Design of Hardware Systems for Professional Artistic Applications

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ABSTRACT

In this paper we present a discussion of the development of hardware systems in collaboration with professional artists, a context which presents both challenges and opportunities for researchers interested in the uses of technology in artistic practice. The establishment of design specifications within these contexts can be challenging, especially as they are likely to change during the development process. In order to assist in the consideration of the complete set of design specifications, we identify seven aspects of hardware design relevant to our applications: function, aesthetics, support for artistic creation, system architecture, manufacturing, robustness, and reusability. Examples drawn from our previous work are used to illustrate the characteristics of interdependency and temporality, and form the basis of case studies investigating support for artistic creation and reusability. We argue that the consideration of these design aspects at appropriate times within the development process may facilitate the ability of hardware systems to support continued use in professional applications.

Author Keywords

Collaboration, Iterative Design, Design Principles

ACM Classification

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing–Systems, H.5.2 [Information Interfaces and Presentation] User Interfaces—User-centered design.

1. INTRODUCTION

Many research questions which involve the effects and implications of the use of new technologies in artistic performance require the use of novel hardware interfaces in real-world performance contexts. As creators of such interfaces, we are often asked to collaborate in research projects with artists who are actively engaged with precisely such questions. Frequently, these artists bring with them years of professional artistic experience, strong opinions on the use of technology in performance, and commitments to public presentations. As designers, collaboration in this context can be extremely gratifying as our collaborators are heavily invested in the success of the project and will invest the time to gain a deep familiarity with our designs. However, bringing such a collaboration to a successful conclusion brings many challenges.

This paper presents some conclusions drawn from an ongoing research project aimed at discovering practices to facilitate the creation of new hardware performance systems for professional artistic productions, typically within collaborative projects. As such, our discussion will assume a distinction between the technology developers and the artists/researchers involved in these projects, and will focus on the point of view of the developers. In practice, this distinction is highly blurred as the research goals of the developers generally will go beyond the development of new technology and the artists/researchers may also have an active hand in development, and in other situations the artist and developer may be situated in the same person. By separating the two in our discussion we seek to focus on the challenges of technology development within this context rather than engaging with specific artistic practices.

Our discussion will centre on the consideration of seven aspects of the design of a hardware/software system, each providing a different perspective on the system, and we will illustrate characteristics of these aspects with example drawn from our experience in three major research projects. The first was the creation of the Prosthetic Instruments, a family of interfaces designed to be worn by dancers in an interactive dance performance [12]. The second was the creation of the *Ilinx* garment, a vibrotactile-enhanced garment worn in an immersive multisensory art installation [13]. The most recent is the ongoing development of the Vibropixels, a reconfigurable and scalable tactile display for use in artistic applications[11]. All of these projects have involved close collaboration with a variety of artists and researchers from different disciplines, and have collectively been used in professional public performances in the EU, North America, and Asia.

Reflecting on our experiences in these projects has led us to the conceptions of the design process we present here. Given the knowledge and interests of researchers in the NIME community, collaborations within contexts like those we discuss in this paper may be increasingly desirable. Our hope is that our articulation of the various design aspects will provide a resource for other researchers in the NIME community who are interested in taking on the challenge of developing hardware systems for professional artistic applications.

1.1 Definitions

Throughout this paper we will continually refer to our 'artistic collaborators' and the artistic creation process. We do

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this as we collaborate with a wide range of artistic practitioners, including music performers, composers, dancers, choreographers, clothing designers, visual artists, and creators of interactive artworks. While the specific needs of our collaborators vary widely, we find that the development process we describe here is generally applicable to all of the collaborations we have undertaken.

We also refer to the hardware components of the system as 'devices' rather than interfaces or instruments as the hardware's function within the artwork may not be primarily as an input device. In addition, while many hardware systems in fact comprise a combination of hardware, device firmware, and software, we will attempt to consistently refer to the combination of all of the aspects as a 'hardware system'.

2. PREVIOUS WORK

To establish the background for the research described in this paper this section presents a brief overview of methodologies and principles for music interface design, as well as an exploration of two design approaches from other fields.

2.1 Music Interface Design

While many publications have addressed the design of musical interfaces, these have largely focused on what we describe below as being *functional* design. Overholt, for example, proposes a Musical Interface Technology Design Space which focuses on gesture, mapping, and expressiveness [16]. Marshall et. al discuss a different approach to design which focuses on the evaluation of transducer technologies for specific musical tasks [15]. As functional design remains the primary focus of research on new musical interface design, publications such as these do not spend much time discussing the challenges of bringing such interfaces out of the lab and into real-world performance contexts.

2.1.1 Perry Cook's Principles

One set of publications which does provide such advice are Perry Cook's Principles for Computer Music Controllers [6, 5]. In 2001, Cook proposed 13 principles sorted into three groupings, "Human/Artistic Principles", "Technological Principles", and "Other Principles". In 2009, Cook expanded these principles to expand upon the previous groupings as well as proposing a new grouping covering "Controller (Re)Design".

Cook bases his principles on his own extensive experience as an interface designer and researcher, and describes them as being opinions more than universal recommendations. Coming from this perspective, his principles engage easily with such diverse issues as artistic motivation, technological implementation, and research methodology. As importantly, however, it reflects a longitudinal view of interface design in the context of research, especially the 2009 paper. Including observations from both his experience with PLOrk as well as with the redesign of an accordion-inspired controller, Cook discusses issues which are not often seen at NIME, including the maintenance, redesign, and evolution of an interface.

2.2 Approaches From Other Disciplines

Many research disciplines focus explicitly and implicitly on design processes. While a full review of these various approaches are outside the scope of this paper, we want to mention a few specific examples which have been influential in our work.

2.2.1 Total Design

Stuart Pugh's *Total Design* describes the overall process of product design from market analysis to sales [17]. This approach to design as a holistic process matches with much of our experience in creating technological systems in that the design process incorporates more than just the conceptual and functional design stages.

The main structure of the Total Design process is a six-stage Design Core consisting of three primary sections – the identification of the market & of user need; four iterative stages consisting of defining the product design specification, creating conceptual designs, creating detailed designs, and manufacturing; and a final stage consisting of considerations in the sales and marketing of the product.

The definition of a Product Design Specification (PDS) is perhaps the most important part of the Total Design process. Comprised of a comprehensive set of design requirements, the PDS should be comprehensive, detailed, and unambiguous. Importantly, Pugh describes the PDS as being a living document, one which will evolve over the course of the design process. This is especially true during the central stages of the design core, which consist of iterating through the four central stages until all of the PDS is fully-defined and met by the technical and detailed design. However, Pugh argues that an insufficient consideration of the first and last stages of the design core can cause a product to fail as readily as any other stage.

2.2.2 Software Design and Interactive Digital Art

Many interactive digital artworks have been created through collaborations between artists and technology developers, frequently supported by academic and artistic institutions [3]. There have been several researchers who have written about design issues within this context, largely focusing on software design, in ways which have influenced our own conception of the design process. Machin presents an overview of the role of the software engineer within a collaborative artistic context, including a discussion of different models of collaboration and the difficulty of defining accurate specifications [14]. One key argument Machin makes is that the successful use of a new technological system in an artistic work will often depend upon the creation of an interface which allows the artist to program the system. As the material manifestation of a technological system can be difficult to specify and visualize, artists will often need to go beyond specifying the sequencing of the system's states based on their initial conceptions. Instead, the creation of a programming interface which is accessible to the artist can allow them to freely explore the behaviours and capabilities of the system in order to generate artistic materials.

Trifonova et. al provide another perspective through a literature review of papers describing the creation of interactive artworks as well as papers describing software engineering practices [18]. Focusing more explicitly on existing concepts drawn from software engineering, the paper remarks again on the difficulty of establishing design requirements, as well discussing system architecture, process management, and testing, validation, and evaluation. One observation they make is that maintenance and open source software is not mentioned in any of their reviewed papers, a lack of concern for the robustness and re-use of the system that we are also concerned with, and which drive those designs aspects we describe below.

3. DESIGN ASPECTS & SPECIFICATIONS

The definition of design specifications is a central part of most design processes, and may also be referred to as identifying design requirements or creating a design brief. This activity is so important that Cather et al. state "[t]he lack of a complete and thorough written specification is now generally accepted as being one of the main reasons for design failure" [4, p. 36]. In his description of Product Design Specifications, Pugh specifies 32 elements which he argues are necessary in a complete PDS [17, pp. 44-66]. While some of these, such as shelf-life storage, competition, and market constraint, may have little impact on applications in our contexts, many of them are surprisingly pertinent, including aesthetics, performance, shipping, installation, and maintenance.

However they are conceptualized, design specifications represent specific characteristics a device must possess in order to successfully meet the device's objectives. One of the challenges in articulating specifications is their interdependent nature, in that they often impact many different aspects of the device's design. This is especially confounding as device specifications change frequently over the course of development, necessitating a continuous re-evaluation of the overall design. Working in collaboration with artists poses a special challenge in this respect, as design specifications will often be vague in the beginning of the project, and will often need to accommodate changes due to experience gained during the artistic creation process.

Within the context of our own work we find it useful to consider a simplified grouping of specifications, which we refer to as design aspects. These aspects are related to Pugh's PDS, but speak directly to our applications of developing hardware systems for professional artistic productions, and each offers a different perspective on the development and performance of a system.

3.1 Design Aspects

In this section we will present an overview of seven design aspects we have found to be relevant for our applications. We stress here that these design aspects are not necessarily mutually exclusive, and the differentiations described here are more to provide a way for designers to gain an overview of the system rather than creating a complete technical description of a system.

3.1.1 Functional

Generally speaking, any new hardware device will be created in order to provide some mechanical or electronic functionality. As discussed above in section 2.1, this aspect is the primary focus of most research in DMI design. While this preeminence will be manifest throughout the design process, focusing on functional design alone will not ensure the success of the device in context.

3.1.2 Aesthetic

Aspects of the design that qualitatively affect the experience of the user or audience. For a digital music interface this might include its visual appearance, forms of gestural interaction, and ergonomics. For a wearable device this will include the fit and feel of the device.

3.1.3 System Architecture

The ways in which the system supports its functionality in context. This includes both technical functionality, such as communication protocols and power management, as well as the system's integration into the actual performance context, which involves interaction with other systems used in the production as well as the production staff.

3.1.4 Artistic Creation

The ability of the hardware system to support the artistic creation process, both during the development process and in the final design, discussed further in section 4.3.

3.1.5 Manufacturing

Many of the projects we are involved with require the creation of multiple copies of our devices, and therefore manufacturing considerations play a key role in our design process. However, no matter the scale of the project, the choice of manufacturing techniques will impact many aspects of a device's final design, including the choice of materials, the ability to reproduce designs precisely, and the time and cost required for manufacturing.[1]

3.1.6 Robustness

Any professional artistic production will require a system that is reliable enough to withstand its use in context, including mechanical, electronic, and digital elements. Robustness in this context means: that the system is able to function without failing; that it will continue to work without failing over the course of its intended use; that maintenance of the system is specified and within the capabilities of the system's users; and that provisions for accommodating potential failures have been made, typically through the provision of backup devices.

3.1.7 Reusability

The use of the system in the initially proposed public presentations is of course a primary outcome, but considering the effort and expense which goes into developing systems suitable for these applications it is also important to consider how they can support other outcomes. We will discuss this further in section 4.4.

4. DISCUSSION

In this section we will discuss case studies from our previous work that illustrate characteristics of the design aspects.

4.1 Interdependencies

While the design aspects each have their own perspective, in practice device specifications frequently interact with multiple aspects, and when considering changes in one specification it can be helpful to consider ways in which they will affect the specifications of other aspects.

4.1.1 The Evolution of the Ribs

An example of this occurred during the design of the Ribs, which are one of the Prosthetic Instruments. In their final form, the Ribs consist of a set of three differently sized controllers which are able to be inserted into mounts on a corset. Sensing on the Ribs consists of eight capacitive touchpads along their length and an embedded 3-axis accelerometer, and sensor data is streamed to a central computer. Figure 1 shows the final design of the Ribs as worn by a performer.

The basic sensing functionality of the Rib was defined and implemented in the first functional prototype, which consisted of a small acrylic form with copper tape serving as touchpads. While these prototypes met the functional specifications, for aesthetic reasons we moved to exploring conductive plastic touchpads in order to allow for fully translucent forms. Once the transparent Ribs were manufactured, though, we observed that the transparent forms did not have as much of a visual impact as the copper-clad Ribs had. Larger sizes of Ribs were constructed in order to make them more visible from a distance.

The larger sizes, combined with the cantilevered design, caused several mechanical issues. First, the longer a Rib was the more it had a tendency to flex along its length as the dancers moved. In addition, the extra weight of the

[1] For a more complete discussion of this see [12].

Figure 1: Marjolaine Lambert plays a set of Ribs worn by Sophie Breton. Delineations between adjacent touchpads can be seen as vertical lines along the Ribs' length. Photo ©Michael Slobodian.

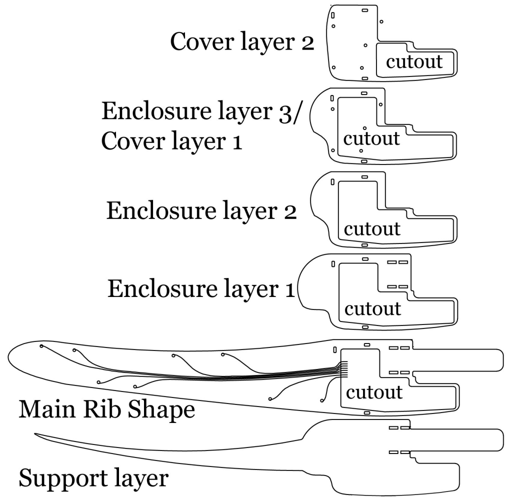

Figure 2: The multiple layers which form the laminated construction of the Rib.

Rib, as well as pressure exerted when its tip would contact the floor, caused the acrylic forms to crack at the base. In order to solve these problems, a multilayer, laminated construction was designed, shown in figure 2, in order to create a stiffer, more robust form. Additionally, two of the layers were constructed from polycarbonate plastic as a precaution in case cracks occurred in the acrylic layers during a performance.

This example shows how the specifications of the various aspects interact: the functionality (capacitive sensing) suggested appropriate materials (copper and conductive plastic); changes in the aesthetic (larger transparent forms) created issues with robustness and flex (due to the material properties of acrylic); changes in the form to meet robustness and stiffness specifications led to the need for new manufacturing techniques (laminated layers of acrylic and polycarbonate). We note these interdependencies may pose problems, but they also offer opportunities for design improvements. In the case of the Ribs, we were quite happy with the properties of the laminated construction across many aspects, including functionality (mechanically stiff but light form), aesthetics, robustness, and manufacturability (it proved to be efficient to manufacture).

4.2 Temporality

Given their different perspectives, it is common for design aspects to be highlighted at different stages of the development process. Again in the case of the Ribs, the functional design and system architecture supporting the sensing was determined quite early, followed by the mechanical functionality, aesthetics, and manufacturing. While this sequence is fairly common the precise ordering is likely to change from project to project.

Occasionally, changes to certain specifications which are made out of step with the overall design process may cause problems. The lighting in the Prosthetic Instruments, for example, was developed more as an afterthought (a timeline of the Ribs' development which depicts this is shown in figure 3), and it wasn't until meeting with the production's lighting designer that we fully committed to lighting all of the instruments. Leading up to the performances, our efforts were mostly directed towards manufacturing, and although we worked on providing wireless control of the lights to the lighting designer we were not able to implement it to our satisfaction before the final rehearsals. In the end, we set the lighting for the instruments to be permanently on for the performances.

One of the goals of considering the design aspects is assisting in consideration of all of the design aspects, even before they become the primary focus of the design activity. Due to the interdependent nature of the aspects, specifications for manufacturing and reusability considerations may suggest approaches to creating the functional design. Similarly, considering the complete set of design aspects over the entire development process may help to prevent the need for extensive redesigns, for example to modify the implementation of functionality in order to satisfy robustness or reusability specifications.

4.3 Support for the Artistic Creation Process

As the systems we create are typically developed in parallel with the creation of artistic works by our collaborators, supporting the artistic creation process goes beyond ensuring that the final design meets certain specifications. Instead, during the development process it is typical for us to provide prototypes with limited functionality, as the artistic creation process often relies upon an exploration of the material properties of the system [14]. When creating these prototypes, we aim to meet the minimum set of specifications that will provide our collaborators with the materials they need to complete their work. For example, in the creation of the Prosthetic Instruments, between workshops 2 & 3 we provided the choreographer and dancers with a full set of instruments which were mechanically but not electronically functional, in order to allow them to work on choreographic materials.

In addition, it is often necessary to provide software tools to facilitate working with the system, which can range from the creation of a user interface to the creation of an API, depending on the knowledge and preferences of the artistic collaborators. In our experience, the key considerations in the creation of these tools are supporting our collaborators' preferred software environments, providing graphical feedback regarding the effect of parameter changes, and providing tools for working on the highest conceptual level of the system while still enabling access to lower levels.[2]

[2]For a further discussion of these issues see our paper on the development of the Vibropixels [11].

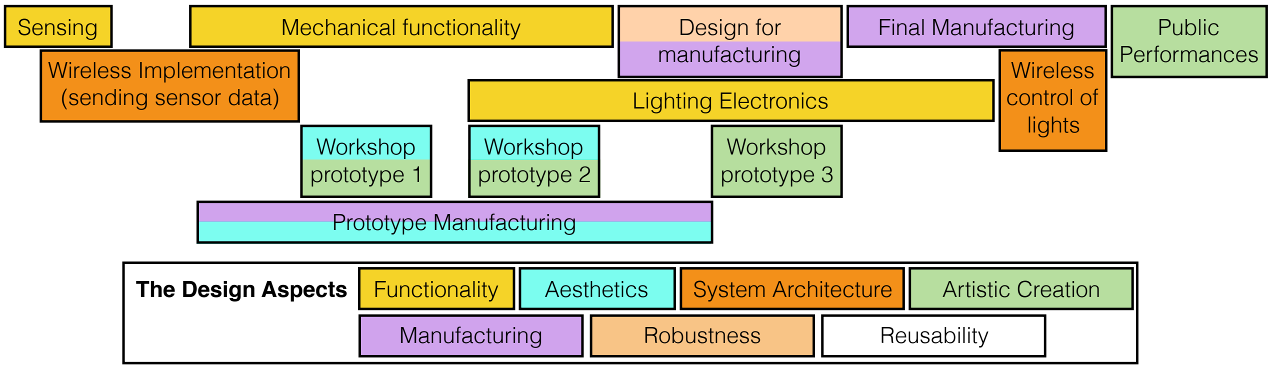

Figure 3: A simplified timeline of the post-conceptual design development of the Ribs, depicting the late attempts to implement wireless control of the lighting. The different activities are colour-coded according to the design aspects they were most directly addressing.

4.4 Reusability

One of the goals of the design aspects is to help maintain an awareness of all of the design goals, especially when the different temporalities cause us to focus on certain aspects at different stages. One aspect that we wish we had addressed more consistently is reusability. There are several forms this can take – either reusing the system as is for another project, modifying the system to be useable for another project, developing a sub-system to be be useable across different projects, or using and disseminating knowledge gained during the design process.

The development of the *Ilinx* garment ([13, 10]) and the Vibropixels ([11]) provide examples of how reusability considerations can lead to different design outcomes. Both systems are wearable tactile displays intended to create full-body tactile stimuli in immersive artistic installations; however, differences in their design specifications, and particularly their reusability specifications, led to very different system architectures.

4.4.1 Reuse of the *Ilinx* garment

The *Ilinx* garment consists of a jacket and two leggings which together are divided into five sections, one for each limb and the torso, each with an actuator driver board and six actuators sewn in a fixed configuration. The sections communicate via Cat5 cables with a minicomputer, which in turn communicates via WiFi with a central PC. Following the initial public presentations using the garment, other researchers in our lab have since used elements of the system for other research projects, including a tactile metronome system and the creation of tactile musical scores.

For the tactile metronome application, the system was modified to distribute single-actuator signals to each of four different performers [9, pp. 142-143]. To accomplish this, a single driver board (encased in a 3D printed housing able to be clipped to a belt) and actuator (attached to a resizable strap) were provided to each performer. The driver boards were also connected to a minicomputer in the same fashion as the regular *Ilinx* garment system, although the minicomputer and PC do not communicate via WiFi but through a wired Ethernet connection.

The *Ilinx* electronics have also been used for prototyping a system for the creation of tactile musical scores [2]. Similar to the *Ilinx* garment, this system uses actuators sewn in fixed configurations – however, the final application demands a different configuration of actuators and therefore necessitates the manufacturing of new garments. Currently the prototypes use the *Ilinx* electronics system as-is; however, the use of the minicomputer to coordinate with the computer (along with the use of a single large battery in the same location) is seen as undesirable. Ultimately, the project is planning a redesign of the electronics system to allow each garment section to have its own wireless transmitter and battery.

While these examples illustrate different approaches to successfully reusing the system, each required quite a bit of customization, in particular due to the fixed actuator locations. Nonetheless, certain aspects of the system have proven useful, notably the driver boards. In addition, the redesign of the system for the tactile score application utilizes many processes and subsystems developed during the design of the *Ilinx* garment.

4.4.2 The Vibropixels

Our experience with the *Ilinx* garment led us to consider ways of creating a tactile display system which could be more easily reused for a variety of applications without significant modifications. While also being a wearable tactile display, the use of a different system architecture in the Vibropixels facilitates their reuse to a much greater degree, which was one of the primary design goals for the project. To accomplish this, the Vibropixels are a modular system in which each actuator location has its own wireless transceiver and battery, removing the need for any wired connections between actuators. This allows for a very flexible configuration, both in terms of location and number for a single person, but also in terms of distribution of the system across multiple people. The initial public presentation accommodated 19 people wearing seven Vibropixels each. Other applications in development include an artwork accommodating 100 people wearing two Vibropixels each; a tactile game consisting of 16 players; and a tactile metronome application using a single Vibropixel. For each of these applications no hardware modifications were necessary.

5. CONCLUSION

The design aspects discussed here were developed over the course of research projects conducted in collaboration with professional artists, and which were focused on creating systems suitable for professional artistic productions. As such, they reflect our personal experience and conceptions of how to structure our research and design activity. However, we would argue that a consideration of these aspects can be beneficial for many different research contexts within the NIME community, and that interface designers who utilize their interfaces in performance engage with these aspects at some level, whether they consider them explicitly or not.

The degree to which design specifications need to be formalized may be disputed, and certainly the approach presented in this paper is coming from the perspective of the technology developer. However, the simplified set of design aspects (as opposed to Pugh's 32 elements) is intended to focus only on those perspectives that will contribute most directly to the ability of new devices to meet the challenges of artistic contexts. From a practical standpoint, failure of any of the design aspects (barring, perhaps, reusability)[3] will make it much less likely for a new system to be used for an extended period. This speaks directly to the frequently made observation that new instruments and installations frequently have a very short lifespan [7, 1, 8]. If continued use of a new interface has the potential to add to the knowledge created by that interface's construction (and we would argue it does), then creating interfaces which support continued use should be encouraged.

Finally, it is clear that the explicit consideration of the design aspects should be in proportion to the amount of time invested in the design process.[4] For work which will only be shown within conference settings, or will only be used in its creator's own artistic practice, the formalization of design aspects presented here may not be relevant. However, we believe that the NIME community would benefit from the exploration of many interesting research questions (including longitudinal use of new interfaces, creation of new interfaces for professional artists, ensemble use of new interfaces, etc.) which require the creation of systems which do engage with the complete set of design aspects. It is our hope that the discussion presented in this paper will encourage other researchers to take on the challenge of developing such systems.

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[3]Although reusability as conceptualized here does have the ability to facilitate design iterations, helping overcome the challenge that, as Luke Dahl observes, "the fidelity required of NIME prototypes can make the design process so long that iteration becomes practically difficult" [7].

[4]Or as Pugh puts it, "it is preferable that the degree of total design rigour expected should increase in sympathy with increased engineering input" [17, p. 29].

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