with recent technological innovations. Microcontrollers have been used since years in manufacturing. Yet, their cost and the knowledge base that they required to operate pushed them out of the design context. An interest in bridging these solutions to the designer/practitioner world has led to the development of the Arduino platform (Banzi 2009)[1]. Since 2005, the Arduino project determined a change of focus in the use of microcontrollers by providing a low cost and easy to program board that can be quickly used in prototyping a variety of applications involving computation and physical objects. In his introductory text, Arduino's main developer Massimo Banzi (2009), rather than focusing on the technical side, mostly discusses the philosophy at the base of the project. In this sort of Arduino manifesto, Banzi underlines the relevance of the "punk attitude". Punk revolution has started from musicians without prior knowledge of music theory and with small resources: rather, the key aspect was appropriation of music production by means of music production itself. This very empirical way of production is what Banzi consider

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[1]More recently, the trend of digital connectivity among heterogeneous objects has further evolved into powerful and configurable small devices ("single-board computers") such as Raspberry Pi (https://www.raspberrypi.org/) or UDOO (http://www.udoo.org).

the key point in Arduino (and in general in physical computing): learning by doing. On the same path, Richards (2008) has proposed as a definition for many experiments in DYI electronics for music production the term "dirty electronics".

This punk attitude can be placed in a wider context if compared to a crucial observation by Bruno Munari. In *Codice ovvio*, Munari (1971) describes the assemblage of an object made up of found tree branches while having a trip on the mountainside. The final object results from a continuous feedback between the found components, with the constraints that they provide, and the ongoing assemblage. Munari sums up the cognitive process in this way: "with a lot of patience, learning the technique while I'm working and without knowing before what will come out after". Here Munari is indicating a subtler cognitive movement, which is not entirely empirical but that depends on an ongoing abstraction that progressively generalizes the whole process by taking into consideration new constraints that drive it. Rather than induction, the operation relies on abduction, to speak with Peirce (see Bonfantini for a discussion in relation to creativity). Not by chance, Munari proposes it as a real methodology by coining a name, TMO ("tecnica mentre opero", technique while I am operating).

This "Punk Munari" attitude is at the basis of the design of residual orchestras that aims at bringing together physical immediacy, re-programmability, DIY attitude, hardware/software blurring.

DESIGN VALUES AND PRINCIPLES FOR RESIDUAL ORCHESTRAS

The design and production of the instruments (hence on, "sound bodies") follow three main principles, inspired by sustainable design (McDonough and Braungart 2002; McLennan 2004; in particular here Tamborrini 2009): refabrication, softening, flexibility. In this section they will be discussed with reference to some examples.

"Mature" capitalism is indeed characterized by a huge amount of wasted resources. Still, many practices around the world have traditionally developed specific attitudes towards the "refabrication" of objects as a normal way of shaping and reshaping the semiotic status of material culture (Seriff 1996). An inspiring concept is the "System-D" approach by the recyclers from Dakar (Roberts 1996). Here "D" means "débrouille-toi!" (French for "to cope with, to find your way"), as a general philosophy of quickly finding a way to go with limited resources, leading to variable strategies of reuse of available materials.

The *Rumentarium* project (Valle 2013) owes its name both to the Latin "instrumentarium" and to the Northern Italian "rumenta", that stands for rubbish, junk. The whole setup of 24 sound bodies is built around small DC motors scavenged from CD/DVD players and mobile phones. They are used to activate a panoply of heterogeneous parts and materials, including disassembled toys, pipe tobacco boxes, broken cymbals, pans, jar, Lego bricks. Some resulting rattles are filled with rice, seeds, buttons.

In various residual orchestras, technological "fossils" are prominent. They are fossils as they have disappeared from the main technological landscape to be relegated to its low cost boundaries, flea markets and rubbish dumps. As an example, radio clocks have been almost completely replaced by mobile and smartphones, but they are particularly valuable as sound

bodies as they generate complex sounds while retaining a compact size. Figure 1 shows their usage in the *Machina logotelica* setup (see later). In *Regnum animale* a prominent place is given to modified electric knives (a typical household appliance from the '80s) used to scrape cymbals (Figure 2). Other relevant media fossils are old Bakelite telephones. Their massive, scenographic physical presence sharply contrasts the lightweight silhouette of mobile/smartphones (Figure 1).

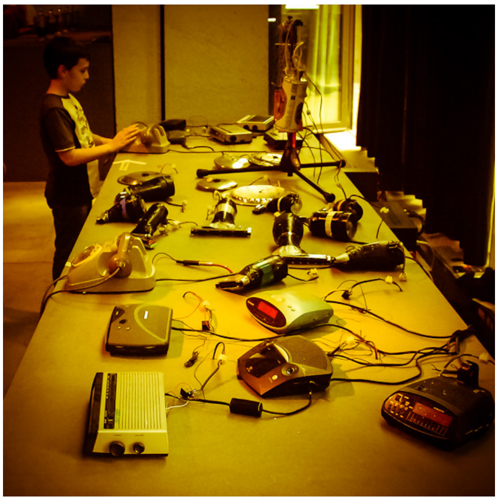

FIGURE 1 - Radio clocks and old telephones in Machina logotelica. (Courtesy of Gianluca Alderuccio)

FIGURE 2 - Electric knives and other objects in Regnum animale. (Courtesy of Carlo Ciceri)

A second design principle is the softening of the hardware. In some sense, it is a symmetrical and opposite feature with respect to the hardening of the software prompted by physical computing, that brings computation into things.

Being so simple and intrinsically costless, sound bodies can be "produced while designed" in an improvisation-like mood, starting from available materials. As a consequence, their hardware nature is quite "soft": sound bodies, and their parts, can be replaced easily and effortlessly. Sound objects in most cases remain open, that is, accessible for manipulation. All the orchestras typically present a no-case look, overtly showing components and connections. In the extreme case of the *Rumentarium*, the wiring connections use exclusively removable alligator clips. Such a wiring technique contributes to the blurring of the boundary between the phase of installation and the phase of usage, as sound bodies can be added/removed on the fly during a live performance, by simply connecting/disconnecting them via the alligator clips. Eventually, broken pieces can be replaced, repaired and reinserted in the *Rumentarium* while it is at work. Flying (or at least weak) connections among the various parts allow to easy assemble/disassemble the whole setups for transports, thus implementing another feature of sustainable design, design for disassembly (Tamborrini 2009). In *Organo fonatorio* (see later) an old suitcase is used both for transportation and as a visible support in the final installation.

Finally, a third principle is flexibility. Flexibility is here intended as the capability of the residual orchestras to be modified in relation to specific needs: as an example, a performance may require a certain setup in relation e.g. to the presence of microphones for the amplification of sound bodies, while in an installation the setup is primarily defined according to the exhibit space. The number and the kind of sound bodies can be adapted to the context of the setup. But flexibility finds its most powerful ally on the computation side. By linking physical objects to a computer, the latter becomes the main control source. In relation to information processing and symbolic manipulation, a computer's main strength is that it ensures not only programming but also re-programming. Thus, residual orchestras are not bound to a unique behavior. Rather, they can be played live by a musician as "normal" instruments (e.g. for improvisation); they can be programmed so to execute precisely a certain set of instructions (that is, a predefined score); they can be inserted into an installation context; where they may autonomously react to other environmental variables (e.g. interaction with an audience). Moreover, control can be delivered through various interfaces, ranging from graphical user interfaces on the computer display to external physical controllers (e.g. MIDI controllers or sensitive surfaces).

Improvisation is a pivotal notion in residual orchestras. It refers both to the final performance side (as one of the ways to play and experiment with sound bodies) but it is projected back onto the design and production phases. As in improvisation the music is both a final product and an on-going project, in building residual orchestras each instrument is always a prototype, and vice versa.

LAYERS AND PRODUCTION

In residual orchestras it is possible to recognize three layers that are both conceptual and technical.

I. THE PHYSICAL LAYER

Physical layer concerns the construction of the acoustic generators. Some examples have already been discussed before, other will be considered in the next section. This layer is crucial in terms of desired sound output as it provides the audible identity of the orchestra. Generators may include percussion-, wind-, string-like instruments, both pitched and non-pitched, but also electric generators (e.g. radios or turntables). Basically, components are re-used, second hand objects but also low cost materials. In *Organo fonatorio* and *Regnum vegetabile* (Figure 3) pipe-like sound bodies are built from PVC pipes. In the first case, the sound sources are small loudspeakers, to be filtered by pipes; in the second one, toy trumpets (like the ones used for live sport events by the supporters) are disassembled, so that their horn is extended by PVC elements.

Acoustics of music instrument building and practices of low cost instruments (e.g. as used for school projects) are the main theoretical references.

II. THE PHYSICAL COMPUTING LAYER

This layer is the interface between the analog and digital domains. The key point is to provide communication between the computational layer (simply, a

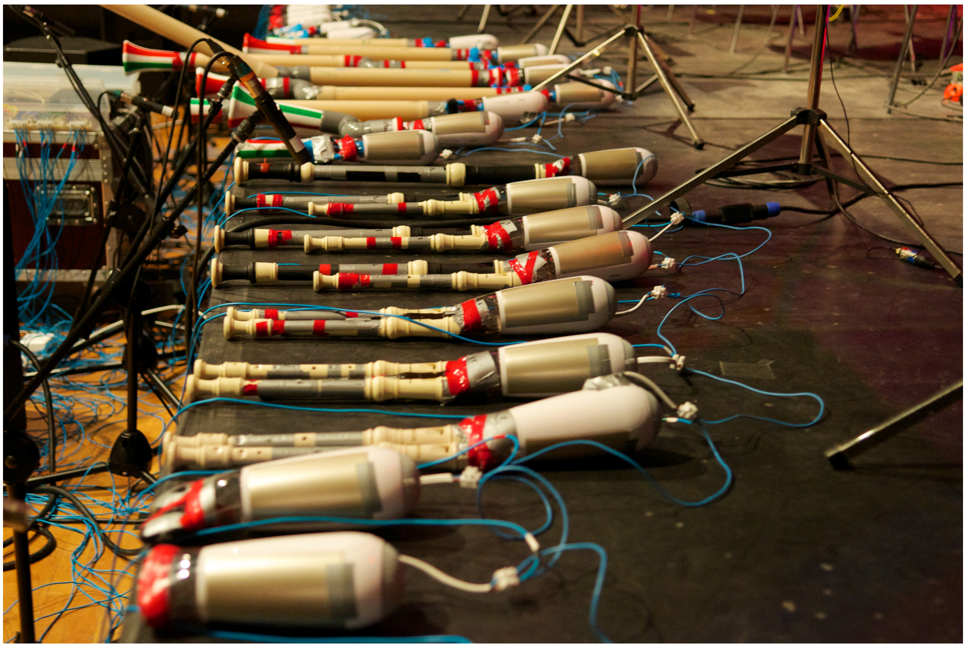

FIGURE 3 - Hair dryers in Regnum vegetabile. (Courtesy of Bludenzer Tage zeitgemäßer Musik)

computer) and the physical objects. Microcontrollers are the key elements, but they have to be complemented by opportune circuitry on the analog side to drive the chosen electric/electronic components and to be programmed consequently on the digital side, so to translate instructions from the computer into electric control signals. The physical computing layer is not necessarily limited to the microcontroller solution. As an example, acoustic information (e.g. from a microphone) can be used to trigger objects' behavior. On the output side, sound itself is a physical source that can be exploited, e.g. by connecting loudspeakers to vibrating surfaces. In general the rationale is to provide a seamless transition between the digital domain where the electronic musician works, and the physical one (an approach that has been called "audio physical computing", Valle 2010).

III. THE COMPUTATIONAL LAYER

The third layer is the purely computational one. On this side, all the projects have exploited the potentiality of the SuperCollider environment (Wilson, Cottle and Collins 2011), which, while providing also graphical user interface, is based on a textual approach that features a very high level, expressive language. First of all, programming languages are abstract, powerful tools to describe complex behaviors (algorithmic scheduling of events or interaction with the users). Secondly, the SuperCollider language can be interpreted interactively in real time, that is, an instruction is written on the screen and can be directly executed. This allows writing instructions so that they can control sound bodies on the fly. The text is the actual playing interface. In this way, a "live coding" perspective is available (Collins, McLean, Rohrhuber and Ward 2003). Figure 4 shows a screenshot from a performance: lines 39-44 have been added during performance.

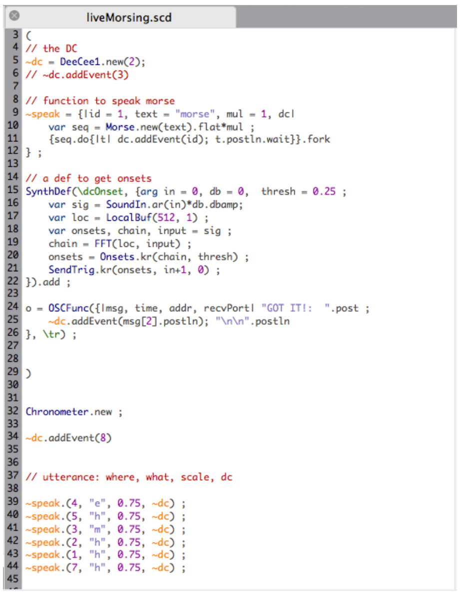

FIGURE 4 - SuperCollider textual interface

The use of a computer, but in particular of a programming language, ensures infinite re-programmability of hardware behavior, thus marking a strong difference to purely analog electronic setups.

The design/production pipeline is shown in Figure 5.

Dashed lines indicate the flow of information in real-time performance (computer, physical computing interface, objects).The bold arrows represent the development flow in relation to layers I-III.The crucial point is the digital-to-analog bridge, which requires technology that couples the abstract computational side with the electro-mechanical one. It is still the most delicate relation as interface requirement on both the computer and electromechanical sides are many, and cannot be easily predicted.Thus, it is developed as first component.Arrows with sharp corners represent influences between various components. Of course, choosing a certain control system impose specific constraints on the object side, but this applies also in the opposite direction, as certain objects can be driven only with a certain control interface. The control hardware also influences relevantly the high level computational strategies. Finally, right-pointing, empty arrows specify which resources are needed to implement each component. In residual orchestras, they are mainly related to knowledge and budget, with an inverse relevance.The control hardware is typically not expensive but requires to devise ad hoc solutions, while the sound bodies part, even if low cost, still absorbs most of the budget, even if not particularly complex per se to implement (dashed lines indicates secondary relevance).

PROJECTS

In the following, some residual orchestras will be shortly discussed. *Rumentarium* has already been substantially introduced, so it will not be considered.

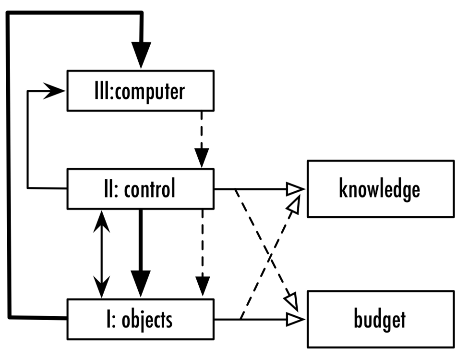

FIGURE 5 - Design/production pipeline

MACHINA LOGOTELICA

An installation prompted by Logotel for the "Making together" exhibition in the context of the Milano Design Week 2012 (2012), *Machina logotelica* features a landscape of 20 radio clocks (Figure 1) that keep on emitting short bursts of sound until one of the two Bakelite telephones is picked up. By speaking in the phone, the visitor triggers a group of percussion-like sound bodies (in the middle of the surface). If both phones are picked up, then a sort of improvised percussion duet by the two visitors becomes possible. Media objects (radio clocks and telephones) are converted into musical instruments.

ORGANO FONATORIO

Presented for the "Passengers" exhibition at the Bassano's Infart festival (2012), *Organo fonatorio* is another interactive installation. Made up of 14 PVC pipes, its main reference is the organ instrument typically associate to the venue (a church).The visitor can speak through an intercom, his/her voice being radically altered by the small loudspeakers placed in and diffused by the pipes.

TRILOBITI

In the *Trilobiti* (trilobites) installation (presented at festival "Le forme del suono", Latina, 2013), a population of 8 media fossils (radio clocks) is spread over a surface, their flat morphology resembling that of those ancient arthropods. Each radio clock has been modified in order to acquire the capability of listening and replying both to its neighbors and to the surrounding environment. With respect to the output sound, the final result is a sort radio-content "stridulation", the latter being the typical sound emission of arthropods. From their phonatory organ (the loudspeaker), the trilobites emit -as their semiotic production- excerpts caught from the air (radio). But, by reversing the loudspeaker wiring, each trilobite is given the possibility of hearing its acoustic surroundings. When a trilobite detects an auditory event, it replies by emitting a sound (i.e. a burst of radio grains) whose features depends on the triggering audio event.

In this way, the whole trilobite population is engaged into a feedback-based communication context that includes three concentric layers of audio communication: their buzzing, crackling neighbors; the audience and the surrounding environment; the broadcast content. This communication flow is auto-generated without any predefined, score-like, organization.

But the computational layer allows to re-program the trilobite population so that the *Trilobiti* orchestra can be tuned into a real performing instrument, that can be used for live improvisation.

REGNUM ANIMALE AND REGNUM VEGETABILE

Regnum animale (2013) and *Regnum vegetabile* (2014) are two related projects that stem from commissions by contemporary music ensembles (respectively RepertorioZero and ensemble mosaik), and both involve traditional instruments and electromechanical devices.

Two references are at the basis of *Regnum animale* and *vegetabile*. The first is the medieval tradition of bestiaria and herbaria, intended as multi-faceted catalogues of miscellaneous beings, among which different relations can be defined. A second reference for the works is taxonomy, that is, the systematic description of living organisms that dates back to Linnaeus' *Systema Naturae* as the rationalistic possibility of ordering the polymorphous (and many times teratomorphic) appearance of nature. This heterogeneity is at the origin of both the setups and the organizations devised for the two *Regna* setups. In *Regnum animale* (Figure 2) a string trio is surrounded by a mass of computer-driven, electro-mechanical devices built from discarded and scavenged everyday objects. It features electric knives, turntables, radios, an electric shaver, a squeezer, a ring bell, finally a light bulb that does not play in itself, but allows to focus the attention on the clicking sound of the electromechanical relay that switches it on and off. Motors from tape recorders are used to produce continuous frictions sounds. Other pitched instruments are built from modified hair dryers blowing into plastic recorders and harmonicas.

The latter are at the basis of *Regnum vegetabile* (Figure 5): 30 hair dryers create an orchestra of wind-like instruments that play together with a string/wind sextet. Apart from recorders and harmonicas, the orchestra includes toy whistles, ocarinas, and a set of toy trumpets that have been extended with PVC pipes.

Design for disassembly has been a leading principle for both setups as they have been built to be integrated into a traditional composition environment, featuring a score for acoustic instruments: consequently, the setups must be transported and rebuilt at each performance exactly in the same way (the pieces have been played in various European venues).

Both projects result from collaboration between the author and the composer Mauro Lanza, so that they are in all respects co-composed. This situation has prompted various solutions to the problem of sharing efficiently and effectively information concerning the orchestras and their organization.

CONCLUSIONS

BY means of automation, residual orchestras aim at bringing together everyday objects and advanced algorithmic control. In this respect, the physical computing scenario is a liberating one.

Residual orchestras are intended as a way to interact with basic reused/recycled materials that are available to everyone. This sustainable perspective is strictly related with the idea of acoustic re-appropriation of everyday objects. But this same perspective, which has been at the core of many practices of self-built instruments, also for pedagogical purposes, can now be coupled with an analogous situation on the computational side, generating a new, complex, potentially accessible, environment.

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THE VIRTUOUS CIRCLE

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DESIGN CULTURE AND EXPERIMENTATION

Design comes out of the interaction between a practice, which seeks to change the state of things, and a culture, which makes sense of this change. The way this happens evolves with time: practices and cultures evolve and so do the ways they interact; and the attention that is paid at different moments to one or other of these interacting polarities also evolves. In the current period of turbulent transformation of society and the economy, it is important to go back and reflect on the cultural dimension of design, its capacity to produce not only solutions but also meanings, and its relations with pragmatic aspects. Good design does not limit itself to tackling functional and technological questions, but it also always adopts a specific cultural approach that emerges, takes shape and changes direction through a continuous circle of experimenting and reflecting. Because the dimension and complexity of the problems is growing, it is becoming evident that to overcome them it is, above all, necessary to bring new sense systems into play. This is ground on which design, by its very nature, can do much. Indeed, the ability to create a virtuous circle between culture and practical experimentation is, or should be, its main and distinctive characteristic. However, for this really to happen it is necessary to trigger new discussion and reflection about the nature and purpose of design practice and culture.