DESIGNING FOR NEW GENERATION ELECTRONIC MUSICAL INSTRUMENTS: STRATEGIES TO IMPROVE INTERACTION, USER EXPERIENCE AND LIVE PERFORMANCE

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ABSTRACT

DESIGNING FOR NEW GENERATION ELECTRONIC MUSICAL INSTRUMENTS: STRATEGIES TO IMPROVE INTERACTION, USER EXPERIENCE AND LIVE PERFORMANCE

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Since the turn of the 21st century, ground-breaking advancements in technology have led to the emergence of a completely new 'species' of electronic musical instrument. These instruments, which are heavily driven or dependant on technology, have been accompanied by an interdisciplinary movement in the field of musical instrument research and design, interconnecting music-making to disciplines including, but not limited to, industrial design, interaction design, user experience (UX) design, computer science, software engineering, electronic/computer engineering, mechanical engineering and materials engineering. Although all of these disciplines have staked a claim to the profession of electronic 'instrument-making', much of the output comprises prototypical research, technical innovation and invention rather than instruments that are clearly aimed at, designed for, or adopted by professional musicians. Notably absent from the field is user-centred research, aiming to uncover professional musicians' needs, preferred interactions and desirable user experiences with electronic musical instruments. Furthermore, there exists a lack of theory concerning how electronic musical instruments should be designed so that the needs and expectations of professional musicians in live performance situations can be fulfilled.

This thesis seeks to address the lack of fundamental user understanding as well as bring forward guidelines and strategies for user-centred electronic musical instrument design. Following a review of the state of the art, a substantial field study based on a hybrid of repertory grid technique (RGT) and cross impact analysis (CIA) is reported. The study involved professional musicians offering expert commentary on the design, interaction and experiences of purposefully disparate electronic musical instrument exemplars. The principles of personal construct theory (PCT) formed the basis of data collection and processing, with the interconnection and prioritization of musicians' constructs revealed qualitatively and quantitatively through CIA. The principal outcome of the thesis is a set of strategies for designers to consider – especially in the conceptual front-end of new product development – to achieve appreciated interaction and desirable user experiences from electronic musical instruments in the context of live performance.

Keywords: electronic musical instrument design, musical interfaces, interactivity, design for interaction, user experience

ÖZ

YENİ NESİL ELEKTRONİK MÜZİK ENSTRÜMANLARI İÇİN TASARIM: ETKİLEŞİM, KULLANICI DENEYİMİ VE CANLI PERFORMANSI GELİŞTİRMEYE YÖNELİK STRATEJİLER

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21. yüzyıla girilirken, teknolojide çığır açan gelişmeler yeni bir elektronik müzik enstrümanı ‘tür’ünün ortaya çıkmasına neden olmuştur. Büyük ölçüde teknolojiye bağımlı ve teknolojiyle işleyen bu enstrümanlara, müzik enstrümanı tasarımı ve araştırmaları alanında disiplinlerarası bir oluşum da eşlik ederek; müziği, endüstriyel tasarım, etkileşim tasarımı, kullanıcı deneyimi tasarımı, bilgisayar bilimi, yazılım mühendisliği, elektronik/bilgisayar mühendisliği, makina mühendisliği ve malzeme mühendisliği gibi çok çeşitli alanları birbirine bağladı. Her ne kadar tüm bu disiplinler elektronik enstrüman yapımı mesleğini sahiplenmeye çalışmış olsalar da, alandaki üretim ve çıktıların büyük çoğunluğunu, açık bir biçimde profesyonel müzisyenleri hedefleyen, onlar için tasarlanmış ve onların benimseyeceği enstrümanlar yerine, prototipsel araştırma, teknik inovasyon ve buluşlar oluşturmaktadır. Alanda görülen en belirgin eksiklik, profesyonel müzisyenlerin elektronik müzik enstrümanlarına dair ihtiyaçlarını, tercih ettikleri etkileşimleri ve arzu edilen kullanıcı deneyimlerini ortaya çıkartmaya yönelik ‘kullanıcı odaklı’ araştırmalardır. Buna ek olarak, profesyonel müzisyenlerin canlı performans

bağlamındaki ihtiyaç ve beklentilerinin karşılanması için elektronik müzik enstrümanlarının nasıl tasarlanmaları gerektiğine dair bir teorik bilgi eksiği de bulunmaktadır.

Bu tez, bir yandan alandaki kullanıcı içgörüsü eksikliğini ele alırken, kullanıcı odaklı elektronik müzik enstrümanı tasarımı için stratejiler ve yönergeler önermeyi amaçlamaktadır. Güncel literatür taramasını takiben, Repertuar Çizelgesi Tekniği ve Çapraz Etki Analizi karma yöntemiyle yapılan zengin içerikli bir alan araştırması sunulmuştur. Çalışma, profesyonel müzisyenlerin, farklı özellikleri doğrultusunda seçilmiş yeni nesil elektronik müzik enstrümanı örnekleri üzerinden yaptıkları uzman yorumlarına dayanmaktadır. Kişisel Kurgu Teorisi'nin esasları veri toplama ve işleme sürecinin temelini oluşturmuş, müzisyenlerin kişisel kurgularının arabağlantılarının tespiti ve öncelleştirilmesi, Çapraz Etki Analizi ile nitel ve nicel olarak ortaya çıkartılmıştır. Bu tezin temel çıktısı; tasarımcıların, yeni ürün geliştirme süreçlerinin özellikle ilk/kavramsal tasarım aşamalarında değerlendirebilecekleri, canlı müzik performansı bağlamında, elektronik müzik enstrümanlarıyla, tercih edilen etkileşimler ve beklenen kullanıcı deneyimleri elde etmelerini sağlayacak bir dizi stratejidir.

Anahtar Kelimeler: elektronik müzik enstrümanı tasarımı, müzikal arayüzler, etkileşim, etkileşim için tasarım, kullanıcı deneyimi

in loving memory of Şehnaz; my grandmother and my best friend…

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ABBREVIATIONS

CIA: Cross Impact Analysis

CIG: Cross Impact Graph

CIM: Cross Impact Matrix

DMI: Digital Musical Instrument

GUI: Graphical User Interface

HCI: Human-Computer Interaction

MIDI: Musical Instrument Digital Interface

NIME: New Interfaces for Musical Expression

OSC: Open Sound Control

PCP: Personal Construct Psychology

PCT: Personal Construct Theory

R&D: Research and Development

RGT: Repertory Grid Technique

RtD: Research through Design

UX: User Experience

CHAPTER 1

INTRODUCTION

1.1 Overview

Having evolved from centuries old music-making paradigms, musical instruments have never been considered a subject of major interest for design or engineering disciplines up until the 20th century. The reasons behind this lack of concern can be speculated based on the following arguments:

Traditional acoustic musical instruments have evolved through a trial-and-error process, which could take centuries (Sachs, 1940). They have been ‘invented’ and not ‘designed’. Thus, they are considered as ‘inventions’ rather than ‘products’.

- While it is possible to mass-manufacture traditional musical instruments, majority of their components are hand-made; causing the ‘instrument making’ process rather inconvenient to be industrialized.
- Additionally, due to the natural materials used (especially wood) even when mass-manufactured each instrument will sound unique due to variations in components’ inner structures.
- In the context of acoustic musical instruments, alterations or fundamental changes in design (i.e. form, dimensions or volume) will inevitably change the character of the generated sound. Thus, design or re-design attempts will transform the instrument into ‘something else’ other than itself (i.e. altering the form or dimensions of a violin will turn it into something that sounds <u>not</u> like a violin).

During the first half of the 20th century, the use of electrical energy for actuating, amplifying and oscillating sound, marks a critical shift in instrument-making paradigms. Actually, the technology behind electric/electronic music has a longer history than it is commonly believed. Holmes (2002) states that rudimentary experiments in electrical production of sound were taking place before the invention of the light bulb. Telharmonium (also known as Dynamophone) was invented by Thaddeus Cahill in 1896 and it is considered to be the first electronic music synthesizer. What Holmes (2002) describes as the most ambitious electronic music project ever conceived; Telharmonium featured 145 tone wheels, nearly 2000 switches, weighed about 200 tons and looked more like a 'power plant' than a musical instrument to the casual viewer (Figure 1.1).

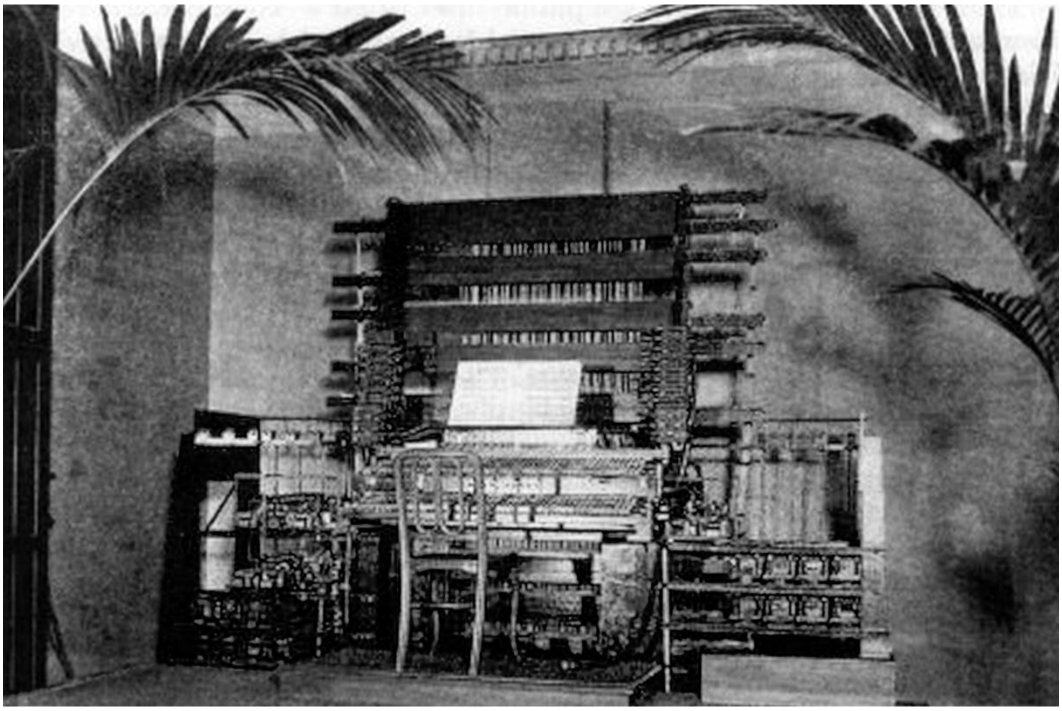

Figure 1.1 Telharmonium console by Thaddeus Cahill, 1897

Noteworthy examples of what followed in the next decades are Theremin (1920), Electrophon, (1921) – which was improved and renamed Sphäraphon (1926) (Glinsky, 2005), Dynaphone (1927), Ondes Martenot (1928) and Trautonium (1928-1930). This first generation of electrical/electronic musical instruments have revolutionized the field of musical instrument design and they became the archetypes and predecessors of modern day synthesisers. Furthermore, these instruments were all designed for live performance contexts. Their inventors, along with the composers of the time (e.g. Varèse, Messiaen, Hindemith, Sala), intended to bring these instruments into the fold with classical music, through composing solo parts for them and featuring them with ensembles composed of traditional acoustic instruments

(Holmes, 2002). Theremin, which uses a very unorthodox interaction model (non-contact gestures made in air) is probably the most popular of the aforementioned musical instruments. Soloists – or virtuosos – of Theremin are still performing with this instrument in many different music genres (e.g. film music, popular music, classical music) with an expanding repertoire.

While the aforementioned inventions looked nothing like conventional musical instruments in regards to their design, semantics or semiotics, the basic working principles of their electro mechanics also shaped the foundations of modern electric and electroacoustic musical instruments such as electric guitar (1932), electric bass (1930s), Hammond Organ (1935) and Moog Synthesiser (1964) and the 'infamous' Minimoog (1970). Furthermore, the infinite possibilities concerning the electrically synthesized/amplified sound inspired instrument makers to experiment with new designs, materials and manufacturing methods. It is reasonable to propose that this critical step upwards in technology brought the field of musical instruments closer in context to industrial design and engineering. In addition, electric and electronic musical instruments either affected the dynamics of existing music genres (e.g. pop, jazz, blues) or facilitated the birth of completely new ones (e.g. computer music, electro-acoustic music, rock 'n' roll and heavy metal).

Going forward into the 21st Century, groundbreaking advancements and innovations in technology had even a bigger impact on musical instrument design. While this progress did not necessarily happen in the field of musical instruments, the miniaturization of computers (e.g. silicon based CPUs), LCD/LED screens and touchscreens, emergence of human computer interaction (HCI) (starting from 1980s) as a discipline in its own right and expanding research on new materials eventually led to a completely new species of electronic/digital musical instruments.

Similar to the 'electrical/electronic step' in the evolutionary journey, this 'electronic/digital' progression gave birth to a new species of musical instruments. But this time, music-making paradigms (in regards to both making and playing musical instruments) shifted severely because they did not derive from the historic 'lineage' concerning previous instruments. These 'archetype-less' instruments feature never-seen-before user interfaces, interaction models, functions and sound compared to their traditional acoustic and electronic counterparts.

As a result, these heavily ‘technology driven’ and ‘technology dependent’ products transformed musical instrument design into an interdisciplinary research area, which interconnects Music to disciplines including and not limited to industrial design, graphic design, interaction design, HCI, user experience (UX) design, computer science, software engineering, electronic/computer engineering, materials engineering and mechanical engineering.

This new ‘breed’ of instruments share 5 unique characteristics:

- *They do not have any archetypes or predecessors (e.g. classical guitar - electric guitar)*

- *They are heavily technology & innovation driven*

- *They offer new interaction models not found in conventional musical instruments*

- *They have advanced features unavailable in traditional/conventional musical instruments*

- *They are not plug & play (Musicians cannot generate sound with them immediately due to often sophisticated Set-up and configuration obstacles)*

In order to further clarify the scope of the research, ‘new musical instrument’ refers to a professionally designed and manufactured new generation electronic and/or digital product in the service of a professional musician to be used in its full potential. Musical toys, objects, hand crafted acoustic artefacts or similar products intended for amateur/hobby use, while they do have their many benefits, are not considered as part of this research.

Lastly, this research considers and explores the musical instrument in the context of live musical performance and not musical composition, because the interaction between the musician and the instrument involves distinctly different dimensions in a compositional context as opposed to a live musical performance.

1.2 Problem Background and Problem Statement

"Many new instruments are being invented. Too little striking music is being made with them" (Jordà, 2004a, p. 59).

Today, almost any product or 'object' equipped with sensors, processors and circuits can be transformed into a 'musical instrument' (Mase & Yonezawa, 2001; Franinovic et al., 2007; Delle Monache et al., 2008; Kim et al., 2011). However, 'technology intervention' does not always translate to improving the product or the users' interaction with that product.

While new musical instruments feature state-of-the-art technology and many new performance possibilities, they also embody un-orthodox user interfaces, novel but sophisticated interaction models, over-engineered or too simple functionality and unfamiliar product semantics/semiotics.

In the current scene concerning new musical instruments, the majority of the products are either:

- Easy-to-use musical instruments with little to no space for mastery (low ceiling for virtuosity), musical expressiveness, or improvement in musicianship through practise, or,

- Over-designed instruments 'armed' with state-of-the-art computing and sound technologies; in other words, what Cook (2001) calls *'Super Instruments'*.

One of the factors affecting musicians' decisions for deciding to engage with a musical instrument is the 'learning curve'. In other words; the amount of time it takes a novice to gain enough skill with the instrument that the experience of playing it is rewarding (Vertegaal & Eaglestone, 1996).

Any human-made device must strike the right balance between challenge, frustration and boredom: devices that are too simple tend not to provide rich experiences, and devices that are too complex alienate the user before their richness can be extracted from them (Levitin & Adams, 1998; Wanderley & Orio, 2002).

While some of these instruments seem to offer infinite potential, it is actually the constraints rather than affordances of an instrument that characterize it (Magnusson, 2010). In addition to the complexity of functions and features, unfamiliar interfaces and interaction models combined with obscure affordances create perception problems for musicians.

Additionally, perception problems are not limited to users (musicians) only. If the three fundamental components of a live musical performance are musician, instrument and audience, the aforementioned features of new musical instruments also affect how the performance is perceived/received by the audience. Lyons and Fels (2013) state that when there is a lack of obvious connection between the musician's gestures and the generated sound, the audience may not understand the interaction, and consequently, may not feel engaged during the performance.

This study proposes three main reasons behind the above-mentioned problems:

1- A paradigm shift concerning the identity of new musical instrument makers

2- Lack of theoretical knowledge in literature concerning the design of new musical instruments

3- Lack of user-centred research to inform the design process of new musical instruments

1.2.1 A paradigm shift concerning the identity of new musical instrument makers

One critical difference in regards to new musical instruments lies within the question of who designs and makes them. Throughout the history of musical instruments, the concept development, design and construction of acoustic musical instruments were carried out by experts with specific training knowledge and experience in the subject matter. These instrument makers passed on from one generation to another through a 'master and apprentice' model and had specific titles, which usually derived from the type of instruments they made (e.g. a 'luthier' is a person who makes lutes; a term, which later evolved to include makers of all types of stringed instruments).

Today, however, many of the new musical instruments are designed by the same people who use them (Jordà, 2005). Thus, it is reasonable to propose that current new musical instrument design scene is populated by ‘self-proclaimed’ interdisciplinary instrument makers coming from diverse backgrounds such as computer scientists, software developers, musicians and engineers. Even within the music-related professions, the once clear borders between instrument-makers, performers and composers are vague and blurry. Furthermore, it is not evident whether if these instrument makers possess the necessary background (in design disciplines) or training. Medeiros et al. (2014) claim that this new generation of instrument makers sometimes fail to incorporate basic design principles into their design and development process.

This is contradictory to ‘traditional’ instrument making which by convention is a skilled craft, requiring a broad and intense training period for each and every instrument.

1.2.2 Lack of theoretical knowledge in literature concerning the design of new musical instruments

Currently, there is an obvious lack of theory concerning new musical instrument design in the literature. Medeiros et al. (2014) mention that there are some design challenges concerning New Interfaces for Musical Expression (NIME) research and practice, which are not well described, analysed together or explicitly discussed in the literature. The authors further propose that dimensions such as usability, efficiency or fun are not obvious when applied to new musical instruments design.

> In fact, some issues are especially hard, such as how to deal with virtuosity, how to include cultural elements surrounding the artefact, how to consider the musician context in his/her experience in using the artefact, how to catalyse the creation of new artefacts, how to define what is a successful design, how to promote adequately the adhesion of adopters, etc. (Medeiros et al., 2014, p. 644).

The aforementioned challenges need to be addressed by researchers working in industrial design and interaction design, particularly who specialize in user-centred design and user experience (UX), since the area sits in the intersection of music, computing and design (Medeiros et al. 2014).

1.2.3 Lack of user-centred research to inform the design process of new musical instruments

> There is no doubt that the most important stakeholder in the process of designing and building a DMI is the performer. Unless the instrument can successfully translate their musical intent into sound in a reliable way it fundamentally fails as an instrument (O'Modhrain, 2011, p. 33).

Mulder (1996) states that existing musical instruments require the musician to adapt to the instrument rather than stretching the parameters of the instrument to make it adaptable to the needs or preferences of the musician. Mulder further proposes that this case is true for both traditional and new musical instruments due to factors such as inflexibility or standardization.

Rebelo (2006), however, suggests that traditionally, a musical instrument is very much treated as a difficulty, an obstacle that needs to be overcome in order for the musician to become 'one' with it. Rebelo believes that a desire to alleviate this obstacle is evident in recent research in the field of musical instrument design using new technologies. Today's technological possibilities also elevated expectations in terms of what new musical instruments can deliver to the musicians on multiple aspects of musical performance (i.e. creativity, expressiveness, efficiency, functionality, etc.)

Decades after their introduction, only a small fraction of professional musicians are aware of the existence of new musical instruments. According to Medeiros et al., (2014) it is hard to find instruments that have been widely or convincingly adopted by musicians. Furthermore, there are very few NIME virtuosi or professional musicians who adopted these interfaces as their main musical instrument.

If the musical instrument is considered as an 'interface' between the musician and sound (music), the lack of awareness and adoption may be explained by lack of user-centred research conducted with professional musicians. Considering the specificity of the subject matter and uniqueness of the dimensions related with music-making paradigms, it is only natural to seek consultation from professional musicians in order to inform the design process of new musical instruments.

The majority of novel electronic musical instruments are *not specifically intended for the musician* (as a highly skilled professional). Rather, a considerable amount of research has been dedicated to designing instruments for non-experts and 'ordinary' users (i.e. people who would not profess to being musicians) (Robson, 2001; Jordà, 2003; Beyer & Meier, 2011; Cappelen & Andersson, 2011; Luhtala et al., 2012).

Throughout the history of music, never before have a class of musical instruments been designed for amateur (not musician) users.

Since the majority of new electronic musical instruments are *neither designed and developed by professional instrument makers, nor intended to satisfy the needs and expectations of musicians,* their design specifications (i.e. affordances, usability, usefulness, expressiveness, etc.) have not emerged from conventionally established criteria.

1.3 Aim of the Study and Research Questions

In light of the arguments revealed in the problem background, this thesis aims to generate strategies and guidelines for designers to consider for improving musicians' interaction, user experience and performance with new generation electronic musical instruments in the context of live musical performance.

As this thesis considers new musical instruments in a professional use context, it is of utmost importance that the contributions of the research is beneficial for the intended expert user group; namely professional musicians. Thus, it is critical that the construction of the aforementioned design strategies is based on findings, which are revealed through an actual user-centred research conducted with the same intended user group; the musicians themselves.

This way, it would be possible to ensure that the findings are actionable and beneficial for both the designers who will act upon them and the musicians who will use the end products.

In order to acquire the knowledge needed to construct the aforementioned design strategies, this study seeks answers to three major research questions:

<u>RQ 1:</u> What are the dimensions of new musical interactions, which matter to musicians?
<u>RQ 2:</u> Why do these dimensions matter to musicians?
<u>RQ 3:</u> How can these dimensions be utilized to improve musicians' interaction, user experience and live performance with new generation electronic musical instruments?

To answer the third research question, it is essential to have a deeper understanding of how these dimensions exist within the conceptual space of the musicians' 'mind-sets'. Hence, the third research question is broken down to two further sub-questions:

<u>RQ 3.1:</u> What are the similarities and diversities between the elicited dimensions?
<u>RQ 3.2:</u> How/In which ways are these dimensions interrelated?

Throughout the thesis, there is a flow of terminology in parallel with the progression of the chapters. Thus, these basic terms need to be defined in order to establish clarity of communication. <u>Dimensions;</u> is an 'umbrella' term, which refers to the network/system of concepts in musicians' mind-sets that define the conceptual space of live performance with electronic musical instruments. <u>(Personal) Constructs;</u> is used in relation to the theory titled 'Personal Construct Theory' (Chapter 3), which forms the methodological basis of this research and it refers to the unique interpretations of individual musicians, which were acquired during the data collection. <u>Qualities</u> (i.e. product qualities, design qualities or qualities of interaction); refers to the shortlist of 31 prioritized qualities, (Chapter 5) which affect the design for interaction with electronic musical instruments in a live performance context.

The aim, objectives and research questions are stated in Table 1.1.

Table 1.1 Aim, objectives and research questions of the study

AIM	OBJECTIVES	RESEARCH QUESTIONS
EXPLORATION OF MUSICIANS' PERCEIVED EVALUATION OF NEW GENERATION ELECTRONIC MUSICAL INSTRUMENTS		
Construction of strategies and guidelines to improve musicians' interaction, user experience and performance with new generation musical instruments in the context of live musical performance	• To elicit each individual musician's perceived evaluation of new musical instruments. • To understand why the elicited dimensions are important.	What are the dimensions of new generation electronic musical instruments, which matter to musicians? Why do these dimensions matter to musicians?
INVESTIGATION OF THE INTERRELATIONS BETWEEN THE ELICITED DIMENSIONS OF NEW MUSICAL INTERACTIONS		
Construction of strategies and guidelines to improve musicians' interaction, user experience and performance with new generation musical instruments in the context of live musical performance	• To explore the similarities and diversities among the abovementioned dimensions. • To investigate the nature, importance and possible implications of the interrelations between the elicited dimensions.	How can these dimensions be utilized to improve musicians' interaction, user experience and live performance with new generation electronic musical instruments? What are the similarities and diversities between the elicited dimensions? How/In which ways are these dimensions interrelated?

1.4 Contributions to Knowledge

This thesis intends to make contributions to both theoretical and practical knowledge. The proposed strategies and guidelines to improve musicians' interaction, user experience and performance with new generation electronic musical instruments contribute to theoretical knowledge in the field of musical instrument design. The hybrid methodological approach, which is employed for this thesis (personal construct theory – repertory grid technique with laddering and pyramiding – cross impact analysis) makes this study the first of its kind in the field of musical instrument design. Thus, design researchers and academics working in the field of new generation electronic musical instrument design may take the methods of the research as well as its findings and the insights, and build further work ultimately directed to help designers in improving new musical interactions.

Furthermore, the aforementioned strategies are also reveal practical knowledge, which is actionable in nature. In other words, the findings of the research can be useful and applicable for design professionals working in product innovation and R&D activities in the area of musical instrument design, especially during the earlier phases of new product development, such as ideation and concept generation.

This user-centred research was conducted with professional musicians. Hence, the findings of the study might convey design professionals a better 'understanding' of the musicians' attitudes needs and expectations concerning new musical interactions.

1.5 Structure of the Research

The structure of the research is presented in Figure 1.2. in relation to the four research questions mentioned in the previous section.

The first stage of the research (Chapter 2) identifies core concepts and dimensions of new generation electronic musical instruments and new musical interactions through the literature. In this stage, a preliminary list of constructs is created to act as a glossary of terms for the study. Second stage (Chapters 3 and 4) involves a series of in-depth interviews with 30 professional musicians through repertory grid technique, in order to elicit the musicians' personal constructs through their perceived evaluations of new generation electronic musical instruments. During this stage, an iterative process was also carried out to identify and add each new musicians' personal constructs to finalize the glossary of terms. As a result, a large and diverse set of constructs were identified as the dimensions of new musical interactions. Third stage (Chapters 3 and 4) was simultaneously carried out during the RGT interview sessions and it involved capturing the superordinate and subordinate constructs in the musicians' personal constructs systems through laddering (asking 'why?' questions) and pyramiding (asking 'what?' or 'how?' questions).

The fourth stage (Chapter 5) is carried out through an initial content analysis in order to cluster and organize the constructs. The first step of analysis grouped the constructs based on semantic similarity, where as, for the second step a conceptual framework was created in order to further cluster and identify the core design qualities in the research. The conceptual framework was also instrumental in establishing a hierarchy between these design qualities based on the three main components (musician, instrument and audience) of a live musical performance. The fifth stage (Chapter 5) employs cross impact analysis in order to identify and interpret the interrelationships and interactions between the core dimensions of the study. Cross impact analysis also established a hierarchy of importance and purpose between the design qualities that form the whole system while identifying the system's end goals as well as the means to achieve them. The combined findings of the abovementioned stages led to the development of a set of design strategies and guidelines to improve musicians' interaction, user experience and performance with new generation musical instruments, in the context of live musical performance.

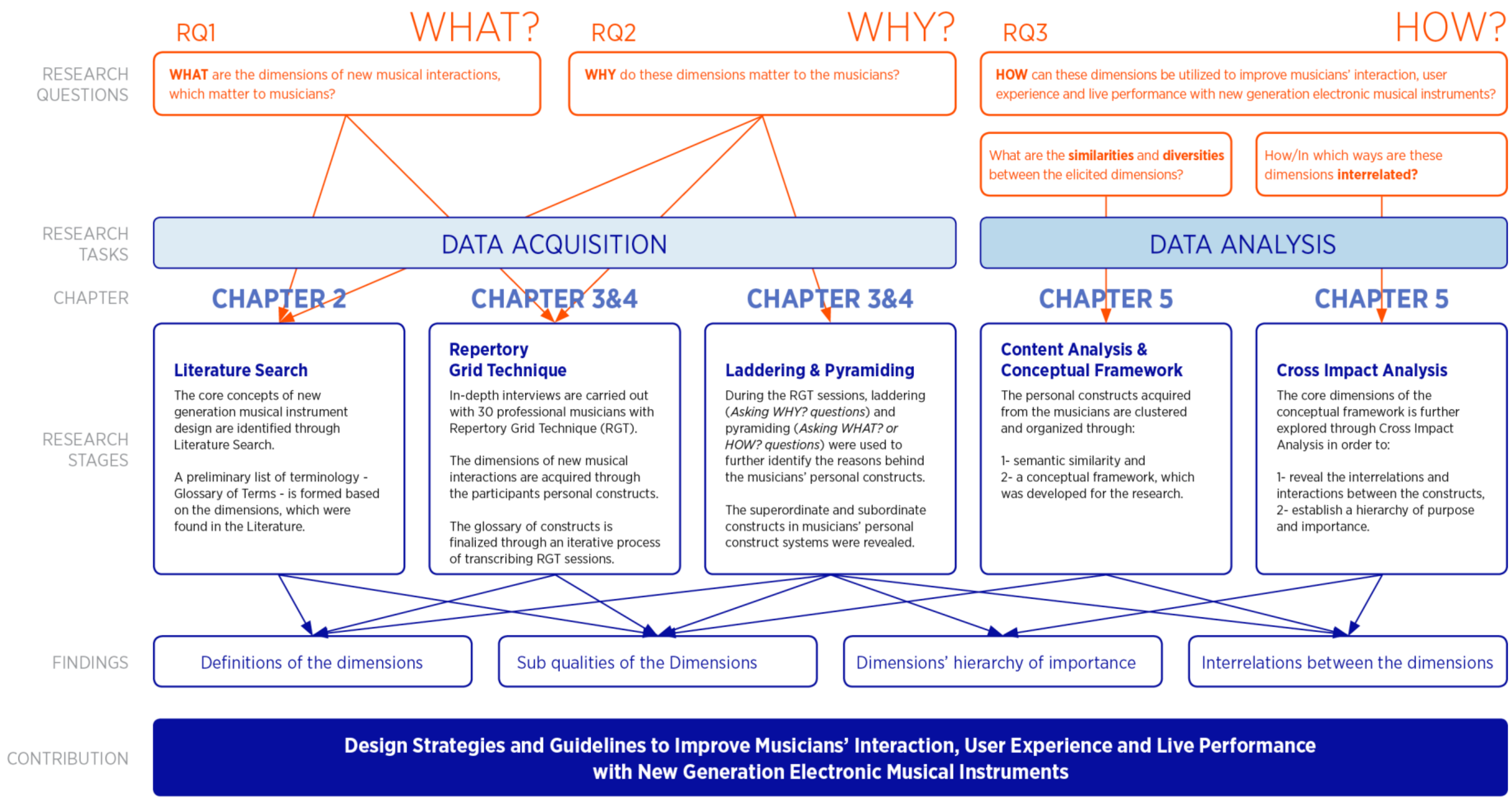

Figure 1.2 The Structure of the Research.

1.6 Structure of the Thesis

The thesis is composed of seven chapters. The first two chapters provide an overview and insight into the theoretical background in literature in regards to the research area under investigation.

Chapter 1 states the research area, its brief historical origins and lineage, problem background, aim of the study, research questions and expected contributions to knowledge.

Chapter 2 is a detailed review of the theoretical background and state-of-the-art in the literature. It is composed of seven sections and explores core concepts related with new musical instrument design, which are essential for the research.

Chapter 3 gives detailed information regarding the background of the chosen methodology; personal construct theory (PCT), repertory grid technique (RGT), laddering and pyramiding. The second section gives examples of previous design research carried out with PCT as well as a discussion on the advantages and shortcomings of the selected methodology while reflecting on why it was chosen over other alternatives. The chapter concludes with a brief description of the general philosophy concerning the methodological approach for the thesis and presents the flow of the remaining research stages illustrated by a diagram.

Chapter 4 is a detailed walk-through of the data collection procedure. It starts from the strategic approach, continues to research design and planning, experiment equipment, experiment set-up, participant selection and recruitment, the pilot study and ends with reflections regarding the complete process including a discussion on limitations and hardships of the study.

Chapter 5 reveals the coding and analysis procedures in two sections. The first section is a step-by-step explanation of the coding procedure and the initial content analysis, including the construction of a conceptual framework. The second section gives detailed information on the background and procedures concerning cross impact analysis (CIA) and presents the analysis results through individual discussions and interpretations for each finding.

Chapter 6 presents the main output of the thesis: design strategies and guidelines to improve musicians' interaction, user experience and live performance with new generation electronic musical instruments.

Chapter 7 is a 'conclusion', which summarizes the work undertaken, re-visits the research questions, presents a holistic view of the major findings, states the contribution to knowledge, discusses possible future directions, and ends with further reflections concerning the entirety of the thesis.

CHAPTER 2

KEY CONCEPTS IN ELECTRONIC MUSICAL INSTRUMENT DESIGN

The literature on musical instruments is too broad an area to fit inside the scope of this thesis. Thus, this chapter surveys the literature in the context of new electronic musical instruments and their surrounding interactions, with the exception of a brief introduction on the classification of musical instruments in general.

The first part of the chapter is composed of the scope of literature under investigation, taxonomy of musical instruments as well as a brief product review in relation to new electronic musical instruments. The second part of the chapter explores key concepts and dimensions of new musical instrument design: stakeholders, longevity, decoupling, gesture and mapping, feedback, musical expressivity, virtual instruments, wearables, collaborative instruments, and state-of-the-art in research dedicated to designing and evaluating new musical instruments.

2.1 Scope of Literature Under Investigation

The main research concerning new electronic musical instruments is carried out through The International Conference on New Interfaces for Musical Expression (NIME). NIME initially started as a workshop at the Association for Computing Machinery (ACM) Conference on Human Factors in Computing Systems (CHI) in 2001 in Seattle, Washington. Today, NIME is an annual conference devoted solely to encourage and support research for new musical instruments.

Various terms exist in the literature to identify new musical instruments. Among the most commonly used are: Digital musical instruments (DMI), electronic musical instruments (EMI) and new interfaces for musical expression (NIME). While some authors make distinctions between these terms, based on conventional availability or popularity, they arguably refer to the same class of musical instruments. For the purposes of this thesis 'new musical instrument' is used to refer to all new generation electronic and digital musical instruments.

There is a diverse spectrum of mainstream electronic and digital instruments, which are widely commonplace and available to musicians. This spectrum includes instruments and devices such as MIDI keyboards, workstations, synthesisers, sequencers, real-time samplers, sound modules, sound effects pedals and drum machines. However, these conventional instruments are not considered as part of new musical instruments and thus, are not in the scope of this research.

The above-mentioned term 'MIDI' deserves special attention due to its fundamental connection to new musical instrument design. MIDI (musical instrument digital interface) is a protocol developed in the 1980's which allows electronic instruments, digital musical tools and computers to communicate with each other. MIDI itself does not make sound, it is just a series of 'I-O' messages, which are then interpreted by another device tasked with sound generation.

Dave Smith, founder of Sequential Circuits and Ikutaru Kakehashi, founder to Roland Corporation are the two people who are credited with creating the vision for MIDI (midi.org). Robert Moog announced MIDI for the first time in the October 1982 issue of Keyboard Magazine (Manning, 2004, p. 267). Moog, along with Don Buchla, Harold Bode, Pete Zinovieff and Dave Cockerell, are credited for their work in miniaturizing 'room sized' synthesizers into more acceptable components; with Moog specifically credited for taking them out of the university laboratory and in the hands of the musicians (midi.org). Among similar communication protocols, the most noteworthy alternative is Open Sound Control (OSC), which was first introduced in 2002 with the intention of offering higher resolutions and a richer parameter space (Wright, 2002). MIDI 2.0 was announced in the winter of 2019 and introduced January, 2020. MIDI's developers consider this version as an 'extension' rather than a replacement and they state that the most significant features of the MIDI 2.0 are bidirectional communication (between the devices) and backwards compatibility. Figure 2.1 presents diverse examples of new musical instruments, which use MIDI protocol.

Figure 2.1 (A) MTC Express (B) 'Hands' (C) Yamaha Tenori-On (D) Squeezables (E) Rhytem Tree (F) AudioCubes (G) Haken Continuum (H) Tooka (I) Beatbugs (J) Samchillian

2.1.1 Taxonomies and Classifications of New Musical Instruments

In regards to the taxonomy of musical instruments, musicologists Curt Sachs and Erich Moritz von Hornbostel created the most widely used and comprehensive approach for the classification of musical instruments. The Hornbostel-Sachs System (also known as 'H-S System') (1914), classifies musical instruments in four categories: Chordaphones (stringed (plucked) instruments), aerophones (woodwinds and brass instruments), membraphones (drums) and idiophones (percussion instruments except drums). Each of these classes also have their multi level sub-categories.

The underlying principle is based on the 'nature' of the sound-producing component: an air column (aerophones), string (chordaphones), membrane (membraphones) and the body of an instrument (idiophones). In 1940, Sachs updated the H-Sachs System in order to classify and sort a fifth species of instruments called 'electrophones', which were further grouped into three sub-categories:

1. instruments with an electronic action
2. electro mechanical, acoustic sounds transformed into electric through amplification
3. radioelectric, instruments which are based on oscillating circuits (Sachs, 1940; as cited in Paine, 2010),

Even though the addition of the electrophones category made it possible to categorise all electrically actuated, amplified and oscillated musical instruments of its time, it is obviously insufficient to provide a comprehensive picture in relation to the richness and diversity of current new musical instruments and interactions (Paine, 2010).

Paradiso's (1997) detailed and extensive classification of new musical instruments include a chronological walk-through with all cornerstone instruments while pairing the history of related technological advancements with the mentioned instruments. However, due to its publication date, this taxonomy does not reveal the 'big picture' anymore as it has not been updated.

Birnbaum et al. (2005) propose a dimension space representation, which can be adapted for visually displaying new musical instruments (Figure 2.2.). Binrbaum et al.'s dimension space is composed of 7 dimensions: *role of sound*, *required* *expertise, music control, degrees of freedom, feedback modalities, inter-actors* and *distribution in space.* The authors suggest that the dimension space is useful for both exposing patterns among existing instruments and for informing the design of new ones.

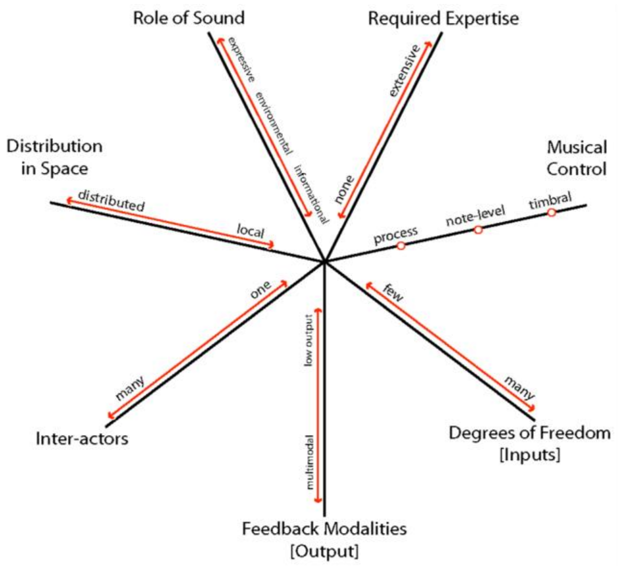

Figure 2.2 The 7-Axis dimension space (Birnbaum et al., 2005)

Pressing (1990) also compares and discusses new musical instruments based on a similar multidimensional space. Pressing's comparison of *extended*, *reconfigured, interactive* and *intelligent musical instruments* approaches these devices with a wide range of concepts such as user control, gesture, reconfiguration, articulation and unpredictability, range of operation, time independence, pre-composed materials and design flexibility.

Malloch et al. (2006) adapted an existing human information-processing model to construct a framework (Figure 2.3) for the categorization of digital musical instruments in terms of *performance context* and *performance behaviour*. According to the authors, the proposed framework is useful in two important ways: Firstly, it may be used to analyse, compare, and contrast existing instruments. Secondly, it may be used for the conceptual design and development of novel musical instruments and interfaces. The research also involves a practice-based study which evaluates three prototypes built by the authors in order to illustrate the framework's utility.

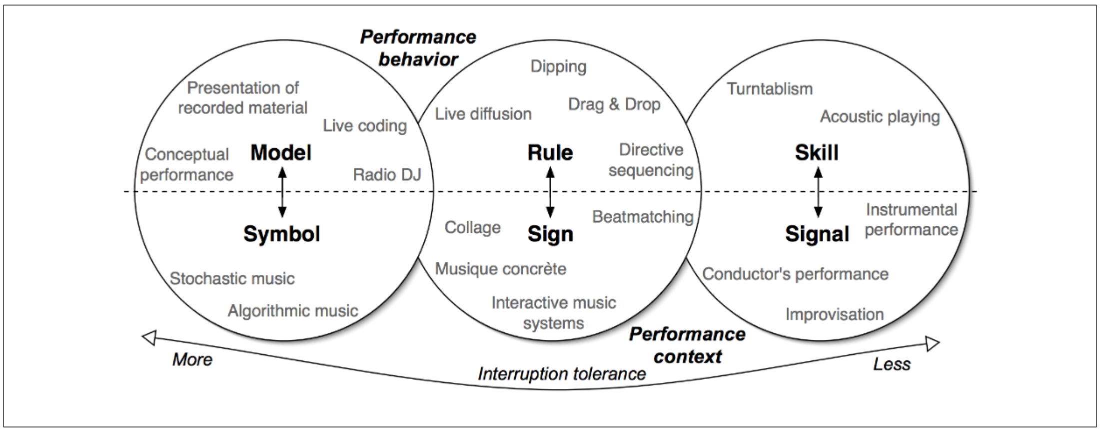

Figure 2.3 A visualization of the framework (Malloch et al., 2006)

Paine (2010) argues that current taxonomies and classifications fail to address evolving approaches concerning the design and use of new musical instruments. Paine conducted an online questionnaire – as part of the TIEM (Taxonomy of Interfaces for Electronic Music performance) project – in order to inform the creation of his taxonomy and identify four main classifiers: *gesture*, *instrument*, *digital controller* and *software*. Paine constructs his taxonomy (Figure 2.4) mainly around three of these classifiers excluding 'instrument' (as it is too broad a term) and proposes the *interplay of control and create* as a possible direction for the classification of real-time interfaces for electronic music performance.

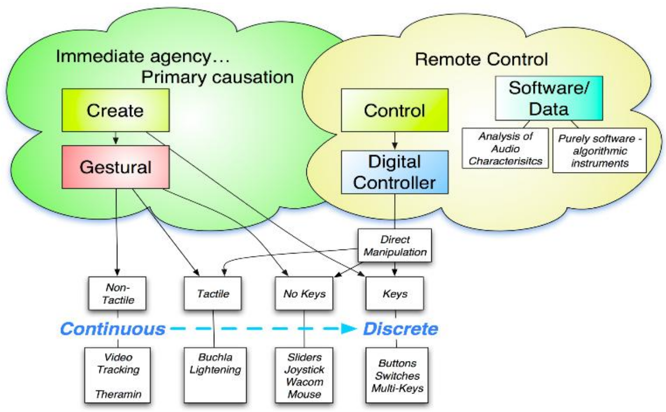

Figure 2.4 Taxonomy of real-time interfaces (Paine, 2010)

Magnusson (2017) considers musical organics to be a philosophical attempt to deal with the problems inherent in the organological classification of new musical instruments. Hence, Magnusson proposes an organic and ‘bottom-up’ organological classification with a collaborative approach. In order to display the open and participatory character of the system, Magnusson also presents an *organological ontogenesis* of three musical instruments the saxophone, the Minimoog and the Reactable (Table 2.1),

Table 2.1 Selected ontogenetic categories of the Reactable (Magnusson, 2017)

Instrument	**The Reactable**
Inventor	Team at Pompeu Fabra
Opposition	Some Catalan media were critical at first
Adopter	Björk
Marketer	Sergi Jordà
Innovation strategies	The release of reacTV source-code, the use of YouTube and social media for marketing purposes.
Time	5 years to become stablished
Networks	100 primary networks
Team size	5-10
Rationale	Physicality in virtual instruments. Synth visualization
Nonhuman actors	Projectors, cameras, real-time video libraries, software protocols, sound synthesis software, etc.
Patents	none
Public awareness	YouTube, project website, social media, festivals and media appearances

All of the aforementioned attempts on the classification and taxonomy of new electronic musical instruments contribute to the field by taking different perspectives (i.e. focus on products or stakeholders) and employing different priorities. However, as new musical interactions and new music-making paradigms continue to evolve constantly, the research efforts for the evaluation and classification of new musical instruments will inevitably update and adapt to these changes simultaneously.

2.1.2 Market and Pre-Market Review

In order to have a better understanding of the field under investigation a brief market and pre-market review has been made to set the scene 'visually' through examples representing the spectrum of available new musical instruments. The market review has been done based on 3 product classes (Figure 2.5, Figure 2.6 and Figure 2.7):

1- Commercially available mainstream electronic musical instruments
2- Commercially available new musical instruments
3- New prototypical (R&D and experimental) musical instruments

Commercially available mainstream electronic musical instruments;

refers to electronic musical instruments, which are already on the market, commonly used by musicians in various musical contexts and genres.

Commercially available new musical instruments;

refers to <u>new</u> electronic/digital musical instruments, which are commercially available on the market and being used by musicians. However, in most cases these instruments are manufactured in very small quantities.

New prototypical (R&D and experimental) musical instruments

refers to <u>new</u> electronic musical instrument prototypes, which are either in R&D stages or unique, one-of-a-kind instruments hand-made for research and experimental purposes.

The breakdown of each class of instruments is based on interaction types and each product section presents the instrument's controller interface components and available feedback modes.

Concerning mainstream electronic musical instruments; the once stand-alone products (e.g. synthesisers, sequencers, samplers, effects modules) are replaced by new generation 'workstations' that combine multiple functions in single products.

Concerning new musical instruments; the essential impression based on this brief review reveals that the current market is heavily dominated by controllers (i.e.

decoupled interfaces) rather than embodied musical instruments (i.e. inbuilt sound generators and sound output). Modularity of form, tangible interfaces, wearables (wearable interfaces), digital pads and mobile touchscreen devices (music apps/soft synths) are some of the defining exemplars of this new species of instruments.

These controllers offer new interactions, a wide range of input possibilities (i.e. not limited to hands), legacy and/or unconventional user-interface control elements and multiple feedback modes. Visual feedback seems to be the dominant feedback mode, in most cases a prerequisite for proper operation; which is completely in contrast with the entire acoustic/traditional musical instrument conventions.

I- Commercially Available Mainstream Electronic Musical Instruments

KEYBOARD CONTROLLER (1) Korg - Krome EX Copper (2) Samson - Carbon 49 (3) Akai - MPK Mini MK2 Red (4) Native Instruments - Komplete Kontrol S61 MK2

CONTROLLER: Keys, Knobs, Buttons, Slider, Fader, Wheel, Ribbon controller, Touch-strip, IR sensor, Touchscreen
FEEDBACK MODE: Audio, Tactile, Haptic (i) Weighted hammer action, (ii) Semi-weighted springier action, (iii) Spring loaded synth style action), Visual (Data & light).

WEARABLE KEYBOARD CONTROLLER (1) Roland - AX-Synth (2) Roland - Lucina AX-09 (3) Yamaha - Vocaloid (4) Alesis - Vortex Wireless 2 Red

CONTROLLER: Keys, Knobs, Slider, Fader, Buttons, Ribbon controller, IR sensor, Accelerometer.
FEEDBACK MODE: Audio, Tactile, Haptic (Spring loaded synth style keys), Visual (Data & light).

KNOBS BUTTONS FADERS ONLY (DJ TURNTABLES AND SIMILAR CONTROLLERS) (1) DJ-Tech - i-Mix (2) Vestax - VCI-100 (3) Pioneer - SVM1000 (4) Rane - Seventy Two Serato (5) Numark - Orbit

CONTROLLER: Knobs, Sliders, Buttons, Fader, Jog dial.
FEEDBACK MODE: Audio, Tactile, Haptic, Visual (Data & Light).

DRUM PAD/KIT CONTROLLER (1) Alesis - Compact Kit 4 (2) Clavia - Nord Drum 3 (3) Alesis - DM Lite (4) Yamaha - DTX Multi Pad (5) Yamaha - DD 75 (6) Pyle Audio - Pyle Pro PTED01

CONTROLLER: Knobs, Pads, Pedal, Cymbals, Sticks.
FEEDBACK MODE: Audio, Tactile, Haptic, Vibro-Tactile (Vibrations transmitted through stick), Visual (Data & light).

FOOT CONTROLLER (1) Yamaha - FC 7 (2) Behringer - FCB 1010 (3) Line 6 - FBV Express MKII (4) ProStage - Foot Controller X07 (5) Roland - PK-9 Pedalboard (6) Nektar - Pacer

CONTROLLER: Pedals, Buttons, Keys (Organ style).
FEEDBACK MODE: Audio, Tactile, Haptic (Free and spring loaded), Visual (Data & light).

BREATH CONTROLLER (1) Yamaha - WX5 (2) Akai - EWI 4000s (3) Morrison - MDT Digital Trumpet (4) Casio - DH 200 (5) Yamaha - BC1 (6) Yamaha - BC3A (7) Roland - Aerophone AE-10

CONTROLLER: Keys (Wind instruments), Mouth piece, Sliders.
FEEDBACK MODE: Audio, Tactile, Haptic.

Figure 2.5 Commercially Available Mainstream Electronic Musical Instruments

II- Commercially Available New Musical Instruments

CONTINUOUS KEYBOARD CONTROLLER (1) Haken Audio - Haken Continuum Fingerboard (2) Roli - Seaboard Rise 49

CONTROLLER: Smart surface (Fabric, silicone).
FEEDBACK MODES: Audio, Tactile, Vibro-tactile.

WEARABLE CONTROLLER (1) Zendrum ZX (2) Eigenlabs - Eigenharp Alpha (3) Artiphon - Instrument 1 (4) Imogen Heap - Mi.Mu Gloves (5) Sonic Instruments - MO-Band (6) Sonalog Gypsy Midi Arm

CONTROLLER: Keys, Knobs, Slider, Touchscreen, Gloves, Smart surface, Exoskeleton, Wrist band, Breath controller.
FEEDBACK MODE: Audio, Tactile, Haptic, Visual (Data & light).

PAD CONTROLLER (1) Novation - Launchpad Pro MK3 (2) Keith McMillen - QuNeo (3) Korg - Kaoss Pad (4) Akai - APC40 MKII (5) Yamaha - Tenori-On (6) Monome Grid 256 (7) AlphaSphere Nexus

CONTROLLER: Pads, Buttons, Sliders, Fader, Screen, Jog dial.
FEEDBACK MODE: Audio, Tactile, Haptic, Visual (Data & light).

TANGIBLE-MODULAR & TANGIBLE-MODULAR WITH BASE/SMART SURFACE CONTROLLER (1) Percussa - Audiocubes v1 (2) Percussa - Audiocubes v2 (3) Reactable Systems SL - Reactable Live

CONTROLLER: Objects, Smart Surface, Touchscreen, IR proximity sensors, RFID tags, Camera.
FEEDBACK MODE: Audio, Tactile, Visual (Data & light).

TOUCHSCREEN CONTROLLER (1) Wizdom Music - MorphWiz (2) Misa - Kitara (3) Reactable Systems SL - Reactable Rotor

CONTROLLER: Smart pad, Smart phone, Touchscreen, Hardware knobs.
FEEDBACK MODE: Audio, Tactile, Visual (Data & light).

BREATH CONTROLLER (1) Smule - Ocarina

CONTROLLER: Smart phone, Touchscreen.
FEEDBACK MODE: Audio, Tactile, Haptic.

Figure 2.6 Commercially Available New Musical Instruments

III- Conceptual, One-of-a-Kind & Prototype New Musical Instruments

KEYBOARD CONTROLLER (1) Leon Gruenbaum - Samchillian (2) Rick Riday - Riday T91 MIDI Controller

CONTROLLER: Keys, Buttons, Jog dial, Whole body (Inertia) spatial.
FEEDBACK MODES: Audio, Tactile.

WEARABLE CONTROLLER (1) Sean Ferguson, Marcelo Wanderley, Isabelle van Grimde - Visor and Ribs (2) Di Mainstone & Tim Murray-Browne - Serendiptichord (3) Michel Waisvisz - The Hands

CONTROLLER: Gloves, Prosthetics, Full-body suits, Head pieces, Touch panels.
FEEDBACK MODE: Audio, Tactile, Haptic, Visual (Data & light).

TANGIBLE CONTROLLER (1) Eitan Shefer - Samchillian v2 (2) Gil Weinberg & Seum-Lim Gan - Squeezables (3) Gil Weinberg, Roberto Aimi & Kevin Jennings - Beatbugs (4) Martin Marier - Sponge

CONTROLLER: Keys, Buttons, Objects, Antennae, Sponge, Screen, Gyroscope, LEDs.
FEEDBACK MODE: Audio, Tactile, Haptic, Visual (Data & light).

DESKTOP TANGIBLE CONTROLLER (1) Jonathan Sparks - Nomis

CONTROLLER: LED Polyphonic octagonal rotating wheel interface, LED tower interfaces.
FEEDBACK MODE: Audio, Tactual, Visual (Light).

TOUCH-SENSITIVE CONTROLLER (1) Formquadrat - Touch-sensitive guitar (2) Artiphon - Instrument 1 (Early version)

CONTROLLER: Capacitive active strings, Multitouch sensitive neck and drum, Touch wheel, LED, Smart phone.
FEEDBACK MODE: Audio, Tactile, Visual (Light).

SPATIAL (NON-CONTACT GESTURAL) CONTROLLER (1) Omer Yosha - AirPiano (2) Peter DeSimone - AirHarp (3) One Thousand Birds - Laser Harp (installation)

CONTROLLER: IR Proximity sensors, Ultrasonic sonar ranging, Laser, LEDs.
FEEDBACK MODE: Audio, Visual (Light).

Figure 2.7 New Prototypical (Conceptual, R&D and Experimental) Musical Instruments

2.2 Key Concepts and Dimensions in New Musical Interactions

This section discusses the key players, concepts and dimensions concerning new musical instrument design and their surrounding interactions. It also includes theoretical and practice-based research efforts for the design and evaluation of new musical instruments.

2.2.1 Stakeholders

In the context of new musical instrument design, one of the most important paradigm shifts happened concerning the 'stakeholders' of new musical interactions. It is possible to propose four major roles in today's new musical interactions: composer, performer, instrument-maker (designer) and the audience. These roles can be further extended to include instrument and component manufacturers (although global music corporations rarely mass manufacture commercially available new musical instruments; an immediate exception would be Yamaha's Tenori-on). Hence, it is also possible to consider 'manufacturers' from the perspective of manufacturing electronic components (O'Modhrain, 2011) for various industries, which are also used in new electronic musical instrument design (e.g. processors, memory, sensors, hard disks, sound cards).

2.2.1.1 Concerning Performers, Composers and Instrument Makers

In traditional/acoustic musical instrument design, the roles of stakeholders are well defined and clearly separated. Even though performer/composers and performer/composer/conductors can be frequently identified especially throughout the history of classical music; instrument makers/luthiers and musicians had clearly defined and separate roles. Furthermore, the audience always had a passive role in the context of live musical performances.

Composer Paul Lansky (1990) stated that the composer-performer-listener triangle – *"a good simple model of a classical notion of musical-social interaction"* – has been rendered obsolete with the new paradigm, which is reflected in the title of his paper

'When machines make music'. Lansky believes that this traditional triadic model is indeed representing a very rigid social structure, where, *the degree of passiveness and activeness of the individual nodes are relatively fixed.* In his words; *"The composer writes, the performer plays, and the listener claps".* However, Gurevich (2017) states that while the composers form the 'creator' nod in the model, they neither make the instruments nor the sounds, but the abstract representation of music, in the form of a score (notation). The performers interpret the scores of the composers in order to generate the actual sounds (music) that the audience hears.

In order to better reflect the social consequences of the 'machine intervention', Lansky (1990) proposes to update the traditional composer-performer-listener model by inserting two more *'nodes'*. He calls the first node *'sound-giver'*. This role represents a wide spectrum from a professional publisher producing CDs (or digital music in today's context) to individuals socially sharing music with each other (through a cassette tape in Lansky's example, or in digital platforms for listening and sharing music in today's world). Lansky's second node is the instrument-builder. However, according to Lansky (1990), the identity, characteristics and capabilities of this role radically transcend traditional luthiers:

> An instrument builder is no longer necessarily dependent on the evolutionary state of the musical climate to determine the next step. Instrument design and construction now become a form of musical composition. The vision of the instrument-builder can be idiosyncratic, and even compositional. Playing someone else's instruments becomes a form of playing someone else's composition. (p. 108)

Lansky further proposes that composers, performers, instrument-builders and even listeners can become sub-classes of each other within different contexts. In other words, in today's music making paradigms, the dividing lines between these previously well defined roles of designer/maker, composer and performer are often blurred; in fact, it is more likely than not, that these once distinct roles are often inhabited by one person; an opinion shared by many researchers in the field (Lansky, 1990; Jordà, 2005; Magnusson & Mendieta, 2007; Stewart, 2009; Magnusson, 2010; Baguyos, 2014; Johnston & Ferguson, 2016; Morreale & McPherson, 2017; Gurevich, 2017; Morreale et al., 2018; Armitage & McPherson, 2018; Hödl, 2019).

Furthermore, the literature also created new names for this new generation of instrument-makers: – 'techno luthier' (Paradiso, 1997) or 'digital luthier' (Jordà, 2005) are commonly used in the current literature to define instrument designers and makers.

Morreale et al. (2018) have conducted an online survey in order to explore the 'identity' of the new musical instruments from the perspective of their performers. The survey was carried out with 102 musicians who have performed in the NIME conferences between the years 2013-2017. The findings reveal striking facts in regards to the characteristics of these stakeholders, which Morreale et al. define as: *designer = composer = performer*. According to the results, 78% of the performers designed the instrument that they play. An even more striking finding was that 97% of the performers have been involved in the instrument making process. The authors also argue that composition can be strictly connected to performing and designing an instrument.

Morreale et al. (2018) explain this equivalence from two perspectives:

i) The performers/composers had to develop their own instrument because commercially available instruments did not meet their artistic needs

ii) The roles are inherently fused together in such a way that it wouldn't be possible for them to be separated, in other words, the instrument itself is conceived as part of the artistic composition and performance. (i.e. the instrument was specifically designed to realize a particular composition)

According to Morreale et al., (2018) there is an ongoing debate in the NIME community in relation to whether the instruments follow the artistic goals or vice versa. There seems to be evidence supporting both points of view. Cook (2001) suggests composing musical pieces first can influence and facilitate the design of the instrument. Conversely, Wanderley (2017) suggests that certain musical instruments, which were designed without a musical piece in mind such as *T-Stick* or *Gyrotyre* (Ferguson & Wanderley, 2010) were extensively used musically. A similar argument can be proposed for the role of the 'sound' in composition. The character of the sound (i.e. designed, tweaked, selected) can have a big impact on the process of composition; especially in the context of electronic music.

The answers to Morreale et al.'s survey suggest that the overlap between the roles of designer-performer-composer results in a tension (Morreale et al., 2018; Hödl, 2019), because the iterative process involving the designing of the instrument intervenes with the designer's role as a performer; as expressed by one of the survey's participants; Abdi Dezfouli: *"dilemma between changing the design of the instrument or learning its current features"*. Another participant; Leeuw states that bringing balance in practising and designing is the most challenging aspect of learning to play his instrument, Electrumpet. A third participant; Blasco makes similar reflections, claiming that covering two roles is the most challenging aspect: *"I could keep on working with it forever, since I am also the designer so it is a constant process of re-tweaking and advancing". "It is hard to just be the performer"* (as cited in Moreeale et al., 2018).

Ferguson and Wanderley (2010) believe that when a single person acts as the designer, composer and performer of a musical instrument, there is a substantial risk of that instrument being ever used only by its inventor. Wanderley and Orio also support this view, proposing that many of these instruments were *"designed to fit idiosyncratic needs of performers and composers,"* and hence, *"have usually remained inextricably tied to their creators."* (Wanderley & Orio, 2002; as cited in Everman & Leider, 2013). Further more, there can be a considerable tension between 'playability' and 'usability' of these 'designer-is-performer' instruments because ergonomic considerations can be very esoteric in such situations, where, making the instrument fit to performers other than its inventor can be very problematic. Morreale and McPherson's (2017) online survey, which was conducted with 70 digital luthiers revealed a similar finding: the most common target user for the new musical instruments were the instrument-makers themselves (58 out of 70 respondents). Furthermore, Gurevich (2017) proposes that all the roles being inhabited by a single person, *can be the failure to create a repertoire* (for new generation musical instruments). Hödl, (2019) also argues that digital luthiers often give their instruments to composers for them to study unconsidered issues and musical opportunities.

2.2.1.2 Audience Perception and Engagement

New musical instruments and their surrounding interactions caused a paradigm shift also in relation to the audience's live performance experience. The emergence of digital technologies empowered performers with immense flexibility in relation to how they generate sounds. In other words, the musicians are no longer bound with specific physical gestures, which form the building bricks of acoustic musical interactions. However, this flexibility creates serious perception problems for the audience due to lack of obvious cause and effect relationships during the performance (Schloss, 2003; O'Modhrain, 2011).

It is common knowledge that for any performing musician, audience's perception (and thus, appreciation) of and engagement to the performance is of utmost concern.

There are multiple factors, which facilitate this appreciation and engagement:

1. Music ('End Product' of the Performance)
2. Visibility of the performance
3. Cultural associations with the music and musical instruments (Fels et al., 2002)
4. Instrument's construction (embodied vs decoupled) (Winkler, 1995; Hunt, Wanderley & Kirk, 2000; Jordà, 2001; Fels et al., 2002)
5. Mapping transparency (Fels et al., 2002; Medeiros et al., 2014)

However, for the audience, 'understanding' the musician's interaction with the musical instrument becomes a prerequisite for being engaged to or appreciating the performance; (Lyons & Fels, 2013) because the audience can get frustrated by the lack of 'observable primary cause' (Paine, 2013). Among the above-mentioned factors, the third and fourth directly influence the fifth. There is a clear consensus in the literature, which suggest that decoupling in new musical instruments cause more opaque mappings compared to embodied instruments. In addition, temporality of a musical instrument (for how long it endured) and the cultural associations linked to that instrument also affect the transparency of the mapping:

> Both player and listener understand device mappings of common acoustic instruments, such as the violin. This understanding allows both participants to make a clear cognitive link between the player's control effort and the sound produced, facilitating the expressivity of

> the performance. For many instruments, this link is sufficiently integrated into the culture as to make it bi- directional. In this situation, observing either the sound or the effort provides access to the other. For example, one can picture the vigorous sawing of a virtuoso violinist while listening to an audio-only recording of a particularly exuberant performance. Likewise, watching a good pantomime of a vigorously sawing virtuoso violinist evokes an expressive sound performance […] The audience also benefits from a long cultural association with traditional instruments, expecting certain inputs to result in certain outputs. Both of these factors make the mapping transparent for the audience. (Fels et al., 2002, p. 110)

Medeiros et al. (2013) suggest that utilizing well-designed visual feedback, (visual cues in instrument's design, visualization of the interaction, visualization of the sound output (Lyons & Fels, 2013) and interaction metaphors (Fels et al., 2002) might be a useful strategy in order to improve audience's perception of and engagement to the performance.

For software instruments and unconventional controllers, the performance dynamics get even more unfamiliar. Live performances, which involve the use of laptop computers or digital tablets (as shown in Figure 2.8) feature extremely opaque mappings. The lack of physical effort (for playing the musical instrument), familiar gestures or visible 'cause and effect', alienate the audience from the performance. From the audience's perspective, interactions involving keyboard and mouse clicks become unknown territory in musical context.

> How could we readily distinguish an artist performing with powerful software like SuperCollider or PD from someone checking their e-mail whilst DJ-ing with iTunes? (Collins 2003, as cited in Jordà, 2005).

In such circumstances (including DJ performances), musicians often exaggerate their physical gestures in order to capture the audience's attention and help them find their way into the performance. However, as these gestures are not directly related to sound generation, they don't improve the situation sufficiently. In a more traditional musical performance such as a classical music concert, audience can easily recognize the 'cause and effect' (e.g. pianist's hands move towards the right hand of the piano and the sounds get more treble) and engage in the performance.

Figure 2.8 Audience engagement: Iron Maiden vs. ‘Laptop Orchestra’

Krefeld (1990; as cited in Vertegaal et. al., 1996, p.2) states that

> 1. Artists need to feel a piece, as it is being created and performed. […]
>
> 2. The audience perceives the physical effort as the cause and manifestation of the musical tension of the piece […]

Fels et al.’s (2002) two-axis transparency framework explores transparency of mapping for the performer and the audience in relation to each other in order to predict the expressivity of a musical instrument. The transparency of each axis varies between 0 and 1 and the transparency of the mapping depends on different factors for the player and the audience (shown in Figure 2.9).

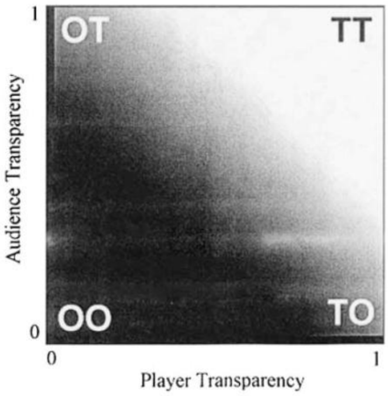

Figure 2.9 Transparency Framework for performers and audience to predict expressivity (Fels et al. 2002)

For the performers, the factors, which determine the transparency of mapping are cognitive understanding and physical proficiency. Cognitive understanding requires the performer to be familiar with the control parameters and their expected sonic outcomes. Experience gained with the instrument improves this familiarity. Physical proficiency is based on the performer’s level of dexterity on the controller interface, which improves through practise. The audience’s degree of transparency does not require physical proficiency but a general understanding of ‘how that musical instrument works’. This understanding comes from both the cultural knowledge and the physical causality relationships (Fels et al., 2002).

As seen in Figure 2.9, there are four regions in the framework marked OO, OT, TO and TT. The OO quadrant indicates a mapping that is opaque for both the performer and the audience, where as, mappings fall within the TT quadrant are transparent for both the performer and the audience. The mappings that are transparent for the performer but opaque for the audience or vice versa fall in the OT and TO regions. Most traditional acoustic instruments (e.g. piano, violin, guitar) fall within the TT quadrant. Embodiment (as opposed to decoupling) and cultural familiarity makes the affordances (Norman, 1990) apparent to both the performer and the audience. Many of the new musical instruments, especially the ones which do not derive from existing archetypes, feature extremely complex or unfamiliar mappings that are opaque to both performer and audience (OO).

Fels et al. (2002) propose that new musical instruments can be moved out of the OO quadrant by:

1. Making an instrument simple
2. Adding desirable functionality

Simplifying a musical instrument might make it easier for the audience to understand the mapping and interaction but it does not necessarily make it simpler to play (OT quadrant) (e.g. a piano keyboard is a simple interface yet very hard to master). Adding functionality might increase the motivation of early-adopters (Norman, 1998) to learn and play the instrument but would not positively affect the audience’s perception or engagement (TO quadrant). Fels et al. further conclude that the drawback of this approach is that neither of these methods have a base in existing literature.

Hundreds of years of acoustic tradition has made it a common known fact that musicians rely on the micro-changes in the vibrations emanating from the bodies of their instruments, i.e. vibrotactile feedback, in order to simultaneously inform and readjust their playing during a performance (Rebelo, 2006). Haptic and vibrotactile feedback is critical for both high levels of control and engagement with the instrument. However, the audience experiences the musical performance through only sonic and visual stimuli. Hence, a lot of research effort have been focused on facilitating the audience's perception of and engagement to live musical performances with new musical instruments.

Gunther et al. (2002) carried out an experiment in order to enhance the audience's performance experience through haptic simulation. Gunther et al. introduced what they call '*tactile composition or aesthetic composition for the sense of touch*'; a musical composition which also included specially designed vibrotactile elements. They developed full-body vibrotactile stimulators (suits) for audience members to experience a series of concerts both sonically and physically in MIT Media Lab in 2001. The results of their experiment revealed that haptic stimulation improved the audience's ability to comprehend and appreciate the compositions.

Similarly, in their research, McDowell and Furlong (2018) propose to enhance audience's performance experience and engagement through an augmentation, which they refer to as *'haptic-listening'*. McDowell and Furlong carried out two consecutive experiments where, the listeners were presented a representation of vibrotactile feedback experienced by a classical guitarist during a performance through a haptic component. The results showed that the haptic stimulation not only improved the audience's engagement, but perceived expressiveness of the performance as well. The authors propose that the multimodal mediation of music could be the next step in improving the audience's performance experience.

Bin et al. (2016) conducted an audience study in order to explore how technical and musical familiarity affect the audience's response to new musical interactions. The authors sought answers to two basic questions: Whether audience's increased understanding of the instrument contributed to their enjoyment or interest in the performance, and whether the music style had any effect on the audience's engagement. The experiment involved a concert where two DMI designer/performers each performed 2 pieces in different styles. The audience were given technical explanations of the instruments each half of the concert. The results showed that while the technical explanation had improved the audience's understanding of the instrument, it had no effect on their interest or enjoyment where as, performance of a conventional music style as opposed to an experimental one significantly increased the audience's enjoyment. Bin et al. (2016) further propose that the audience's listening habits affect their overall experience.

O'Modhrain (2011) proposed a framework for evaluating digital musical instruments (DMI) based on the perspectives of different stakeholders: audience, performer/composer, designer and manufacturer (and even possibly the customer). O'Modhrain believes that the audience evaluate performances based on their engagement and argues the importance of the audience's perception and perspective of the performance as a critical parameter of instrument evaluation; especially in relation to gesture and sound relationships in new musical interactions. O'Modhrain further proposes that involving the audience in the design process of a DMI can ensure that the casual gesture-sound relationships are evaluated by an important stakeholder, who is primarily affected by the opacity of interactions during the live musical performances.

Taking O'Mohdrain's suggestion to include the audience in the actual design process, Fyans et al. (2012) carried out a participatory design study that took into consideration the *'entire ecology of digital musical interactions'* including the audience. A post-performance audience questionnaire was used in order to explore the audience's perception of the novel interactions as well as the performers' skill levels. According to Fyans et al., the audience were neither able to understand the interactions nor make accurate judgments regarding the skill levels of the performers due to the opacity of the interactions. Hence, the authors believe that designing DMIs through a participatory design based approach that includes the audience can address the issues concerning audience's understanding of the musical interactions.

Departing from O'Modhrain's framework, Barbosa et al. (2012) proposed an evaluation methodology based on the audience's perspective. The authors demonstrated the practical application of their methodology through a case study carried out with a prototypical instrument called *Illusio*. Similarly, Jordà and Mealla (2014) followed O'Modhrain's ideas on the importance of different stakeholders and proposed a methodological framework for teaching evaluating and informing NIME design, where they specifically consulted the audience's perception in relation to mapping strategies. Wu et al. (2016) carried out an empirical evaluation of a gesture controlled vocal processing DMI (Tibetan Singing Prayer Wheel) where they compared the effectiveness of alternative gesture mappings through the audience's perspective.

Fyans et al.'s (2010) experiment explored how the audience forms an understanding of error between a performer and an interactive electronic instrument.

Taking into account O'Mdohrain's framework, Lai and Bovermann (2013) carried out a practice-based research study in live sound performance with electronics in order to investigate audience experience for new insights. Their experiment was based on a structured improvisation system called *WOSAWIP,* which involved two players and two instrument sets. Following the *WOSAWIP* performances, Lai and Bowermann (2013) conducted post-performance interviews with the audience members and they were able to generate four guidelines, which may be used in the decision processes concerning the design of new musical instruments, interactions and the performances:

1. Make a performance space that is visually and sonically comprehensive.
2. Consider showing the instruments and your interaction with it to the audience.
3. Consider having clearly evolving musical and performance structures.
4. Involving multiple performers in an ensemble setting adds contrast and dynamic to the performance, however, closer connections, such as the performers' roles and the music-making process, have to be established. (p. 173)

Similar to Magnusson's (2010) study on designing constraints, Bin et al. (2018) explores how disfluency of a musical instrument affects the audience's perception of the musical interaction. Bin et al. argue that while constraints and disfluency appear to be analogous, the main difference between these two dimensions lies in their temporality. Constraints of an instrument remain stable over time where as, performers improve on a disfluent instrument as they get more familiar with it in time. A user-centred study was carried out with 6 professional musicians who performed on 3 prototypes with varying levels of disfluency (i.e. none, mild and heightened) in front of a live audience. According to Bin et al., (2018) incorporating disfluency does not have an impact on audience's perceived enjoyment, however, it facilitates the audience's understanding and appreciation of the performer's skill because the disfluency of the interface allows the performers to display *effort* and *control* on the instrument.

2.2.1.3 Audience Participation

While the audience has remained a 'passive entity' in live musical performance contexts for centuries, the new musical interaction paradigms have indeed attributed new roles to the audience as 'participant' or 'co-creator' of the performances. On the other hand, the audience participation in computer music has long been limited due to resources and technology (Hindle, 2013). A substantial amount of practice-based research has been carried out, especially with mobile musical instruments, which enable and facilitate audience's active participation to the live musical performances.

Golan Levin's Dialtones: A Telesymphony (2001) is the first large scale live musical performance to engage the audience by using their mobile phones (Freeman, 2005; Lee & Freeman, 2013). While this performance can be considered as a collaborative work between the audience and the composer, the audience still retains its 'passive' role (McAllister et al., 2004; Freeman, 2005; Oh & Wang, 2011; Lee & Freeman, 2013) because the music is created by dialling audience mobile phones at specific times to play pre-composed ring tones.

Hindle (2013) proposes a framework, which uses mobile phones and similar mobile devices to provide the audience an interface of a 'shared' computer music instrument in order to facilitate their interaction with the musical performance. Hindle's (2013) practice-based research involves seven different instruments that can run on a relatively cross-platform system called *SWARMED* (Shared Wi-Fi Audience Reactive Musical Extemporization Design), which can be used on any web-enabled device such as smart-phones tablets and laptops. *SWARMED* allows the audience to control part of a sonic performance or installation through the browsers of their mobile devices.

Weitzner et al. (2012) also proposed a client-server system for mass audience participation called *massMobile,* which allows for real-time bi-directional communication between the performers and the audience through existing wireless protocols. They describe *massMobile* as being a configurable flexible and scalable framework for collecting and processing audio input.

Similarly, Lee and Freeman (2013) propose a work called *echobo* for large-scale audience participation and engagement through networking the audience's mobile phones. Lee and Freeman's system provides two types of instruments: a 'master musician' controls the high-level musical structure but does not generate any sounds. The musical structure is then transferred to the audience's mobile phones, where they can generate sounds in a harmonically controlled manner. An additional acoustic instrument player also joins the performance not only to improve the music but also to improve audience engagement through co-creation.

S. Park et al. (2013) report a collaborative work called *Sound Surfing Network (SSN). SSN* is a new mobile phone based interactive system which facilitates the performer and audience to control spatial sound distribution. *SSN* uses the audience's smartphones to form a multichannel speaker system, where the audience can sense the sound's spatial movement not only aurally but also visually through their smartphone screens and an on-stage visualization.

Mazzanti et al. (2014) employ a different approach and facilitate audience participation through the use of augmented reality (AR). The authors report their concept and platform titled *Augmented Stage*, where participatory audiovisual performances are created with audience collaboration. Their concept is based on superimposing virtual objects on the concert stage and allowing the audience to manipulate these objects through their mobile devices' camera in order to control visual and sonic feedback.

Nishida et al. (2019) explore the performer-audience interaction and collaboration on smart mobile devices through AR, VR, real-time 3D audio/video streaming, advanced web audio and gesture controller virtual instruments. According to the authors, the performers can use the audience's mobile phones in order to add an additional layer of musical expression to their performance while also turning the audience into active collaborators. Nishida et al. believe that VR and AR technologies have a strong potential in facilitating the paradigm shift regarding the role of the audience in live musical performances.

The use of biometrics to create sonic and visual outputs have been a popular method in new musical interactions. According to Angel (2011), composers and artist such as Alvin Lucier, David Rosenboom, Atau Tanaka, Yoichi Nagashima and Mariko Mori have experimented with biometrics to create music, installations and interactive performances as early as the mid 1960s.

Since then, various research studies have used a wide range of biometric identification techniques, such as: hemodynamics (measuring blood volume changes through a photoplethysmograph (PPG) (McGee, Fan & Ali, 2011), electromyography (EMG) (measuring electrical currents generated in muscles) (Nagashima, 2003; Angel, 2011), electroencephalography (EEG) (picking up electrical activity from the scalp surface) (Angel, 2011), galvanic skin response (measuring fluctuations in the electrical resistance of the skin) (Hamilton, 2006).

While the aforementioned studies have focused on the user (performer), thanks to the developments in wireless communication and smart devices, recent research has also collected biometric data from the audience in order to facilitate audience participation and co-creation during live performances.

Fan and Sciotto (2013) report a study, where they achieve audience co-creation of real-time audio-visual content through a hybrid interface for mobile devices that collects biometric information from the audience through PPG (heart rate) and EEG (brain waves).

van Hout et al. (2014) propose a different direction in audience participation in live performances through a system they designed for dance clubs. *Experio* is composed of several designated interactive areas on the dance floor, which have been illuminated through laser beams. While dancing, the audience members influence the music by interrupting the laser through their movement. In other words, they shape their sonic experience by their own gestures and dancing.

Lee et al. (2014) introduced a system that requires no infrastructure and minimum user configuration in order to distribute mobile applications using mobile ad-hoc network in context of audience participation.

Hirabayashi and Eshima (2015) developed a method of communication, which they call 'Ultra Sound Communication' (USC), in order to enable the participation of the audience by utilizing high frequency sound IDs. Through their musical work titled *Sense of Space*, Hirabayasahi and Eshima (2015) achieved synchronized real-time music compositions between the main performance and mobile devices of the audience.

Shaw et al. (2015) report their project *Fields*, a web based sound diffusion method, which enable the audience to participate in the live performance through their handheld mobile devices that are used as a collective array of speakers.

Similar networked collaborative studies have been carried out by Tanaka and Toeplitz (Tanaka, 2000) where their multi-site network music installation enabled performers and visitors in physically different places on Earth to collaborate with each other in real time.

Gimenes et al. (2016) conducted two live sound installations titled *Performance without Borders* and *Embodied iSound* respectively through two distributed computer systems called Sherwell and Levinsky Music. The former offered a cloud based voting system for the audience where as, the latter enabled the audience to participate in sound generation by motion tracking through their smart phones.

2.2.2 Design and Evaluation of New Musical Instruments

> The task of evaluating DMIs is in fact strongly linked to that of designing them, and knowledge gained in any side of the equation should complement the other (Jordà and Mealla, 2014).

Perry Cook's *Principles for Designing Computer Music Controllers* (2001) is one of the earliest sources in the literature, which gives recommendations for designing new musical instruments. Cook considers his principles (and in his words: '*a loose philosophy*') as a set of opinions based on his practice-based research spanning over

15 years of designing and constructing controllers. Cook (2001) believes that his principles relate to '*practical issues for the modern instrument craftsperson/hacker':*

Some Human/Artistic Principles

1. Programmability is a curse
2. Smart instruments are often not smart
3. Copying an instrument is dumb, leveraging expert technique is smart
4. Some players have spare bandwidth, some do not
5. Make a piece, not an instrument or controller
6. Instant music, subtlety later

Some Technological Principles

7. MIDI = Miracle, Industry Designed, (In)adequate
8. Batteries, Die (a command, not an observation)
9. Wires are not that bad (compared to wireless)

Some Other Principles

10. New algorithms suggest new controllers
11. New controllers suggest new algorithms
12. Existing instruments suggest new controllers
13. Everyday objects suggest amusing controllers

While Cook's principles successfully point out desirable musical instrument features functions and properties, Cook's work doesn't reveal enough detail in regards to how to achieve these goals (O'Modhrain, 2011; Jordà & Mealla, 2014). Additionally, more recent developments in technology may render some of Cook's principles obsolete.

Cook (2009) re-visited his design principles (2001) in 2009 with an expanded and revised version, where he self-reflected on the validity of his original principles, while adding new recommendations, which cover a wide range of subjects from compatibility to practicalities of logistics, new musical ensembles to music education through new instruments. Cook also conducted a practice-based experiment where he re-designed one of his controllers in order to inform his principles concerning *Re-designing controllers*. *Building more than one prototype* (re-design), *backward compatibility*, *colour-coding new wires* (connections of new functions and features), *documenting these alterations for future modifications, constructing controller* *proxies* (through creating a graphical user interface (GUI) that sends the same signals as the controller), and *building diagnostic features and displays* are the main outcomes of his updated principles.

In his PhD dissertation, Jordà (2005) proposes a conceptual framework to inform both the design process and qualitative evaluation of new electronic musical instruments. Jordà elaborates on some very important and universal criteria, which are relevant for not only new instruments but also traditional ones. Playability, learnability (and learning curve), efficiency (or as specified by Jordà; musical efficiency), effort, ease of use, diversity (flexibility of the instrument to be used in different musical styles or contexts), idiomatism and individualities, improvisation, configurability, controllability, virtuosity, variability and reproducibility (repeatability), scores and musical notation, composers vs performers, predictability, fault tolerance, explorability, time and expressiveness are among the concepts and dimensions he discusses in relation to designing and evaluating new musical instruments and interactions. Jordà discusses the possible connotations and meanings of what he terms a *'good instrument'* and he explores the aforementioned dimensions in different contexts and use scenarios (i.e. novices vs virtuosi, live performance, longevity) as well. As a professional *'digital luthier'* (Jordà, 2001) who has been both designing and building software and crafting in his terms: *'musical computers'*, Jordà states that his conceptual framework is mostly based on his own work and research – including other luthiers' research that he considers canonical and paradigmatic – and thus, his principles, suggestions and explanations are ideologically tied to his personal ideas tastes or beliefs about music and aesthetics or even politics. Jordà's dissertation (2005) also includes a 'digital lutherie decalogue' where he 'synthesizes' all the key concepts and relevant ideas concerning new electronic musical instrument design in 25 successive steps. This digital lutherie decalogue is at least as important and useful as his framework, especially in relation to how Jordà (2005) makes connections between critical aspects of traditional acoustic instruments and the future of electronic musical instrument design:

1. Identification of the quintessence of new digital instruments; <u>what they can bring of really original to the act of music performance; how can they redefine it.</u>

2. Identification of the drawbacks or obsolescences of traditional instruments; what limitations or problems could be eliminated, improved or solved.
3. Identification of the essential generic assets of traditional instruments; what qualities we should never forget or discard. (p. 9)

Wanderley and Orio (2002) proposed one of the earliest evaluation guidelines for new musical instruments, where they borrowed various methodologies for the evaluation of input devices from Human Computer Interaction (HCI) and discussed their applicability to musical interaction. Wanderley and Orio suggest that certain dimensions of usability such as: learnability, explorability, feature controllability and timing controllability are relevant to musical interaction and they can be used as guidelines for the development of musical tasks. Furthermore, the capacity to perform certain musical tasks can act as benchmarks for the evaluation of musical controllers. However, it has been noted in the literature that existing HCI evaluation methods (e.g. talk-aloud protocols) may not be suitable for evaluating musical interactions because how to conduct them in musical contexts is not obvious (Marquez-Borbon et al., 2011) as musical interactions have creative and affective aspects, which cannot be described as tasks, and dimensions such as timing and feedback interactions further complicate the development of reliable experiments (Stowell et al., 2009).

Overholt (2009) proposes a conceptual framework for the design of expressive musical instruments called *The Musical Interface Technology Design Space*. Overholt's framework explores concepts such as gesture (intuitiveness, comprehensibility, physicality), controller behaviour, synthesis algorithm, instrument identity, mapping methodology and expression range. Overholt (2009) suggests that his framework provides designers a theoretical base for creating new musical instruments and interactions while also acting as a set of guidelines for analysis and a taxonomy of design patterns for interactivity in musical instruments.

As mentioned in the Stakeholders section of this Chapter, O'Modhrain's (2011) framework for evaluating digital musical instruments brings a multidimensional perspective in the literature by emphasizing the possible differences in different stakeholders' criteria when evaluating new musical instruments and interactions.

These stakeholders are: audience, performers/composers, designers, (component) manufacturers and consumers. O’Modhrain’s framework also proposes four goals; *enjoyment, playability, robustness* and *achievement of design specifications,* which should be evaluated from the perspectives of these stakeholders.

> In summary, performance should be considered as the ultimate evaluation of any instrument design, and digital instruments are no exception. Performers are the only people who can provide feedback on an instrument’s functioning in the context for which it was ultimately intended, that of live music making. And yet performers, too, can adapt to properties of instruments that are non-ideal – the sticky pedal on a piano, for example – so that an impartial assessment of an instrument’s playability is also desirable if a solid design is to be assured. (O’Modhrain, 2011, p.35)

Barbosa et al. (2011) conducted a user-centred study in order to propose an evaluation methodology from the performer’s view. Their research involved user-testing a prototype instrument through both solo-sessions and a focus group. The performer is undoubtedly the most important stakeholder in the design process of a musical instrument (O’Modhrain 2011). However, Barbosa et al.’s research was carried out with only four users and while the authors mention that the users were familiar with technology and music, they were not professional musicians. It would be interesting to conduct the same study with a larger group of professional musicians and compare the results in relation to their dimensionality.

Magnusson (2010) approaches software based musical instrument design from an *affordances and constraints* perspective. In his study, he deliberately creates certain constraints on three software instruments and explores which dimensions of new musical interactions are affected by the system’s affordances and constraints. Magnusson refers to affordances and constraints as *two sides of the same coin,* where musicians make use of affordances to explore the instrument’s features (i.e. usability issues) where as it is the constraints that define both the primary *character* and the *limits* of the instrument; in other words, its musical expression possibilities. Magnusson further conclude that constraints become available for the performer and the composer to explore at the level of sound and mapping engines (Boden, 1990; cited in Magnusson, 2010). Hence, expressiveness and virtuosity is not to be found at the level of the interface where performer interacts with the affordances, but at the code-level where the instrument designer sets the structural and conceptual limitations for the 'expressive space' of the instrument (Magnusson, 2010).

Morreale et al. (2014) base their conceptual model *MINUET* on the *'experience of the player'*, with the intention to reduce the complexity of the design space in order to emphasise the experience of the performer. They verify the reliability of their framework based on comparisons with the related work and a case study carried through a prototypical study. Morreale et al. believe that their model can help designers to *i) position their work in a structured design space, ii) to elaborate ideas and objectives when designing a new interface and iii) to guide the evaluation process.* Additionally, the framework also introduces a temporal dimension, composed of two consecutive stages for designing and evaluating new musical instruments: goals and specifications (Figure 2.10). The first stage; Goal describes the design objectives based on 'People' (performers and audience), 'Activities' (motivation, collaboration, learning curve and ownership) and 'Contexts' (music style, physical and social environment) where as, the second stage; Specifications proposes 'Technologies' (control, mapping, operational freedom, embodied facilitation, input, feedback), which are necessary to achieve the objectives. Once the designers move on to the prototyping stage through the specifications, they can go back and evaluate their designs based on the goals of the model. The authors explain that these four entities enable designers to explore the design process from a user-centred perspective and the sub dimensions of these entities offer directly applicable design perspectives.

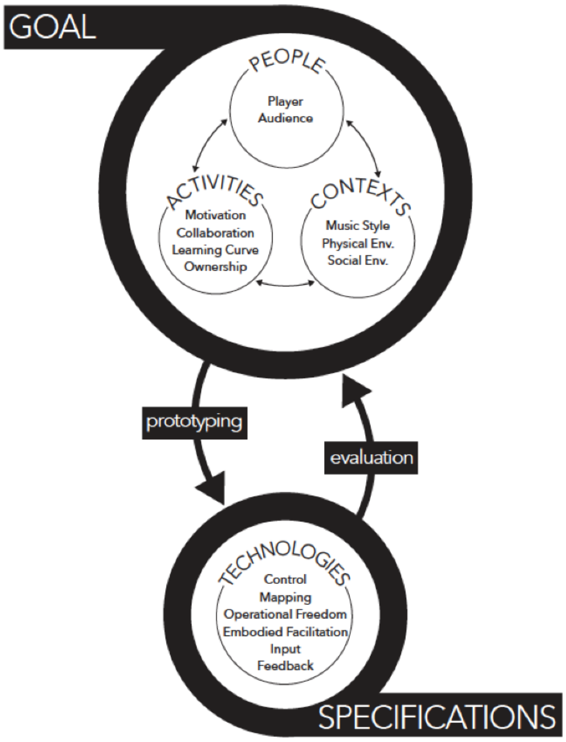

Figure 2.10 MINUET Framework (Morreale et al. 2014)

Jordà (2004a) focuses on the relationship between the musician and the instrument and approaches the design and evaluation of new musical instruments from concepts such as *apprenticeship* (balance between challenge, frustration and boredom), *learning curve, ease of use, playability* and *efficiency*. Jordà's (2004b) second publication of the same year acts as complementary to the first one and further explores key concepts from a musician-instrument interaction perspective: *musical instrument's output diversity* (Macro/Context, Style, Mid/Performance and Micro/Nuances), *improvisation, virtuosity and expressivity, variability and reproducibility, linearity, control* and *predictability* are the major dimensions, which Jordà associates as possible 'starting points' that need further study and exploration for the design and development of new musical instruments.

> What we are affirming is that the performer should never be the instrument's slave and that a good instrument should not impose its music to its player. A good instrument should not be able to produce only good music! (What is good music anyway?) A good instrument should also be able to produce "terribly bad" music, either at the player's will or at the player's misuse. Only under these conditions an instrument will allow its performers to play music and not only to play with music! (Jordà, 2004b, p. 707).

Blaine and Fels (2003) explore collaborative experience through multiple-performer instruments and argue that collaborative interaction facilitates communication between performers. Blaine and Fels's research focuses on instrument design with low entry-level skill aimed at novice users but they also acknowledge the importance of balancing the trade-off in relation to sacrificing a high ceiling of virtuosity. The authors propose ten dimensions for designers to consider while designing interfaces for collaborative performance experiences: *focus, location, media, scalability, player interaction, musical range, physical interface, directed interaction, pathway to expert performance* and *level of physicality.*

Erkut et al. (2011) repurposed an existing multimodal interaction and evaluation model (Obrenovic & Starcevic, 2004; Obrenovic et al., 2007) for the design and evaluation of new musical instruments. According to the authors, the design of the musical interface can employ a simple (visual or auditory) or complex (combination of simple modalities; i.e. audiovisual or audiotactile) modality. Similarly, the model can be used to evaluate basic or complex constraints. The basic constraints can be related to the user (user feature, user state and user preference) or external factors (device constraint, environmental constraints and social context).

Cantrell (2017) proposes a critical framework composed of five broad cultural categories for understanding historical, creative and technical dimensions surrounding new musical instruments. These categories are: *practical research, artistic performance, hacking/making, commercial production* and *self reflexivity.* Cantrell argues that the comparisons between the relative strengths within and between these five categories can be used to assess NIME works based on criteria drawn from areas of practice within the field.

User-Centred Research Carried Out with Professional Musicians

While all the aforementioned models frameworks and guidelines make substantial contributions to the design and evaluation of new musical instruments, what they lack in common is the fact that they usually rely on the researchers' personal/practical experiences. In cases where those studies involved user-centred experiments; either the sample size is too small or the users were not professional musicians. This section presents noteworthy user-centred research carried out with music professionals (i.e. professionals from the music industry including makers, composers, producers, etc.). While these research works consult experts, their findings often fall short of generating actionable design-relevant information due to insufficient depth of detail. This issue is particularly important because designers (and musical instrument makers) need more concrete and practicable starting points.

Paine (2009) suggests that while electronic music performances with laptops have become widespread, the keyboard/mouse interaction and the opacity of the emerging relationship between performance gestures and the musical output creates engagement problems for the audience in relation to what Paine calls *communication of musical intent.* Furthermore, Paine argues that the development of new electronic instrument design has been impeded by the absence of a generic model for musical control. Hence, a user centred study was conducted with professional acoustic musicians (Paine et al., 2007) in order to explore the fundamental control parameters professional performers use while performing on traditional instruments. The study also investigated – from the performers' perspective – how these control parameters affect the timbral characteristics of their music. Based on the semi structured interviews carried out with nine professional acoustic musicians, Paine et al. used a two step qualitative analysis procedure in order to reveal fundamental music parameters of acoustic instruments such as: *tone, dynamics, volume, expression, duration, vibrato, articulation, attack, release, sustain, pitch* and *intonation.* The second stage of the analysis led to the development of two models: *music parameters model* and *control parameters model.* Through these models, Paine et al. were also able to identify five essential music parameters: (*dynamics, pitch, vibrato, articulation* and *attack/release*) and four predominant physical control parameters (*pressure, speed, angle* and *position*), which the musicians use in order to generate the musical parameters. The model also reveals the interrelationships between the control parameters and audible timbral characteristics from a 'performer perspective' while the role musical expression or musicianship plays in aesthetic decisions.

Following the creation of the models, Paine (2009) also carried out a prototypical experiment in order to use the knowledge generated by the models to better understand the dynamics related to real-time musical performance contexts. According to Paine, the models which is derived from a performer perspective can be used for the design of computer music interfaces, which utilize a gestural language for live musical performances on a laptop computer. Additionally, Paine believes that *pressure*, *speed*, *angle* and *position* can act as design guidelines for the design of future musical interfaces.

Jordà et al. (2016) argue that especially for commercial musical instruments eliciting the insights of potential users is critical for the success of the instrument. Hence, Jordà et al. consulted professional electronic dance music producers through both in-depth interviews and online surveys to iteratively inform the design and development of an interactive drum generator. The professional user insight was used as design requirements involving high level user control, musical style and variation possibilities.

Santos (2019) conducted a user-centred study with six expert woodwinds musicians in order to explore the interrelationships between timing manipulations and physical gestures. Santos concludes that relationship between sound and gesture is indeed related to the performer's artistic/expressive intentions.

Similarly, Berthaut et al. (2015) propose a design framework in order to improve the perception of 'liveness' in DMIs. The authors argue that the audience's perceived causality between a performer's gestures and the musical output is central to liveness. Berthaut et al. base their framework on a psychological theory; *Theory of apparent mental causation* (Wegner & Wheatley, 1999), which suggests three criteria for inferred causality: priority (temporal order of events), consistency (congruence between the content of intention and related action) and exclusivity (number of possible causes for an action). Berthaut et al., (2015) conducted a user-centred experiment by designing and visually augmenting three prototype DMIs for each of the aforementioned three criteria. According to the authors, the results of the experiment suggest that the causality facilitates the audience's understanding of the relationship between performer's gestures and the sonic output.

Gurevich et al. (2010) explored the emergence of musical style through constraints in new musical instruments. Gurevich et al. designed nine identical copies of a one-button simple musical interface and user-tested the prototypes with nine undergraduate and postgraduate music performance students. According to the authors, the participants were able to develop a significant degree of diversity in personal music style (posture, ways of holding, ways of playing and musical variations) within the possibilities suggested by the constraint while also discovering non-obvious affordances and techniques which are not directly suggested by the instrument. Gurevich et al., report that the participants were able to develop stylistic variations both in spite of and because of the perceived constraint.

Zappi and McPherson (2014) took Gurevich et al.'s (2010) study as a basis for further exploring the effects of constraints on the process of appropriation in new musical instruments. The authors designed ten intentionally constrained musical instruments for their study, where five of the instruments had single degree of freedom where as, the other five had two degrees of freedom. Ten musicians with varying backgrounds (five musicians experienced in unconventional/experimental electronic interfaces, five musicians experienced in conventional styles e.g. classical, rock, folk) user-tested the instruments through both personal practise and live performances. According to the authors, while all ten musicians were able to achieve individual styles with simple musical interfaces, enhanced freedom had a counter-intuitive effect on the performers' exploration of the instruments' affordances and hence decreased the level of appropriation (affordances, musical variations, postures and interaction techniques) for the musicians who were given the prototypes with two degrees of freedom. According to Zappi and McPherson, (2014) hidden affordances constituted the large portion of the variations between individual styles. The study proposes that highly constrained instruments actually facilitate the appropriation of diverse and unusual playing styles among musicians.

Similarly, Tez and Bryan-Kinns (2017) carried out an experiment with professional musicians to explore how (intentional) interaction constraints affected their performance experience in relation to live improvisation. The authors designed the constraints as physical implementations and hidden rules defined on a network between the instruments. The results of the study suggest that constraints can lead to more structured improvisation however, the final output may not fit with the musicians' intentions.

Barbosa et al. (2015) state that the current inventory of DMI are either developed by academic research based on North American or European contemporary classical and experimental music, or as DIY projects designed and built by luthier/performer/composer individuals. The authors argue that there is an obvious lack of research, which focuses on designing DMIs for musical communities of specific/particular cultures which has their own established instruments, recognized virtuosi, repertoire and playing styles/gestures. Thus, Barbosa et al. (2015) carried out a research study specifically aimed at a local popular music community at the Brazilian northeast, where they collaborated with the professional musicians of Pernambuco in order to design two new musical instruments. Barbosa et al. employed the Design Thinking methodology (Brown, 2008), which is an iterative and cyclical process involving three non-linear stages: inspiration, ideation and implementation. Barbosa et al. first carried out interviews with the local virtuosi in order to gain a better understanding of their *modus operandi*. Then, the authors iteratively designed and evaluated their prototypes in collaboration with the local musicians. This study is particularly important in the sense that it is one of the rare examples which consult professional musicians for the design and development of musical instruments, which will be used by the same musicians. Barbosa et al. also propose that user-centred and participatory research carried out with the musicians of local musical cultures also improve the chances of acceptance of the DMI by those communities.

Momeni et al. (2018) practice-based research also consulted the actual performers who would use the instrument and thus, is a valuable example of participatory user research that informs the design process through iterative collaborations with the parties involved. The prototype was designed in relation to a dance/music performance, in which the performing musician is engaged in choreographed movements with mobile instruments. The collaborative design methodology involved musicians, composers, choreographers, dancers and technologists through an iterative design and evaluation process. Momeni et al. suggest that the methodological approach facilitated a 'dialogue' pertaining to design and the desired sonic effect as early as the project's initiation. According to the authors, the interactions between the parties involved, produced an organic and responsive design process. While musical evaluations with musicians and dancers identified what changes should be made in each iteration, technical dimensions such as sensor quality, audio capture, sound diffusion, processing power, computing platform and performance assessment of the instrument's overall interactivity were also carried out as in-lab assessments.

Similarly, Hattwick and Wanderley (2017) carried out multiple practice-based research projects in collaboration with professional artists with the aim to create systems suitable for professional artistic productions. Through their research projects, the authors were able to identify seven design specifications relevant to new musical instrument design: *function, aesthetics, support for artistic creation, system architecture, manufacturing, robustness* and *reusability.* The authors propose that considering these seven design aspects within the design and development process may facilitate the instruments' support for continued use in professional contexts. Hattwick and Wanderley also propose that the interdependencies (i.e. interrelations and cross-impacts) and temporality (i.e. in which phases of the design process they are considered) of these seven design aspects are key for achieving longevity in professional use contexts.

Armitage et al. (2017) argue that the majority of new musical instrument design frameworks do not provide applicable design suggestions, especially concerning subtle and important details. Hence, the authors used traditional lutherie as a model for conducting a user-centred study with both violin makers and professional violinists in order to explore the subtle nuances in instrument making as well as their perception by the performers. The results of the study suggest that: i) frameworks and goals form the foundations (and constraints) for design, ii) tacit knowledge (of the designer) is mandatory for creating high quality and detailed instruments, iii) tacit knowledge needs comparative tools, iv) playing and testing an instrument are different (performer) skills and v) verbal performer feedback (as opposed to demonstration) misses details (i.e. identification of differences). Armitage et al. (2017) also introduce the term *NIMEcraft* to describe subtle differences between otherwise identical instruments and their underlying design processes. The authors argue that NIME evaluation relies on audience response or the performer's judgement. Hence, complementing it with the designer's interpretation may lead to a more constructive, complete and nuanced DMI evaluation. Armitage et al. also argue that the design tools for creating new musical instruments with an engineering mindset diminish the role of the designer's embodied knowledge. Hence, engineering tools are neither suitable for the development of NIMEcraft skills nor for the dissemination of NIMEcraft.

> Digital lutherie should not be considered as a science nor an engineering technology, but as a sort of craftsmanship that sometimes may produce a work of art, no less than music (Jordà, 2005, p. 9)

2.2.3 Longevity of New Musical Instruments

> A huge number of DMIs are presented every year and few of them actually remain in use (Mamedes et al., 2014, p. 509)

As mentioned in the previous sections of this Chapter, *'longevity'* i.e. sustainability of new musical instruments has been a popular topic approached by many researchers. The last 20 years of the field made it evident that the majority of the new musical instruments are being ever used only by their own creators (Wanderley & Orio, 2002; Jordà, 2005; Ferguson & Wanderley, 2010; McPherson & Kim, 2012; Jordà et al., 2016; Morreale & McPherson 2017; Gurevich, 2017). Only a few new musical instruments can be considered as 'exceptions' that are widely or commercially adopted and used (e.g. Reactable).

There are diverse arguments pointing to different causes behind this issue. The main causes can be summarized as: multiple roles combined in a single individual (designer/composer/performer), lack of participatory studies with target users (professional musicians), lack of idiomatic repertoire, low ceiling for virtuosity, practice based research where the prototypes are built only to inform the research questions, and instruments created for performing a specific composition.

McPherson and Kim (2012) are among many researchers in the field who agree to the argument that most of the new musical instruments fail to attract a significant following and the designer ends up being the only composer and performer of the instrument. The authors conducted a user-centred study with musicians in order to explore how musician feedback can be used to inform and refine an existing musical instrument's design. The research's main goal was to explore how a designer can establish a continuing role for the instrument in the broader music community. However, McPherson and Kim believe that user-centred studies may be more beneficial for the redesign or refinement stages of an instrument rather than during its original conception. They summarize their argument in their own words as: '*Just build it, give it to musicians, and learn from what they do. The reason for this partly lies in the difference between how designers and new users explore the capabilities of an instrument'.* McPherson's (2010) electronically augmented a grand piano; 'Magnetic Resonator Piano' (MRP) was used to conduct a user-centred study with six composers and four performers. For the original design decisions of the MRP, McPherson took Cook's (2001) advice and designed the instrument based on a musical composition he wrote. Over the course of two years, during the various performances of the composition, musician feedback was used in order to redesign the instrument's constraints. The redesign process involved a complete revision of the hardware system as well as adjustments in mapping and control specifications. Then, six composers were invited to write musical pieces for MRP and the instrument's design was further refined based on the musician's feedback and suggestions. As a result of their study, McPherson and Kim (2012) offer four suggestions (i.e. guidelines) for designers who seek to establish their instruments in a broader music community:

1. Design for the first performance; then iterate.
2. Demonstrate uniqueness but connect to familiar models.
3. Sell to the audience; follow up with the performer or composer.
4. Provide access. (p. 26)

Wallis et al. (2013) also explore how musical instruments can achieve long term engagement with musicians. They borrow from the self determination theory of motivation and propose that *mastery, autonomy* and *purpose* as the three motives that affect perceived enjoyment and thus lead to long term engagement with a product. Wallis et al.'s analysis generates seven heuristics: *incrementality, complexity, immediacy, ownership, operational freedom*, *demonstrability* and *cooperation*. The authors believe that these qualities can be used throughout the entirety of the design process; from ideation to the evaluation of prototypes.

Morreale and McPherson (2017) investigate the longevity problem with DMIs, arguing that most DMIs have difficulties in establishing themselves following their creation. The authors conducted an online survey with 70 digital luthiers in order to explore the longevity of the DMIs which were created between 2010 and 2014. The results suggest that most of these instruments had difficulty in sustaining long-term use. Morreale and McPherson also asked the instrument makers to reflect on the specific factors that either facilitated or hindered the longevity of their instruments. The authors propose a series of design considerations based on these reflections as well as existing research on NIME and HCI as follows: i) <u>signature (idiosyncratic) features</u> (functionality, aesthetic and craftsmanship), ii) <u>user experience</u> (familiarity, simplicity of interaction, set-up time), iii) <u>technology</u> (common platforms, open-source, portability and low latency, modularity), iv) <u>musical possibilities</u> (ownership (personalizability), subtle control) and v) <u>design process</u> (scenario development, participatory design, prototyping, market analysis)

Vasquez et al. (2017) approach the longevity problem from a compositional perspective, proposing that certain traditional musical instruments at least partially owe their longevity to a dedicated repertoire of music that has been specifically composed for them. Hence, the authors discuss – through presenting various projects that involve idiomatic compositions for new musical instruments – how the concept of idiomatic (*a style appropriate for the instrument for which particular music is written*; Harvard Dictionary of Music, 2003; as cited in Vasquez et al., 2017) compositions has influenced research and composition practises within the NIME community, resulting in specific affordances for sonic social and spatial interactions. Vasquez et al. propose that the historical evidence in relation to acoustic instruments make musical instrument development through repertoire, which is guided by the design and sonic features of new musical instruments, a viable option for the next step in the evolution of future musical instruments. The authors argue that idiomatic compositions may in fact shape the characteristics of new musical instrument design to a more established musical identity, while also providing a shared understanding and common literature to the NIME community.

Gurevich (2017) seems to agree with Vasquez et al. (2017) and propose that *a repertoire provides a landscape of aesthetic reference points, a shared map among performers, composers, designers, and audiences onto which individual performances can be situated, and around which critical discourses can develop* (p. 168). Gurevich (2017) further proposes that the NIME community should consider ways to create a repertoire that facilitate not only performances but the development of new musical instruments; *where as, the process too frequently happens the other way around* (p. 168).

2.2.4 Decoupling: Musical Instrument vs. Musical Controller

'Musical instrument' by definition, refers to a device, which allows the user to generate sounds. The sound generation process involves two basic functions:

1. The musical controller; an 'input' component the musician uses in order to create, control and modify the music (i.e. musical notes, melodies, chords, clusters, noise, loops, textures, silence)
2. The sound generator; an 'output' component that generates the actual sound

In the context of traditional acoustic instruments, these two functions are 'embodied' (integrated within a single structure). (Mathews, 1963; Hunt et al., 2000; Wanderley 2001). In the case of a violin; the neck, fingerboard and the strings serve as the musical controller (input), while the body of the instrument and the 'f-holes' (sound holes) generate the vibrations and project the sound waves (output). Similarly, in wind and brass instruments such as a flute, clarinet, saxophone or trumpet, the musician blows into and fingers the same structure, which also generates the sound.

In the second half of the Twentieth Century, advancements in computer-based sound synthesis techniques such as 'additive synthesis' (Chamberlin, 1976; DiGiugno, 1976), 'physical modelling' (Hiller & Ruiz 1971a, b; McIntyre et al., 1983), FM (Chowning, 1973), 'wave-guide' (Smith, 1992), and 'scanned synthesis' (Verplank, Mathews & Shaw, 2000) have enabled computers to generate sounds and play them back through loudspeakers (Levitin et al., 2002).

This achievement led to the birth of a new species of input devices called 'musical controllers'. A musical controller – or more commonly referred to as a 'controller' – is a device, through which, the musician controls how the sounds created (real-time) or stored (pre-recorded) in the computer will be released (Roads & Strawn, 1985; Mathews & Pierce, 1989).

In the context of musical instrument design, the invention of controllers resulted in a paradigm-shift of critical importance because it allowed the aforementioned two basic functions of a musical instrument to be physically and structurally separated; in other words, as a separate controller and a sound generator (Winkler, 1995; Hunt, et al., 2000; Jordà, 2001; Fels et al., 2002).

Furthermore, the paradigm-shift concerning controllers had a radical impact on the temporality of sound generation as well, because, in decoupled instruments, there is no requirement for user input to result in immediate sonic output (Reid et al., 2019).

As the physical constraints of acoustic instruments do not apply to musical controllers, decoupling of functions makes new musical instruments more 'flexible' in regards to design (Roads, 1996; Paine, 2013) and can open up new possibilities for alternative control devices (Wanderley, 2001) and new ways of producing live music beyond the traditional focus on how musical notes are played (Paine, 2013). In other words, new musical instruments extend musical notes control to 'process control'; (Medeiros et al., 2014) enabling the musician to not only play notes but also trigger pre-recorded samples, effects and loops (Paine, 2013).

> Electronic input devices detach the control of sound from the need to power the sound; any one of dozens of input devices can control the same sound generator. This translates into musical flexibility. With electronic instruments, a single wind controller can create the low bass sounds as easily as the high soprano sounds. Creating extremely soft or loud sounds

requires minimum effort since the control is electronic. Obviously, the detachment of sound control from sound production has a negative side – the reduction of the 'feel' associated with producing a certain kind of sound. (Roads, 1996).

While acknowledging the advantages of 'flexibility' gained through decoupling, what Roads (1996) negatively points out with *reduction of the feel*, actually refers to the lack of physical feedback the musician receives from the sound generator. In other words, the musician sacrifices a strong relationship with the concrete body of the instrument (Medeiros, 2014); what Paine (2013) describes as an embodied relationship. This discussion is illustrated in Figure 2.11:

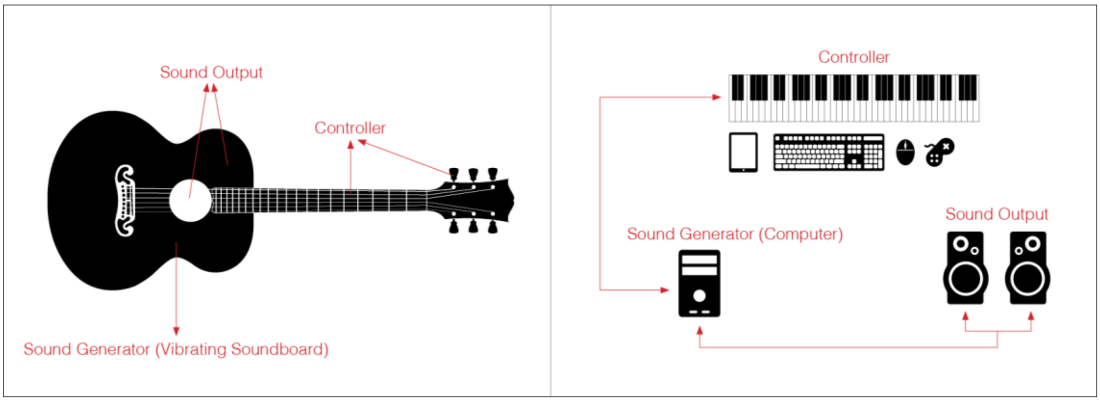

Figure 2.11 Representation of an Embodied Musical Instrument vs a Decoupled Musical Instrument

According to Levitin et al., (2002) during the 1990s, research in synthesis and computer-generated sound has placed great emphasis on the development of 'better sound' while comparatively little attention has been given to the devices that would control that sound. The most common early examples of musical controllers were designed after piano keyboards (Roads, 1996). The hammer-action of a traditional acoustic piano is an extremely complex invention that is composed of around 100 (per single key) components. Every one of these components – pressing a key initiates a chain of events that eventually lead to sound – has a physical impact on the generated sound. While a MIDI controller keyboard physically resembles an acoustic piano's keyboard (identical white key-black key layout) the controller itself does not generate any sound, the chain of events – which involves various sensors receivers and transmitters – is completely electronic (Levitin et al., 2002). While this argument is true in principle, mainstream conventional musical instrument manufacturers try to compensate for the lack of physicality in the hammer action by giving a semi-weighted or weighted feel to the keys through spring loaded actions or similar mechanisms, which in turn provide physical resistance and feedback. These kind of attempts aimed at improving the 'aesthetics of interaction' form an important part of the synergy between industrial design, interaction design and engineering.

In addition to controller keyboards, early examples of novel controllers include Yamaha WX7 (1987), a wind controller with the product semantics of a soprano saxophone where the player can control the sound output by blowing and pressing keys, Roland CompuRhythm CR-78 (1970), a programmable rhythm box composed of a large array of knobs and buttons, and other electronic controllers, which were designed to look like guitars, drum pads or other acoustic instruments.

By the end of the Twentieth Century, controllers further evolved to feature new designs that did not mimic acoustic instruments. These instruments were designed to translate musicians' intuitive gestures more directly into sound manipulation (Levitin et al., 2002) (for examples, see: Mathews, 1991; Rich, 1991; Boulanger & Mathews, 1997; Mulder et al., 1997; Marrin-Nakra, 2000).

Wanderley (2001) proposes that systematic study of how musical sound can be controlled is yet to receive sufficient scientific attention. Additionally, evolution of musical controllers inevitably created the need for a new classification system (Levitin et al., 2002) due to the inabilities of previous classification systems to sort controllers into their existing structure.

2.2.5 Gesture and Mapping in New Musical Instruments

In musical context, gesture and mapping are two interlinked concepts that apply to all musical instruments. However, the relationship between gesture and mapping becomes more decisive in the context of new musical instrument design. Therefore, this section attempts to define and explore these concepts based on their interconnection.

2.2.5.1 Gesture in New Musical Instruments

Mulder (2000) describes gestures as: *'dynamic human actions'* as opposed to static postures. Among other noteworthy definitions of gesture, such as: *'motions of the body that contain information'* (Kurtenback & Hulteen, 1990; as cited in Miranda & Wanderley, 2006), or *'movements that convey meaning to oneself or to a partner in communication'* (Hummels et al., 1998; as cited in Miranda & Wanderley, 2006), Miranda and Wanderley's (2006) definition; *'Any human action used to generate sounds'* proves to be the most holistic approach for musical context. As human actions are not limited to hand movements; Miranda and Wanderley's definition of gestures includes all intentional contact and non-contact body movements.

Miranda et al. (2006) classify gestures in two main groups:

1. Gestures for which no physical contact with a device or instrument is involved. These are referred to as: empty-handed, free, semiotic or naked gestures.
2. Gestures where some kind of physical contact with a device or instrument takes place. These are referred to as: manipulative, ergotic, haptic or instrumental gestures.

Theremin (invented by Leon Theremin in 1920), is considered as one of the archetypes of new musical instruments and it features a free (non-contact) gesture controlled interface. Since the musician plays the instrument without any physical contact with the interface (Figure 2.12), s/he receives no primary tactile, vibro-tactile or visual feedback but only sound (secondary) feedback. Thus, the instrument is considered very difficult to master on a virtuoso level.

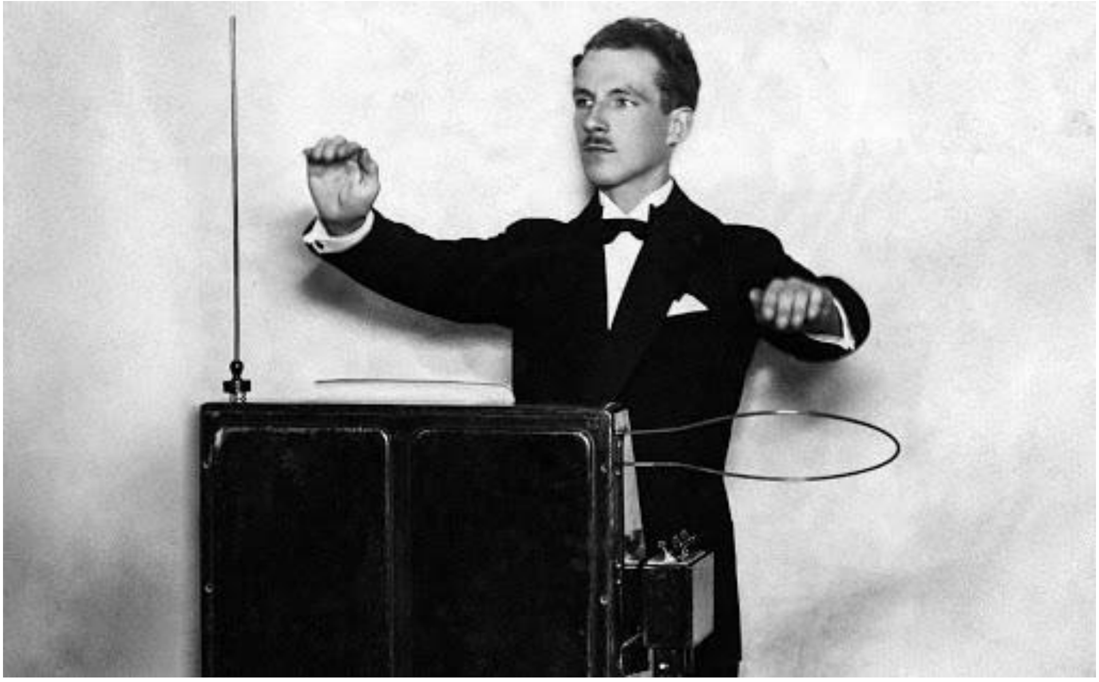

Figure 2.12 Leon Theremin, performing on his electronic musical instrument; Theremin.

Jensenius et al. (2010) define musical gestures as *human body movement that goes along with sounding music*, and take a different perspective by dividing it in two main categories including the ‘receivers’ of music: *the gestures of those that produce the sounds (the musicians), and the gestures of those that perceive the sounds (the listeners or dancers).*

Jensenius et al. (2010) propose a general framework based on the work of Zhao (2001) and McNeill (2000), which approaches gestures from the viewpoints of <u>communication,</u> <u>control</u> and <u>metaphor</u>: Communication gestures are used in the context of social interaction (i.e. linguistics, behavioral psychology, social anthropology) where as, control gestures are used as elements of interactive and computational systems such as HCI and computer music. Metaphorical gestures work as concepts that project physical movement or sound to cultural topics (i.e. cognitive science, psychology, musicology).

Even though control gestures seem to be the main source for generating musical interactions, Jensenius et al. (2010) propose to consider metaphorical gestures *as a mental entity that can be evoked from musical sound.* In other words, the experience of gesture ‘within music’ (Hatten, 2003; as cited in Jensensius et al., 2010) or what

Delalande calls figurative gesture, which may be conveyed through sound (Delalande, 1988; as cited in Jensensius et al., 2010).

A study developed by Delalande (1988, as cited in Cadoz & Wanderley, 2000) on the playing technique of world-renowned Canadian pianist Glenn Gould, suggests that gestures related with instrumental performance can be analysed on at least three levels; ranging from purely functional to purely symbolic:

> **Effective Gestures:** Gestures, which actually generate the sound.
>
> **Accompanist Gestures:** Body movements such as shoulder or head movements.
>
> **Figurative Gestures:** Gestures that are perceived by the listener but do not necessarily correspond directly to movement by the performer.

According to Delalande (1988, as cited in Cadoz & Wanderley, 2000) the function of accompanist gestures is equally related to both imagination and sound production. While effective and accompanist gestures are related to the physical actions of the performer, figurative gestures are completely symbolic (Cadoz & Wanderley, 2000).

Jensenius et al. (2010) further expand Delalande's work and classify musical gestures based on work by Gibet (1987), Cadoz (1988), Delalande (1988) and Wanderley and Depalle (2004) according to their functional aspects into four categories:

> **Sound-producing gestures** are the ones that are effective in producing sound. They can be further subdivided into gestures of excitation and modification. Sound producing gestures are called instrumental gestures in (Cadoz, 1988) and effective gestures in (Delalande, 1988).
>
> **Communicative gestures** are intended mainly for communication. Such movements can be subdivided into performer-performer or performer-perceiver types of communication. Communicative gestures are called semiotic gestures in (Cadoz & Wanderley, 2000).
>
> **Sound-facilitating gestures** support the sound-producing gestures in various ways. Such gestures can be subdivided into support, phrasing and entrained gestures. Sound-facilitating gestures are called accompanying gestures in (Delalande, 1988), non-obvious performer gestures in (Wanderley, 1999), and ancillary gestures in (Wanderley & Depalle, 2004).
>
> **Sound-accompanying gestures** are not involved in the sound production itself, but follow the music. They can be sound-tracing, i.e. following the contour of sonic elements (Godøy et al., 2006a), or they can mimic the sound-producing gestures (Godøy et al., 2006b).

In regards to space and temporality, Jensenius (2015) classifies musical actions (gestures) in three spatial levels:

> Micro: the smallest controllable and perceivable actions, happening at a millimetre scale (or smaller)
>
> Meso: most sound-producing and sound-modifying actions on musical instruments, such as moving the fingers on a keyboard or MIDI controller, happening at a centimetre scale
>
> Macro: larger actions, such as moving the hands, arms and full body, happening at a decimetre to metre scale. (p. 16)

2.2.5.2 Mapping in New Musical Instruments

In the musical context, ‘Mapping’ refers to the action of pairing or matching gestures with sound generation. As mentioned in the previous section, a musical instrument is composed of two main components: controller interface facilitates the input function and sound generator facilitates the output function. Don Buchla describes an electronic/digital musical instrument similarly, consisting of three components: *an input structure that we contact physically, an output structure that generates the sound, and a connection between the two* (Diliberto, 1983; as cited in Reid et al., 2019). What Buchla refers to as *a connection between the two* is in fact the mapping strategies between the input and the output.

There are two main points of view (Hunt et al., 2000) regarding the role of mapping in interactive systems:

- Mapping is a specific feature of a composition;
- Mapping is an integral part of the instrument.

Hunt et al. (2000) subscribe to the second point of view and suggest that mapping should be considered as part of an instrument, and that it influences the way a performer makes use of it in different contexts. Similarly, Fels et al. (2002) and Miranda and Wanderley (2006, p. 3) define the musical instrument as composed of three parts: the input interface, the mapping and the output interface (as illustrated in Figures 2.13 and 2.14 respectively). There seems to be a consensus in the literature, which considers mapping as the ‘essence’ (Rovan et al., 1997; Hunt et al., 2003) of a musical instrument.

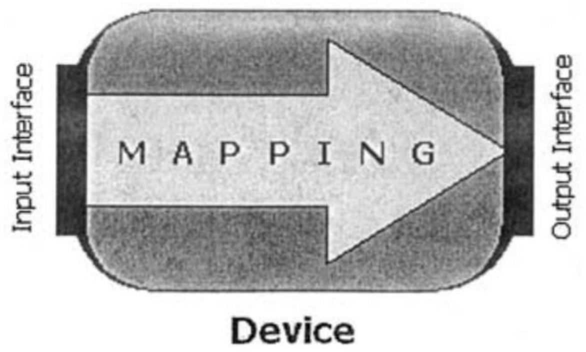

Figure 2.13 The musical device has an input interface and an output interface. The two are related by the mapping (Fels et al., 2002).

According to Fels et al. (2002) mapping becomes more important in new musical instruments as opposed to traditional acoustic instruments because when the components of an instrument are physically separated (decoupling), it becomes harder for the musician to mentally process the connections between gestures and sound production (Winkler, 1995; Hunt et al., 2000; Jordà, 2001). Where as, in traditional acoustic instruments, implementation of mechanical systems (e.g. strings on a violin, hammer action mechanism on a piano) and form factor (embodiment) make the mapping easily perceivable for the musician. Fels et al. propose that the concept of ‘transparency’ is the quality of mapping, which facilitates this understanding: “Transparency provides an indication of the psychophysiological distance, in the minds of the player and the audience, between the input and output of a device mapping” (2002, p. 109).

Consequently, mapping is the primary decisive element for instrument controllability (Moore, 1998; Fels & Lyons, 2009). Moore’s (1988) concept of ‘Control Intimacy’ directly points to the link between mapping and controllability:

> The best traditional musical instruments are ones whose control systems exhibit an important quality that I call ‘intimacy’. Control intimacy determines the match between the variety of

musically desirable sounds produced and the psycho-physiological capabilities of a practiced performer. It is based on the performer's subjective impression of the feedback control lag between the moment a sound is heard, a change is made by the performer, and the time when the effect of that control change is heard. (p. 21)

Since control intimacy depends upon gesture to sound mapping (Fels & Lyons, 2009) control related problems occur based on:

- Dimensionality of mapping
- Complexity of mapping
- Mapping strategies

As illustrated in Figure 2.14, it is possible to employ virtually countless (Rovan et al., 1997) mapping strategies between control and sound generation. However, Hunt et al. (2003) suggest that different mapping strategies for the same set of inputs and outputs will affect how the musician reacts musically and psychologically to the musical instrument. It is suggested that mappings are best when they are intuitive, and when they afford the maximum degree of expression with minimal cognitive load (Keele 1973; Mulder et al., 1997). Additionally, while having infinite possibilities for designing different mappings seems like an advantage, Medeiros et al. (2014) suggest that this advantage can actually become a problem because there is no established method or tool to guide designers in regards to how gestures should be mapped to sound variables (Calegario et al., 2013).

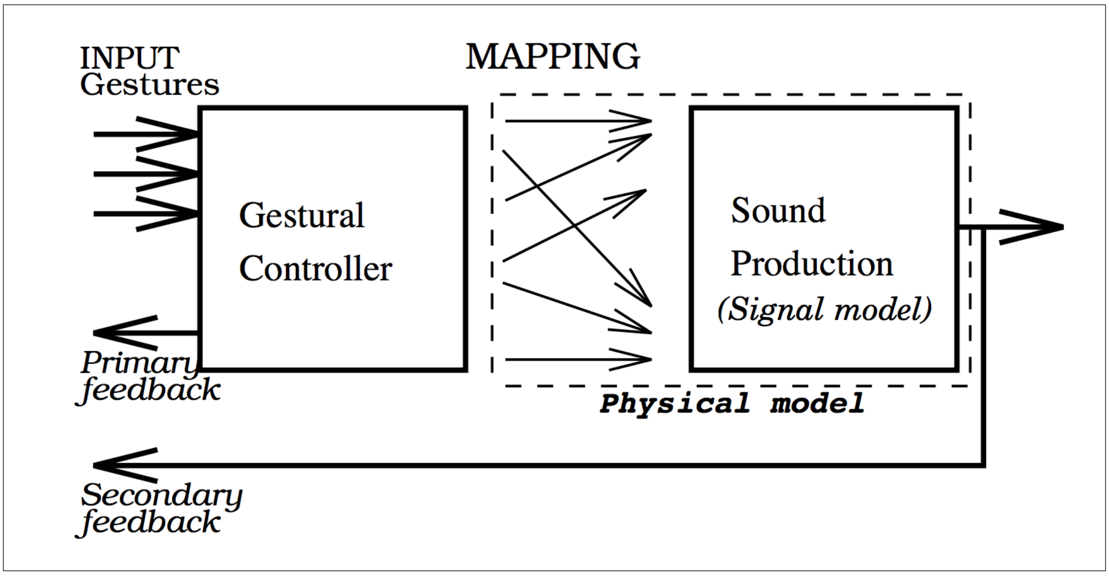

Figure 2.14 A virtual instrument representation (reproduced from Rovan et al, 1997, p. 68).

Through properly designed mapping strategies, the musician eventually starts to develop a higher level of control and comfort on the instrument, which Burzik describes as: *Flow in musical expression* (Figure 2.15) (Burzik, 2002; as cited in Fels & Lyons, 2009)

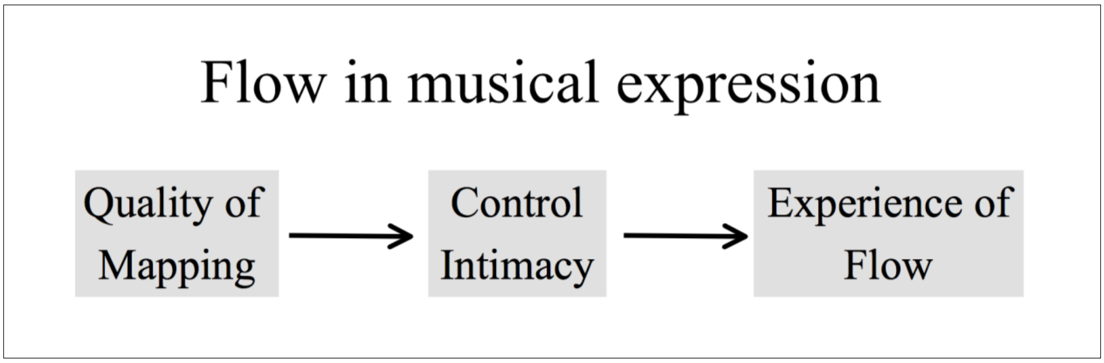

Figure 2.15 Flow in musical expression (Burzik, 2002; reproduced from Fels and Lyons, 2009).

In regards to classifying mapping strategies, Rovan et al. (1997) propose to combine them in three groups:

1- One-to-one Mapping: Each independent gestural input is assigned to one musical parameter, usually via a MIDI control message. This is the simplest mapping scheme, but usually the least expressive. It takes direct advantage of the MIDI controller architecture.
2- Divergent Mapping: One gestural input is used to control more than one simultaneous musical parameter. Although it may initially provide a macro-level expressivity control, this approach may nevertheless prove limited when applied alone, as it does not allow access to internal (micro) features of the sound object.
3- Convergent Mapping: In this case, many gestures are coupled to produce one musical parameter. This scheme requires previous experience with the system in order to achieve effective control. Although harder to master, it proves far more expressive than the unity mapping.

Today, thanks to the advancements in technology, it is possible to combine the above-mentioned three mapping strategies to create a fourth multi-dimensional mapping model (Fels & Lyons, 2009) illustrated in Figure 2.16.

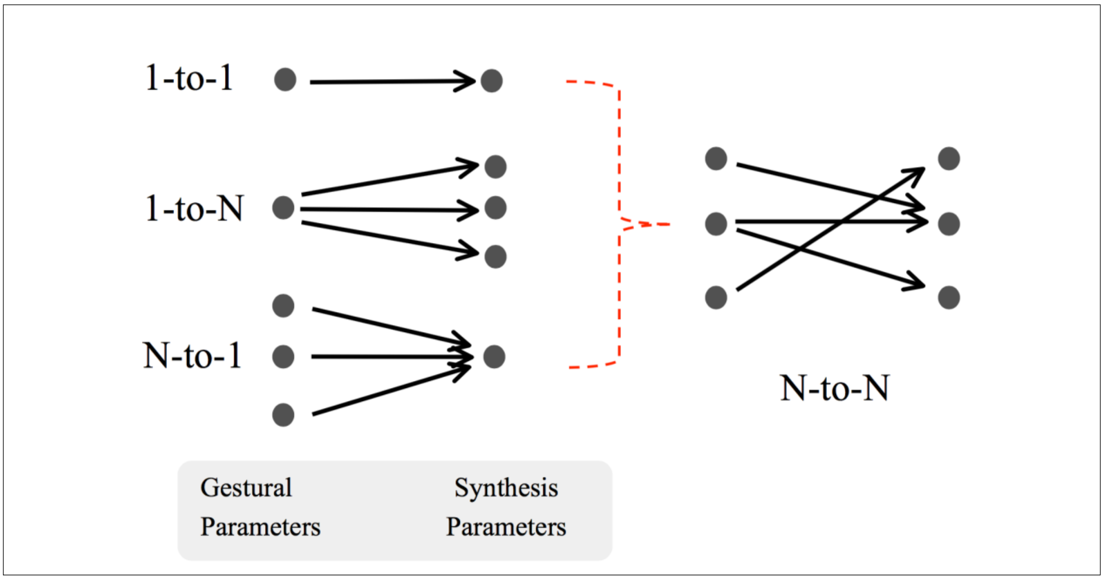

Figure 2.16 Types of mapping strategies (reproduced from Fels and Lyons, 2009).

Furthermore, Hunt et al. (2004) claim that even though there is substantial amount of research on improving the effectiveness of mapping, new musical instrument designers do not dream up the complex types of interaction that occur in acoustic musical instruments. Suitable mappings must be found between a musician's gesture and the control of various aspects of a musical tone (Cadoz et al., 1984; Wanderley, 2001).

A substantial amount of research has been conducted in order to explore the use of metaphors – an already well established tool for problem solving in the context of Product Design among many other disciplines – for creating new and effective mappings. Wessel et al. (2002) explored a variety of cognitively meaningful metaphors through their practice-based research where they present custom controllers and unique adaptations of gestural interfaces, which are used through metaphors such as: scrubbing, drag and drop, catch and throw and dipping.

Similarly, Fels et al. (2002) explore the use of metaphors to improve musical expressiveness through their four novel music and voice controller prototypes, where, the authors used the metaphors of guitar playing, sculpting (claying, carving, chiselling, assembly), falling rain and an articulatory model of speech. According to the authors, the results reveal an improvement in expression where the metaphors matched the implementation. However, Fels et al. also point out the inherent difficulties with the use of metaphors (e.g. lack of tactile feedback, opaque mapping) and that they work well if the performer's initial understanding of the metaphor is consistent. Fels et al. suggest the use of metaphors in design as a *stepping-stone* for performers and audiences and recommend designers to provide a directly accessible and enhanced functionality when the metaphor cannot achieve consistency.

2.2.6 Feedback in the Context of New Electronic Musical Instruments

Feedback is a very critical element of musical interaction, simply because it informs the musicians the results of their actions. Traditional acoustic musical instruments generate similar modes of feedback due to their physical construction and implemented mechanical systems. These feedbacks – in most parts – is exclusive to the performer rather than shared with the audience.

In the context of musical interaction, types of feedback can be listed as: tactile, kinaesthetic, haptic, vibro-tactile, audio (or sonic) and visual. As explained by Bongers (2000), the sense of touch consists of three main senses, which are often difficult to separate:

> Tactile perception receives its information through the cutaneous sensitivity of the skin, when the human is not moving. Proprioceptors (mechanoreceptors that sense forces in the muscles, tendons and joints) are the main input for our kinaesthetic sense, which is the awareness of movement, position and orientation of limbs and parts of the human body. Haptic perception uses information from both the tactile and kinaesthetic senses. Active haptic perception, when actively gathering information about objects outside of the body, is the main sense that can be applied in interfaces. The tactile, kinaesthetic and haptic perception together, is called tactual perception as defined by Loomis & Leederman (1986) building on the seminal work of J. J. Gibson in the fifties. (p. 45)

While only the performers receive tactile, kinaesthetic, haptic or vibro-tactile feedback (they require physical contact with the musical instrument), audio and visual feedback are shared by the performer and the audience. The audience's perception of the physical gestures of the musicians, as well as the physical changes on the interfaces of the musical instruments, (e.g. depth change in piano keys or movement of bows and strings on a cello) can be considered as 'visual feedback' as well.

In traditional acoustic instruments, the musician has an embodied relationship (Paine, 2013) with the concrete body of an instrument. This relationship enables the performer to adjust his/her playing dynamics instantly through tactual or haptic feedback:

> A pianist can see and locate a specific key before playing it, can use the resistance of the key-action mechanism to help know how hard to press the key, and can use the feeling of adjacent keys to keep track of hand position. (Dobrian and Koppelman, 2006, p. 280)

However, in new musical instruments, the emergence of popular interfaces such as touchscreens (Figure 2.17), do not always provide the intended results for musical interaction due to lack of tactual feedback. Tufte (2011) – through examples of his sculpture work – suggest that tactile information transmitted from non-flat surfaces, is critical for perceiving the environment with which, humans interact. These surfaces are *complex, luscious, subtle, responsive, warm or cool and three-dimensional to the touch; offering rich microphysical information,* which is created and detected by hand, when the artwork is touched.

> There is no such hand in touchscreen computer devices. The touchscreen has no texture variation, has no physical surface information, is dead flat, reflects ambient light noise, and features oily fingerprint debris when seen at a raking angle. Also the elegant sharp edges that encase many touchscreens require users to desensitize their hands in order to ignore the physical discomfort produced by the aggressive edges […]. (Tufte, 2011)

Figure 2.17 A Soft-instrument app on a digital tablet with a touchscreen interface.

According to Victor (2011) there's a reason that human fingertips have some of the densest areas of nerve endings on the body; *The sense of touch is essential to everything that humans have called 'work' for millions of years.* Victor further suggests that this is how humans experience the world close-up, as well as how tools 'talk back' to humans. Touchscreen interaction – in Victor's terms *Pictures Under Glass* – is a technology, which sacrifices all the tactile richness of working with hands, offering instead a 'hockey visual façade'.

> Pictures Under Glass is an interaction paradigm of permanent numbness. It's a Novocaine drip to the wrist. It denies our hands what they do best. And yet, it's the star player in every Vision of the Future. To me, claiming that Pictures Under Glass is the future of interaction is like claiming that black-and-white is the future of photography. It's obviously a transitional technology. And the sooner we transition, the better. (Victor, 2011).

According to Norman (2010), even though marketers label touchscreen products as 'Natural User Interfaces' for more effective promotion, they are far away from being 'natural' for users:

> Most gestures are neither natural nor easy to learn or remember. Few are innate or readily pre-disposed to rapid and easy learning. Even the simple headshake is puzzling when cultures

> intermix […] More important, gestures lack critical clues deemed essential for successful human-computer interaction. Because gestures are ephemeral, they do not leave behind any record of their path, which means that if one makes a gesture and either gets no response or the wrong response, there is little information available to help understand why. The requisite feedback is lacking. Moreover, a pure gestural system makes it difficult to discover the set of possibilities and the precise dynamics of execution. These problems can be overcome, of course, but only by adding conventional interface elements, such as menus, help systems, traces, tutorials, undo operations, and other forms of feedback and guides […]. (p. 6)

Starting with the second half of the Twentieth Century, the advancements in technology conceptually and practically re-defined 'Visual Feedback' in the context of digital musical instruments. The implications of this paradigm-shift became a real 'game-changer' for both musicians and the audience; offering new performance possibilities for the former and new performance experiences for the latter.

Visual feedback in new musical instruments (Fels & Lyons, 2009, module C, p. 6) may refer to:

- Visual appearance of the instrument
- Visualization of the interaction
- Visualization of the sound output

While the practical implications of visual feedback offer infinite possibilities, it also creates drawbacks and potential risks. For traditional acoustic instruments, once the musician develops a certain level of control and proficiency over the instrument ('Flow' in musical expression; Burzik, 2002) the interaction becomes intuitive and it is always possible to perform without having to look at the instrument. From this perspective these instruments can be referred to as 'blind instruments' and the interaction they offer as 'blind interaction'. However, in the case of new musical instruments, majority of the information, which the musician needs in order to perform before (set-up) and during the performance is transmitted through visual cues. Thus, it is literally not possible for the musician to interact with the instrument without constantly looking at the interface. This is a new interaction model, which has no foundation concerning existing music making traditions. Thus, it potentially creates problems especially for classically trained musicians.

‘Meaning’ of visual cues being transmitted from the instrument is equally important. When the visual feedback is mapped properly within the musical interaction, the visualization of that interaction makes sense to both the performer and possibly to the audience. In other words, visual feedback becomes a ‘helper’ or a facilitator. However, when the visual cues are way too abstract, or unrelated with the musical interaction they interfere (Figure 2.18) with the performance and become a ‘distraction’, both for the performer and the audience.

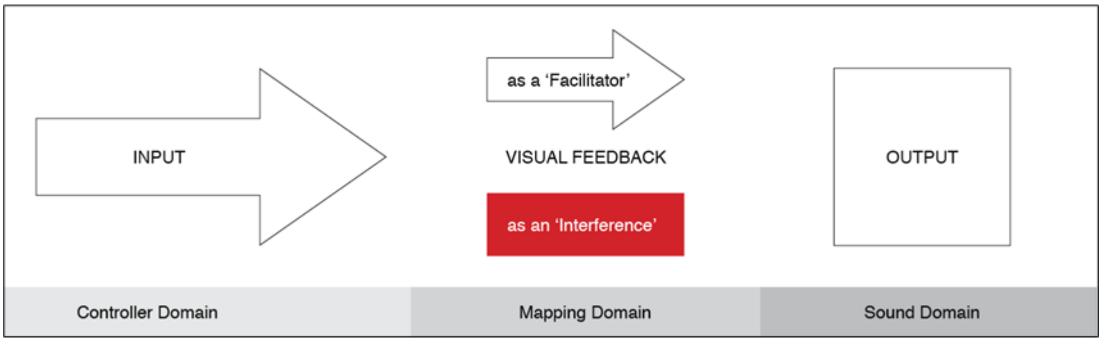

Figure 2.18 Representation of Visual feedback as an ‘Interference’ in New Musical Instruments

2.2.7 Musical Expressivity

In the broadest sense, ‘Expressivity’ is a very abstract concept and there is not a consensus in the literature regarding neither its definition nor dynamics. Expressivity has been mythicized due to strikingly different definitions by different authors in time (Williamon, 2004; p. 248). According to Williamon, this has led to the belief that expressivity is a completely subjective quality, which cannot (or should not) be described in scientific terms (Hoffren, 1964; Howard, 1989; as cited in Williamon, 2004, p. 248). Building on Fels et al.’s (2002) definition of Expressivity; *‘the act of communicating meaning or feeling’* for the purposes of the thesis, ‘Musical Expressivity’ is defined as: The act of musically communicating a feeling, emotion, message or meaning. In the context of musical interaction, expressivity concerns both the sound (musical outcome) and the physical gestures of the performer. Consequently, expressivity of a musical performance becomes a subject matter, which involves both the performer and the audience (Fels et al., 2002).

Musicians manipulate or combine various physical dimensions of sound to achieve an expressive performance. These dimensions can be temporal (duration of musical notes), volume related (loudness related nuances), touch related (also called 'voicing'; involving different levels of pressure for individual notes or chords) or articulation related (involving the relationship between how consecutive notes are played; e.g. disconnected vs tied to each other). Depending on the nature of the instrument, the performers may use multiple parts of their bodies to achieve these dimensions in their playing. The shift from acoustic musical instruments to electronic/digital music instruments offer new possibilities in this regard as well.

Consequently, expressivity becomes equally important for the audience because it enables the listeners to identify the subtle differences in the feeling or meaning that is being conveyed by the musician. Especially concerning classical music repertoire, where different performers play the same musical score in a 'note to note' identical way, expressivity becomes a critical identifier of an interpretation. Thus, musicians are able to communicate their unique musical identities through an expressive performance.

In the context of new musical instrument design, the technical basis of expressivity is achieved by gesture recognition and mapping (Rovan et al., 1997; Fels et al., 2002).

While a transparent mapping alone does not guarantee achieving expressivity (Fels et al., 2002), "…the more transparent the mapping is, the more expressive the device can potentially be […] Expressivity is not guaranteed – expression is complex, and transparency facilitates expression" (pp. 109-110).

> […] However, because traditional acoustic musical sound is a direct result of the interaction between an instrument and the performance gesture applied to it, if one wishes to model this expressivity, in addition to modelling the instrument itself -whatever the technique/algorithm- one must also model the physical gesture, in all its complexity. (Rovan et al., 1997, p. 68).

In traditional acoustic instruments, the range and diversity of gestures are determined by the physical limits of the instrument (i.e. mechanical system, form factor). In contrast, new musical instrument designers are free to map any kind of gesture to any type of sound output (Arfib et al., 2005). Additionally, Arfib et al. further propose that expressiveness in the design of electronic musical instruments is not restricted to producing expressive gestures; the gestures do not have to be "expressive" themselves, but they have to enable the generation of expressive sounds. Another criterion for measuring the expressivity of a musical instrument is its flexibility to be used to play diverse music styles.

> The expressiveness will be correlated with the ability of an instrument to allow the performer to adapt his playing to a context […] An 'expressive musical instrument' can therefore also be said to be an instrument, which allows a performer to follow other musicians in various musical directions. (Arfib et al., 2005, p. 128).

According to Jordà (2001) there is a common belief that more hard-to-play instruments lead to richer and more sophisticated music. However, Jordà suggests that expressivity does not really imply difficulty, and in that sense, one of the obvious research trends in new musical instrument design can be the creation of easy-to-use and, at the same time, sophisticated and expressive instruments.

According to Juslin (2003), 'Expression' refers to a set of perceptual qualities that reflect psychophysical relationships between 'objective' properties of the music, and 'subjective' (or, rather, objective but partly person-dependent) impressions of the listener. Juslin (2003) also proposes that expression resides on a diverse set of factors, which are limited to neither the performer nor the music itself:

> […] expression does not reside solely in the acoustic properties of the music (different listeners may perceive the expression differently), nor does it reside solely in the mind of the listener (different listeners usually agree about the general nature of the expression in a performance). Expression depends on both of these factors, in ways that, although complex, can be modelled in a systematic fashion. (p. 276)

Juslin (2003) further discusses a more restrictive approach to expression that is common in research, which proposes that music is expressive of a certain quality only to the extent that there is some minimum level of agreement among the listeners. Thus, a link between expression and communication also becomes significant:

> The concept of communication (of emotion, for instance), in contrast, goes further: accurate communication, I believe, requires that there is both a performer's intention to express a specific concept and recognition of this concept by a listener. Perhaps, it may seem strange to talk about communication accuracy in the context of music. Still, most performers are probably – or should be – worried about whether their musical interpretation is actually

> perceived by listeners the way they intended it. (What is the purpose of a specific interpretation if every listener fails to perceive it?) The performer may, for instance, wish to highlight an emotional character that is latent in the composition. The extent to which performer and listener agree about the emotional expression of the performance could pragmatically be seen as a measure of the accuracy of the communication. (p. 277)

Juslin (2003) states that the main reason behind the problematic nature of expressivity in a research context, is a large set of complicated real-world relationships, which need to be taken into account in order to fully understand, evaluate or measure expressivity. These relationships are not limited to the performer and the instrument; they are in fact part of an extensive eco-system including the performer, instrument, audience, (musical) composition and context. Juslin proposes a comprehensive 'list of factors' (Table 2.2), which may -in principal- influence expressivity.

Table 2.2 Examples of factors that might influence expression in music performance (Juslin, 2003)

Type	Examples of factors
Piece-related	The musical composition itself Notational variants of the piece Consultations with composer or composer’s written comments Musical style/genre
Instrument-related	Acoustic parameters available Instrument-specific aspects of timbre, pitch, etc. Technical difficulties of the instrument
Performer-related	The performer’s structural interpretation The performer’s expressive intention with regard to the mood of the piece The performer’s emotion-expressive style The performer’s technical skill The performer’s motor precision The performer’s mood while playing The performer’s interaction with co-performers The performer’s perception of/interaction with audience
Listener-related	The listener’s music preferences The listener’s music expertise The listener’s personality The listener’s current mood The listener’s state of attention
Context-related	Acoustics Sound technology Listening context (e.g. recording, concert) Other individuals present Visual performance conditions Larger cultural and historic setting Whether the performance is formally evaluated

2.2.8 Augmented Musical Instruments

One popular convention in new musical instrument design is to augment musical instruments with computers, high technology/legacy controllers and a diverse variety of sensors. In other words, designers pair processing power and conventional controllers through wired or wireless protocols with acoustic or electronic musical instruments or other devices in order to alter, improve or extend the inherent capabilities of musical devices. From this perspective, *augmented instruments can be a bridge between traditionally established musical instruments and novel digital* interfaces (Schramm et al., 2018). *Extended*, *expanded, electronically excited*, *smart, hyper, meta* and *hybrid* are among the terms that are used to define different types of augmented musical instruments based on various technological interventions. Irrespective of technological variations, augmentation heavily relies on the implementation of sensors. Hence, Medeiros and Wanderley (2014) present very useful information in their comprehensive review of sensors in relation to sensor technology and application in the context of musical instrument design and musical interactions.

Schiesser and Schacher (2012) state that the design and development of augmented instruments can be traced back to the days when the miniaturization of computing technologies enabled electronic components (e.g. tiny computers, micro-controllers, sensors and transducers) to be added to musical instruments. In regards to form factor, augmentation of musical instruments can either be embodied similar to acoustic instruments or they can physically separate the controller interface from the sound generator.

Musicians and designers may have many different reasons to augment existing musical instruments: *in order to enhance control* (Schiesser & Schacher, 2012), *extend sonic capabilities* (Pardue et al., 2019) or to *repurpose the performer's existing skill and technique on a traditional instrument* (Pardue et al., 2019). The augmentation can be done in order to improve performer-instrument interaction, to explore alternative sound generation methods, or both. (Schramm et al., 2018) Furthermore, an augmented musical instrument may also be designed in relation to realize a specific musical composition or a live musical performance (McPherson & Kim, 2012).

An example of an augmented instrument; the augmented violin ‘*Svampolin’* (Pardue, et al., 2019) is presented in Figure 2.19:

Figure 2.19 ‘Svampolin (Pardue et al., 2019)

However, when the instruments are augmented with controllers that feature excessively with multiple knobs or sliders, this strategy gives birth to sophisticated and complex user interfaces instead of musically inspired ones. Additionally, musicians may need to consult a user manual in order to set-up, learn, memorise and eventually use these instruments. Concepts associated with traditional acoustic instruments such as ‘immediate sound generation’ or ‘immediate interaction’ may not apply to this group of instruments unless the musician is already very experienced with similar kinds of gear.

Patten et al. (2002) point out interaction problems caused by the complexity of such augmented user interfaces:

> Knobs and sliders are almost too modular: musicians spend more time remembering what each knob does than focusing on the performance. Furthermore, these interfaces lack an expressive character, and it is difficult to control multiple parameters at once. (p. 148)

Schiesser and Schacher (2012) express similar concerns:

> Depending on the degree of awareness necessary to control these additional layers, the instrumentalist may face a lack of mental resources necessary to play at the same time an acoustic instrument and a controller at a virtuoso level.

2.2.8.1 Augmenting Existing Musical Instruments

Augmenting existing musical instruments has been a very popular research interest since the early days of new musical instrument design. Many diverse practice-based research studies have been carried out to augment traditional acoustic, electric, electronic and even ethnic musical instruments. Noteworthy examples include: augmented **violin** (Overholt & Gelineck, 2014; Pardue et al., 2019), **classical guitar** (Meneses et al., 2018; Morreale et al., 2019), **double bass** (Liontiris, 2018), **violoncello** (Eldridge & Kiefer, 2017), **mandolin** (Turchet & Barthet, 2018), **piano** (Berdahl et al., 2005; McPherson & Kim, 2012; Dahlstedt, 2015; Granieri & Dooley, 2019), **timpani** (Sello, 2016), **drums** (Champion & Zareei, 2018), **clarinet** (Normark et al., 2016), **trumpet** (Reid et al., 2016; Neill, 2017), **saxophone** (Flores, et al., 2019), **flute** (Heller et al., 2017), **trombone** (Snyder et al., 2018) **traditional South American plucked string instruments** (Brazilian Cavaquinho, the Venezuelan Cuatro, the Colombian Tiple and the Peruvian/Bolivian Charango) (Arango & Iazzetta, 2019), **didgeridoo** (Hindle & Posnett, 2017), **trombo marina** (medieval instrument) (Baldwin et al., 2016) **digital keyboard** (Dahlstedt, 2017; Dahlstedt, 2019), and a **theremin** (Gibson, 2018).

2.2.8.2 Augmenting Non-Musical Objects

Augmentation is not necessarily limited to existing musical instruments. There is an ongoing trend within the new musical instrument design community to sonically augment non-musical objects. Since it is possible to transform any object into a musical instrument with the integration of various electronic components and sensors, a diverse spectrum of prototypical research reveals extremely unorthodox sonically augmented objects. The main motivation behind augmenting non-musical objects is based on *giving objects a 'voice' through technology* (Delle Monache et al., 2008; Van Troyer, 2012). Furthermore, these *everyday musical instruments* (Delle Monache et al., 2008) are most often easy to use, easy to engage and inviting for musicians with different levels of experience.

One of the earliest examples in relation to everyday-life media is a project carried out by Mase and Yonezawa (2001), who sonically augmented clothes, water and stuffed dolls to create augmented musical instruments. Similarly, Savary et al. (2012) used sand and water through their prototypical instruments called Dirty Tangible Interfaces. Other liquid based augmented instruments have been designed by Lerner (2017) and Arbel et al. (2019) who created an electromagnetically excited musical instrument with several partly-filled wine glasses.

Delle Monache et al.'s (2008) research on sonically augmenting found objects and Van Troyer's (2012) tangible step sequencer that transforms everyday objects into percussive musical instruments both provide novice users means for musical self expression and immediate engagement. Similarly, Gerhard and Park (2012) propose a device called 'the instant instrument anywhere' (IAA) which can be attached to any metal object to transform it into a musical instrument.

Other diverse examples of sonically augmented objects include: **pendulum** (Henson et al., 2012), **a spray can,** which uses the spray paint art metaphor (e.g. spray, grip, shake, swing, draw, mask) to generate sounds (Park & Lee, 2013), **authentic museum artefacts** (geological samples and fossils) (Bowers & Shaw, 2014), **games; chess-board** (Tveit et al., 2014) **peg solitaire** (Keatch, 2014)**, dice used in tabletop role playing games** (Berndt et al., 2017), **Rubik's cube** (Mannone et al., 2018), **computer keyboard** (Waite, 2015; Nash, 2016), **typewriter** (Lepri & McPherson, 2018), **iron and wooden ironing board** (Schedel et al., 2019), **a wooden tobacco pipe** (Feldt et al., 2015), in which the interaction is based on breath control; using sips and puffs as control input, **bicycle wheels and a skateboard** (Lind & Nylén, 2016) as a collaborative musical instrument, **door and its knobs** (Kleinberger & Van Troyer, 2016). Stretching possibilities even further, Brown et al. (2015) used a 3D model obtained from CT scans of a **dinosaur skull** (Corythosaurus) to design a musical instrument and sound installation based on the hypothesised sounds of the extinct dinosaur (Figure 2.20).

Figure 2.20 'Rawr!' being played at Arizona State University's Emerge 2013 Festival (Brown et al., 2015)

Augmentation can also be done in the opposite direction. Bowers and Archer (2005) propose the concept of infra-instruments; a species of instruments in total contrast to numberless design led research efforts on augmented hyper-, meta- and cyber-instruments. Bowers and Archer's design-led research downgrades the abilities of various conventional musical instruments by physically breaking them down to their components and re-building them up with restricted interactions through the integration of various sensors. Resulting instruments feature a low ceiling for virtuosity, however, the authors argue that they are extremely easy to use. Bowers and Archer further propose that especially for musicians who use multi-device performance settings, the restricted interaction techniques of infra-instruments enable the performer to free one hand for other purposes; such as engaging with other instruments and devices.

2.2.9 Wearables

Wearable instruments – or shortly 'wearables' – constitute an important part of research concerning new musical instrument design. While gloves seem to be the most popular wearable instruments, the possibilities are not limited to hands. Substantial amount of research has been carried out in order to explore new interactions, gestural possibilities and musical expressions utilizing the whole of the human body as a controller and musical instrument.

One of the pioneering and most famous wearable instruments is Michel Waisvisz's *'The Hands'* (Figure 2.21) (Krefeld, 1990; Torre et al., 2016). Exhibited by Waisvisz in 1984 for the first time, *The Hands* (Figure 2.22) is composed of a pair of data gloves equipped with a diverse array of sensors.

Figure 2.21 Michel Waisvisz performing with The Hands (photo credit unknown).

Waisvisz designed and developed hands for almost a quarter of a century through an iterative process, resulting in three versions (Torre et al., 2016). One interesting aspect of this wearable instrument is that while the third and definitive version is a fully finished product, which considers both design and comfort of wearability, all three version of *The Hands* are wired instruments. However, Torre et al. explain that this was an informed choice rather than being dictated by the technological challenges concerning the wireless communication protocols in the early 2000s.

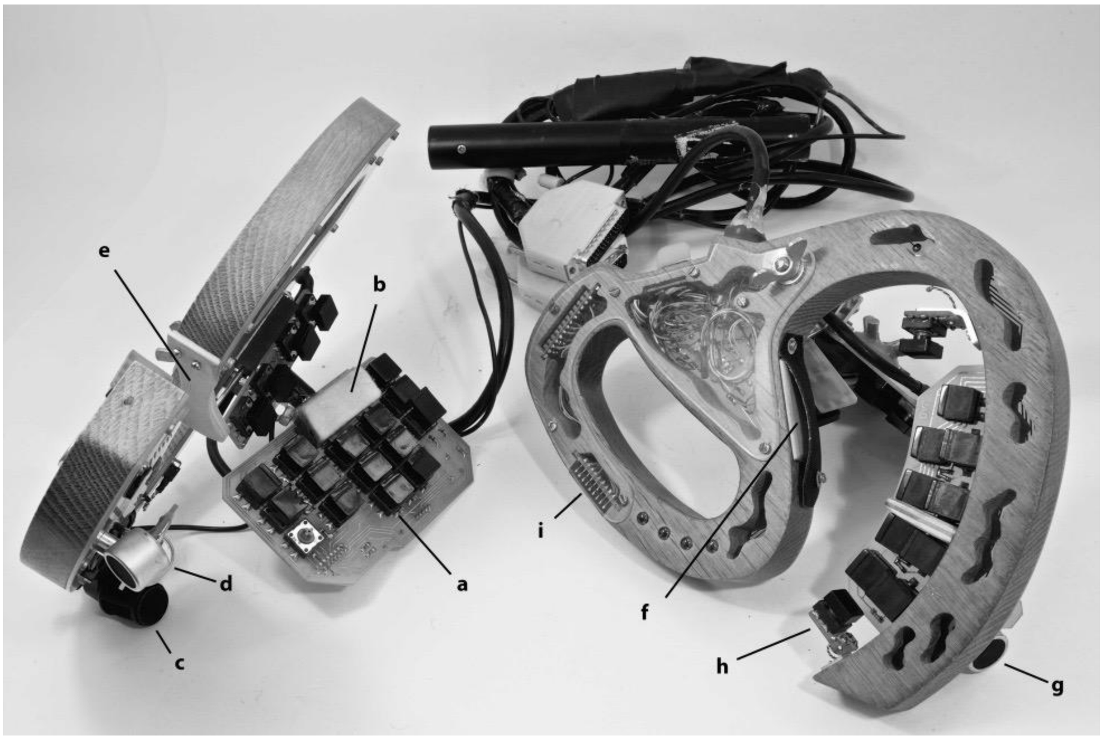

Figure 2.22 The Hands version 3 (Photo courtesy of Daniel Buzzo.) (Torre et al., 2016).

Left-hand data glove on the left; right-hand data glove on the right. Labelled components: pitch keys (a), pressure sensor (second pressure sensor in same location as f) in right hand (b), clip microphone (c), one of the three ultrasonic receivers (d), potentiometer (e), ultrasonic transmitter (g), a close up of the thumb momentary switches (h), side of the four-character display board (i) (Toree et al., 2016)

The Hands paved the way for generations of instrument makers who have been inspired by Waisvisz's work and followed in his footsteps. Among the noteworthy examples are: *FutureGrab* (Han et al., 2012), a wearable hand controller which maps human vowel pronunciation to hand gestures; *Soundgloves* (Lai & Tahiroğlu, 2012), three different glove instruments designed to enhance the communication flow between the performer and the audience; *Hand-Controller* (Pardue & Sebastian, 2013) a new wearable hand interface designed to feature detailed control of audio and visual parameters; *Finger-Synth* (Dublon & Paradiso, 2014), a musical bracelet and set of rings, which enable its player to generate sound by touching any surface in their environment; *Glove* (Myllykoski et al., 2015), a musical glove designed and developed for music pedagogical use; *Kontrol* (He et al., 2015), a wearable hand controller designed for physical gesture acquisition for Guqin (a 3000 years-old

Chinese fretless stringed instrument) performance; *Leimu* (Brown et al., 2016), a gloveless musical interface using a wrist-mounted leap motion; *Ghostfinger* (De Jong, 2017) a dynamic audio-visual fingertips controller; *Alto.Glove* (Thorn, 2018) a glove controller designed to extend performance abilities on a violin; and *Locus* (Sardana et al., 2019) a glove controller designed to interact with an immersive high density speaker array environment.

The *Mi.Mu. Gloves (Heap, 2013)*; the brainchild of technology innovator and Grammy artist Imogen Heap, deserves special attention for being one of the very rare new musical instruments, which received global recognition and commercial success. Mi.Mu. Gloves allow the performer to 'sculpt' music through gesture and movement (Voutsinas & Haefeli, 2017). According to the instrument's website, *Mi.Mu. Gloves* (Figure 2.23) offer unparalleled expressive control for both composition and live performance. *Mi.Mu. Gloves* have been developed by Imogen Heap alongside researchers at the University of the West of England in Bristol and since its introduction in 2013, *Mi.Mu.* Gloves have been used by vocalists, pianists, beat boxers, guitarists as well as artists controlling live visual projections. The instrument has also been used by Ariana Grande on her world tour in 2015 (mimugloves.com).

Figure 2.23 Imogen Heap, during a performance with her Mi.Mu. Gloves (YouTube).

In addition to hand controllers, various research projects have been carried out unique approaches to wearables. Examples include **arm bands** (Nymoen et al., 2015; Jensenius et al., 2017; Martin et al., 2018), **full-body suits** (Wilcox, 2007; Vetter & Leimcke, 2017; Bhumber et al., 2017; Lamounier et al., 2019), **shoes** (Murray-Leslie & Johnston, 2017; Konovalovs et al., 2017)

Hattwick et al. (2014) explore four different manufacturing approaches – artisanal, building block, rapid prototyping and industrial – to create what they term as *prosthetic instruments* (Figure 2.24); wearable controllers designed to be worn as hypothetical prosthetic extensions to the body with unique constraints and opportunities beyond the ones available in conventional interactive dance systems. Hattwick et al. discuss prosthetic instruments from the perspectives of both aesthetics and professional performance.

Figure 2.24 Violinist Marjolain Lambert plays the Ribs on dancer Sophie Breton (left), Sophie Breton wearing the Visor (right). Photograph credit: Michael Slobodian.

A most unique approach; Play-a-Grill (Chacin, 2011) combines a digital music player with a grill (mouth piece jewellery) (Figure 2.25). As the instrument is worn over the teeth, sounds can be transmitted through bone conduction hearing instead of headphones or speakers.

Figure 2.25 Functionality of Play-A-Grill (Chacin, 2011).

2.2.10 Virtual (Software) Musical Instruments

Virtual instruments (also known as software instruments or ‘soft-instruments’) came to existence thanks to the advancements in the fields of computer science and various engineering disciplines. Silicon based CPUs and increase in speed/capacity of memory and storage, contributed to the creation of soft-instruments. The spectrum of virtual instruments features a wide range in regards to complexity, function and use context. On one pole of this spectrum, very capable and extremely sophisticated software instruments (e.g. Max/MSP) provide musicians unlimited means for composition, live processing and live performances. On the other pole, exists daily increasing – at an astonishing rate - musical ‘apps’ developed for various mobile platforms (i.e. smart phones, and digital tablets) with user-friendly graphical user interfaces (GUI), most of which are aimed at bringing music-making together with novice/hobbyist users. One of the most widespread and well received examples of mobile musical apps is Smule’s Ocarina (Wang, 2009). To use Ocarina, the performer blows into the microphone of the iPhone, while using different fingerings to control pitch, and the accelerometer to control vibrato (Figure 2.26). Furthermore, Ocarina allows performers from around the world to share music through a centralized network.

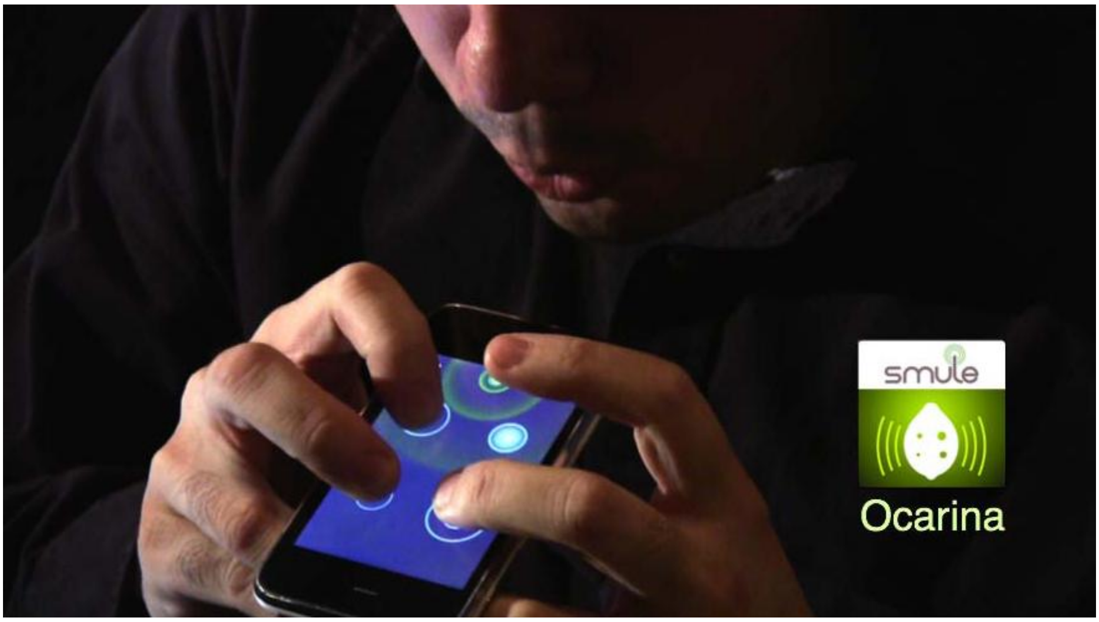

Figure 2.26 Smule's Ocarina in action (Wang, 2009).

However, in most cases, the virtual instruments designed for professional use contexts require an advanced level of computer language and coding skills. An example of a complex Max/MSP instrument patch is shown in Figure 2.27. These pre-requisites make it very challenging for musicians to interact with the soft-instruments intuitively. Most often than not, musicians are required to consult manuals and tutorials in order to fully understand, learn and use these instruments in their full capacity. Furthermore, as these instruments require a hardware platform to run such as laptop computers, digital pads or smart phones; keyboard mouse and touchscreen interactions replace musically inspired and intuitive interfaces and thus, become unfamiliar territory especially for traditionally trained musicians.

To review numberless musical software and apps would be beyond the scope of this thesis. Hence, this section will focus on research efforts, which employ creative and unique approaches as well as practice-based studies that try to improve issues common with laptop and touchscreen interactions. There exists a substantial amount of research aiming to improve the shortcomings of these devices not only for the audience (as mentioned in the Stakeholders section) but the performers as well.

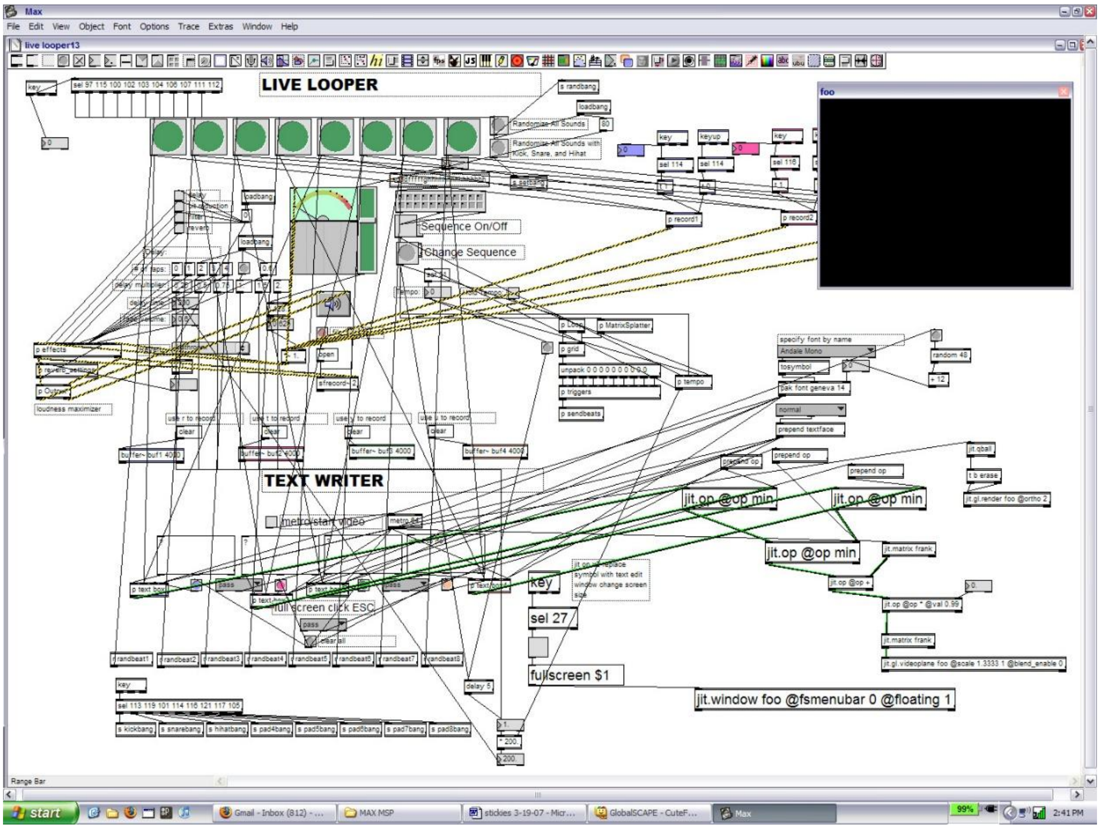

Figure 2.27 Max/MSP software GUI of a virtual instrument patch.

Taking a user-centred approach, Tanaka et al. (2012) conducted an online survey with music technology practitioners who have been using mobile phones musically, to inform the design of new mobile music apps. Themes such as *limitation of the touchscreen, lack of consistency in sensor input, latency, networked possibilities, toy-like music applications.* The authors report that by combining the aforementioned dimensions into high-level themes such as *Frustration to Potential, Workflow and Expressivity,* they reached two main areas: *device interaction* and *social interaction.* Based on these findings, Tanaka et al. (2012) proposed a mobile application with an adaptive graphical display interface that divides the mobile music workflow into composition and performance modes.

Berthaut et al. (2013) acknowledge the opacity of interactions in electronic music performances with laptop computers and propose a mixed-reality display system and a 3D visualization application in order to reveal the mechanisms of digital music instruments by amplifying performers' gestures with virtual extensions of sensors and representing the sound components with 3D shapes through dynamic graphical displays to the audience.

Park and Nieto (2013) address the lack of haptic feedback in touchscreen controllers and propose an easy-to-build robust and expressive system called *fortissimo (ff)*, which provides force-feedback for interacting with mobile musical instruments. Park and Nieto's proposal is very smart in the sense that it makes use of a very simple construction composed of an angular placement of foam padding and an accelerometer to effectively capture the pressure of the performer's gestures in real-time (Figure 2.28). The system maps the accelerometer readings to musical parameters such as tremolo, vibrato, and velocity. However, since the proposed system cannot improve the material properties and homogeneity of the touchscreen, the common problems related with touchscreen interaction (i.e. tactile richness, micro-control) remain to be solved.

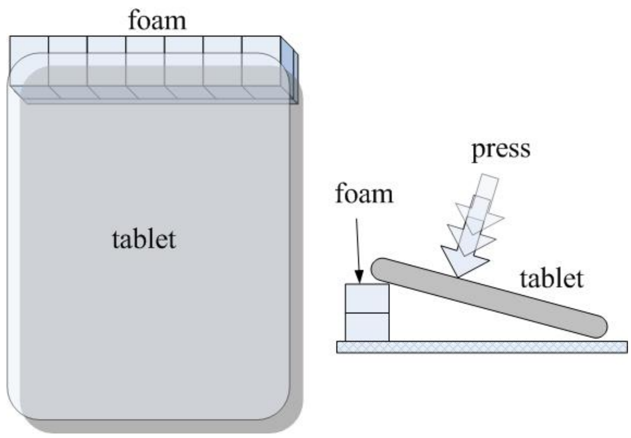

Figure 2.28 Typical fortissimo setup, from a top view (left) and side view (right) (Park and Nieto, 2013)

Sarier (2014) argues that current control paradigms concerning touchscreen musical interfaces do not require the same level of physical effort, which in turn negatively affects the musicians' experience in relation to expressiveness, engagement and enjoyment. Hence, Sarier proposes *Rub Synth;* a touchscreen musical instrument with an exertion interface; which features artificial physical difficulty and an intentionally inefficient interaction. According to Sarier, creating physical difficulty can enhance user experience by *allowing greater bodily expression, kinaesthetic feedback, more apparent skill acquisition and performer satisfaction*.

Similarly, Berdahl et al. (2016) explore ways to improve haptic interactivity of touchscreen interfaces through the electromagnetic actuation of 3D-printed conductive vibrotactile tokens. The authors use interaction metaphors such as:

plucking virtual harps and strings and crossfading with a joystick, with different tokens in order to test their prototype on mobile devices.

Lim and Yeo (2014) further extend the performing abilities of mobile musical instruments to conducting. The authors propose to replace the conducting baton with a smartphone, through mobile music interface called *vMaestro;* which can capture conducting motions, enabling the conductor to control the tempo as well as improve traditional cueing for different instruments/sections of the orchestra.

Meacham et al. (2016) explore unconventional ways to interact with laptop computers in order to improve performer-instrument interaction and pleasure in use, based on familiar music-making metaphors. The authors suggest that recontextualizing existing musical gestures offer new aesthetic and expressive possibilities for commodity hardware. The *'Laptop Accordion'* utilizes the opening and closing of the laptop screen as a physical metaphor for the stretching and compression of accordion bellows and the laptop keyboard as a musical buttonboard (Figure 2.29). The system uses the laptop camera for motion tracking and maps this interaction to the volume of the real-time sound synthesis. Meacham et al. also propose that repurposing widely-available computing devices are approachable for inexperienced musicians as well.

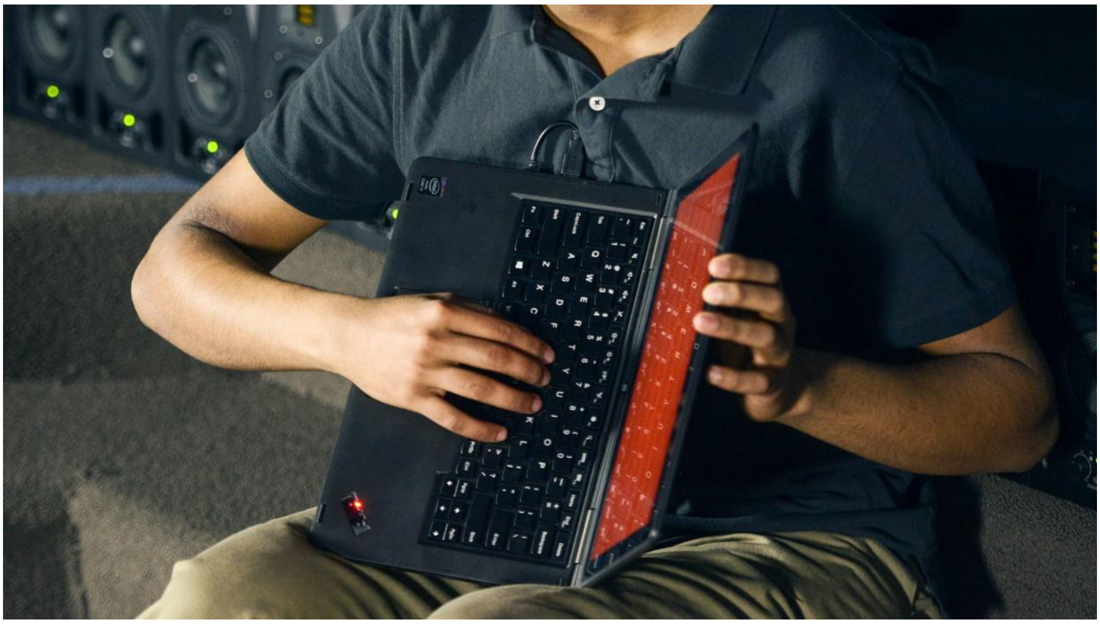

Figure 2.29 The Laptop Accordion (Meacham et al., 2016)

Cavdir et al. (2019) approach the subject matter with very similar concerns, and explore ways to take advantage of the physical affordances of laptop computers. The authors explore innovative ways to make use of built-in laptop components such as microphones, cameras, trackpads keyboards and accelerometers and discuss the evolution and evaluation of three embodied physical laptop instruments: *Taptop, Armtop and Blowtop*. The names of the instruments suggest the performer's respective gestures and bodily interactions. *Taptop*'s interaction model is essentially built around the trackpad's multitouch recognition feature. *Armtop* builds on *Taptop* by adding a tether to the laptop interface for the performer's free hand. The performer uses the trackpad for real-time sound generation while the arm swings control the vibrato and tremolo effects on the sound through stretching and extending the tether forward. *BlowTop* primary interaction utilizes the laptop's microphone to capture breath pressure in order to amplify a synthesized flute sound while the instrument also uses tilt motion to detect movement in three directions through its accelerometer. Cavdir et al. explain that all three instruments are essentially based on existing traditional instruments; *ArmTop* is played through expressive gestures of cello playing, BlowTop adopt a flute interaction where as the TapTop focuses on the sound itself and uses a string instrument interaction. Through performances of specific compositions, the authors also explore how these embodied interactions affect the communication between the performers and the audience as well.

Wang (2016) on the other hand, explore the dynamics at the intersection of video games and music; presenting observations and strategies for designing game-like elements for expressive mobile musical interactions. By discussing five popular mobile music apps (*magic piano, magic fiddle, magic guitar, ocarina and leaf trombone;* collectively reaching 125 million users) through case studies, Wang presents common goals as: *lower inhibition for music-making by presenting expressive musical experiences as games, create satisfying core music-making mechanics aimed to induce a sense of flow*, and *motivate longer-term engagements through social and peripheral gamification.* Wang suggests that game-like musical interactions aim to invite and engage users while maintaining and encouraging musical expression and exploration.

Michon et al. (2016), employ a design strategy based on the concepts of ‘augmented mobile device’ and ‘hybrid physical model controller’ and present an iPad-based musical instrument named *BladeAxe*, which partly uses the form factor of an electric guitar (Figure 2.30). According to Michon et al., the instrument is fully standalone and can be easily used on stage through connection to a traditional guitar amplifier or a sound system. Furthermore, the instrument also features an acoustic plucking system to provide the performer an extended expressive potential. Michon et al. also suggest that *BladeAxe* paves the way to a new class of instruments called *‘mobile device based hybrid musical instrument’*.

Figure 2.30 The BladeAxe (Michon et al., 2016)

In a very similar approach, Michon et al. (2017) propose a framework for designing and prototyping passive mobile device augmentations in order to transform mobile devices to mobile musical instruments. Michon et al.’s system makes use of an open-source computer aided design (CAD) software to 3D print various augmentations for mobile devices. These augmented prototypes include cases, generic passive amplifiers, horns and mouthpieces, which not only alter the form factor of the smart phones but also transform the performer-instrument interactions to more familiar and musically inspired models.

2.2.11 Collaborative Musical Instruments

Concerning traditional and mainstream musical instruments, multi-performer interactions on a single musical instrument is not a common convention. The only exceptions being occasional collaborations on a piano or percussive set-ups, which are most often either composition specific (e.g. Schubert's Sonata in C Major for piano four-hands) or improvisational (spontaneous collaborations in jazz concerts) contexts. It is reasonable to propose that one of the paradigm-shifts surrounding new musical instrument design led to the emergence of three classes of collaborative instruments:

1. Single musical instrument performable by multiple musicians
2. Identical multiple musical instruments – communicating with each other – performed by multiple musicians
3. Different musical instruments 'talking to each other' through various communication protocols, performed by multiple musicians

Concerning the first class, Reactable (Jordà, 2003) is one of the best examples because it allows for both multi-user and single-user interactions (Figure 2.31).

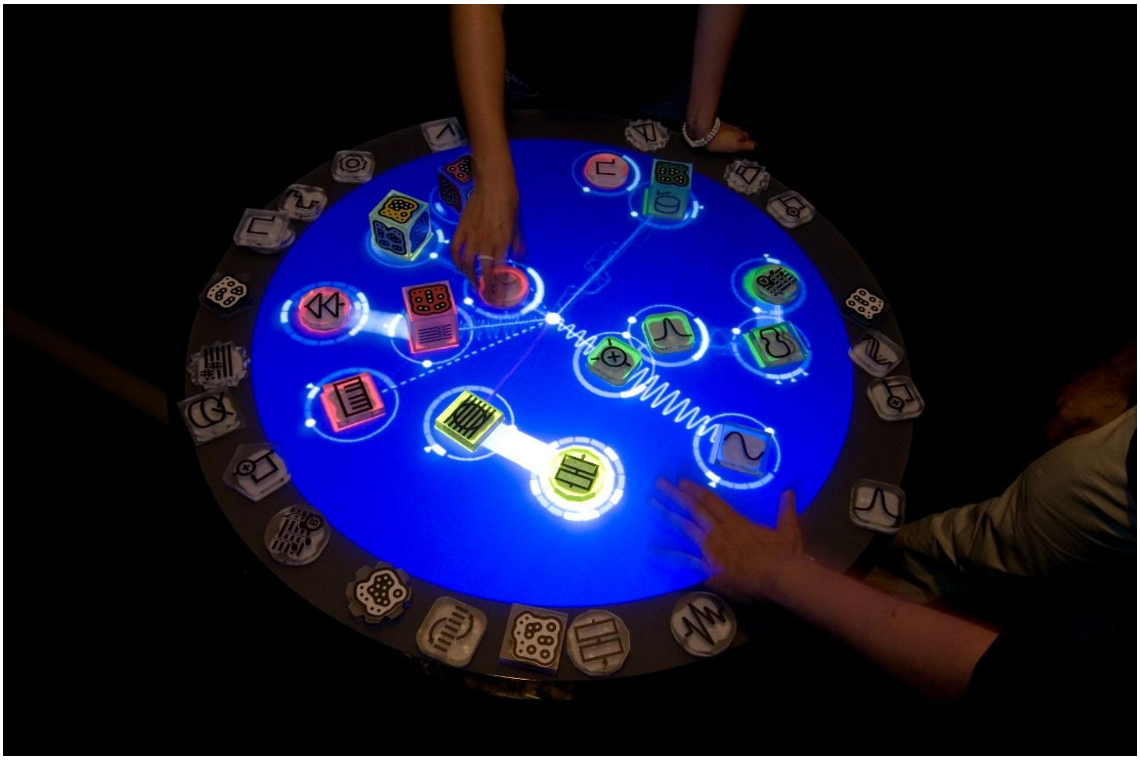

Figure 2.31 Reactable ((Jordà, Geiger, Alonso, and Kaltenbrunner, 2007))

However, some musical instruments are intentionally designed in such a way that collaborative interaction is a prerequisite for proper operation and functionality.

Rotondo et al. (2012) explore this type of collaborative interaction through two prototypical instruments called *Feedbørk* and *Barrel*. *Feedbørk* is a two-player instrument comprising two iPads. When the iPads face each other, the recurring video feedback loop is used for sound generation. Barrel is performed by eight symmetrical Gametrak controllers operated by eight performers arrayed around a steel barrel. The ninth player who stands atop of the barrel assumes the role of conductor, directing the remaining performers through various gestures. Rotondo et al. report that relationships between the roles of the performers has a significant effect on communication between the performers and the audience's perception of the performance.

Zamorano (2012) employs a similar approach and explores collaborative performance possibilities aimed for non-musicians through a prototype interactive sound system. The system – titled *Simpletones* – allows users to create simple compositions in real-time by collaboratively playing physical artefacts as sound controllers. Zamorano uses an interaction model that makes 'collaboration' mandatory by physically configuring the artefacts to require coordinated actions between the performers to control sound, hence emphasising on collectivity and communication in music-making.

Barraclough et al. (2014) explore collaborative interaction through the modularity concept. Their proposed system – titled *Modulome* – is a modular controller with application dependant use cases (Figure 2.32). Barraclough et al. acknowledge the often criticized obscurity of electronic music performances with laptops and smart phones, and attempt to avoid this issue by using a variety of interactive and interdependent hardware control modules, linked through wireless communication.

Figure 2.32 Button-pad module (left), Encoder module (centre) and Fader module (right) (Barraclough et al., 2014)

In the literature, most of the collaborative interactions based on multiple identical instruments are based on mobile/smart devices due to their availability and technological capabilities.

Lee et al. (2012) propose to use mobile iOS devices as ‘drumsticks’ through their collaborative instrument app called *Tok!*. According to the authors, users can make acoustic music with Tok! By tapping their mobile phones on flat surfaces. The system is networked features a shared interactive music score to which, the users can tap their phones and create a real-time collaborative percussion ensemble.

Tahiroglu et al. (2013) explore the dynamics of collaborative interactions through a system that uses mobile phones as tangible and expressive musical instruments in parallel with a spatial system. The environment created by the mobile phones and motion tracking technology enables performers to move and interact with each other with a twist: their social interactions also contribute to the sonic outcome.

Ramsay and Paradiso (2015) report a browser-based collaborative audio feedback control system titled *GroupLoop*. As the system is based on laptops and connectivity, it is suitable for users across all skill levels and geographies. The authors suggest that starting the interface is as easy as opening a browser on a laptop, but it provides enough flexibility for complex sonic designs and virtuosic mastery. Furthermore, performers can share their microphone stream with each other, while simultaneously controlling the mix of other performers’ streams played through their speakers. Ramsay and Paradiso explain that GroupLoop can be used by experienced players in a shared space or by novices around the world through simultaneous linked remote systems.

In a similar effort to explore remote collaborative interaction, Tome et al. (2015) argue that social platforms can be used to change the world of music creation. The authors report their project titled *Massively Multiplayer Online Drum Machine (MMODM)*, an online collaborative interface based on the Twitter streaming API, which uses tweets from around the world to create and perform musical sequences together in real-time. According to Tome et al., users can create 16-beat note sequences across 26 different instruments through plain text tweets on a variety of mobile devices. Furthermore, user on the drum machine’s dedicated website can use the GUI to locally DJ the rhythm, filters and sequence blending. The authors claim that MMODM opens a new path towards synchronous musical collaboration between users across a wide range of devices and cultures.

The collaborative interaction possibilities with new music making paradigms also extend to sonic augmentation of spaces. Knichel et al. (2015) report their collaborative tangible musical installation titled *Resonate,* which allows visitors to interact with different objects collectively to influence both the musical expression and visual response of the installation. Knichel et al. conceptualized the installation as a *huge musical instrument responding to visitors' interaction.* The system is composed of eight components with inbuilt speakers and a display. Tangible interaction is provided through elastic cords that were attached to each component and the ceiling. Through ultraviolet illumination, these cords were turned into attractive visual focus points inviting the visitors to collectively interact with them (Figure 2.33).

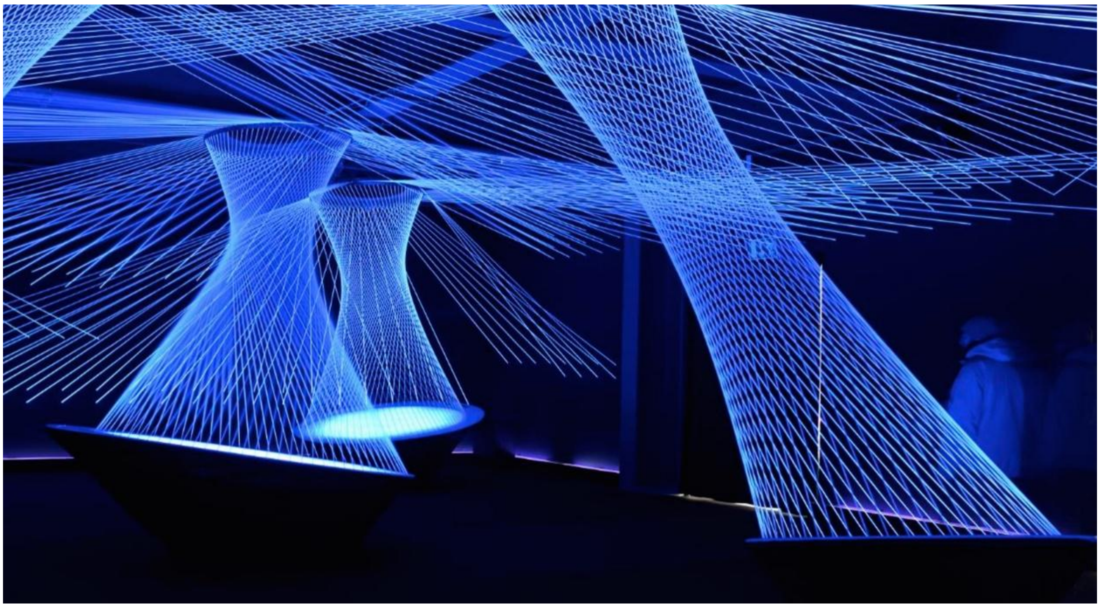

Figure 2.33 Resonate installation in a museum (Knichel et al., 2015).

Hattwick and Wanderley (2012) argue that much of the literature regarding the creation of new musical instruments is focused on individual musical expressivity. Hence, the authors propose a dimension space representation (Figure 2.34) of collaborative approaches, which can be used to inform the evaluation and design of future collaborative musical instruments and interactions. Hattwick and Wanderley's dimension space presents six axes: *texture, equality, centralization, physicality, synchrony* and *dependence.*

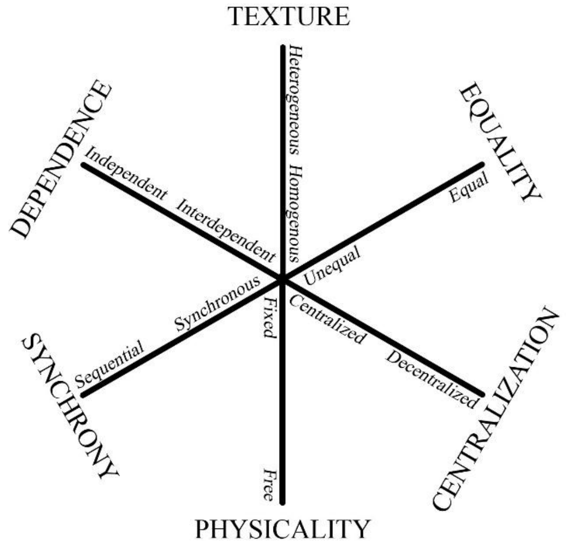

Figure 2.34 Collaborative dimension space (Hattwick and Wanderley, 2012).

This chapter has surveyed the literature concerning new electronic musical instrument design, exploring research efforts on theory building as well as key concepts and dimension related with new music making paradigms and new musical interactions. The main reflections of this survey are as follows:

The roles of the stakeholders in new musical interactions are evolving. This paradigm shift brings its particular complications as well as opportunities. Especially concerning the audience, co-creation of/participation in live performances is a completely new territory and promises further immersion and engagement. It may be interesting to propose that designer-performers and designer-performer-composers can be considered as a new generation of 'Renaissance' makers; however, literature agrees on the problems of longevity and isolation in regards to their creations.

It seems that controllers (i.e. decoupling) dominate the future of musical instrument design thanks to the flexibility they offer to musicians in relation to the diversity of use contexts, creative intentions and musical genres. Personalization and customization has become common practise in the greater field of design and it seems musical instruments are no exception. Hence, controllers provide the users more means and ‘space’ for re-designing both their instruments and the ‘end product’ (i.e. sound) from scratch.

While augmentation has been a familiar practise for acoustic musical instruments especially during 20th and 21st centuries (e.g. John Cage’s prepared pianos) the concept has been taken to a totally different level thanks to the technology intervention. The extent of the spectrum of augmented instruments; both based on traditional instruments and everyday objects prove that ‘anything’ equipped with sensors and processors can become a musical instrument.

Visual interactivity has become the predominant ‘norm’ for majority of the new generation DMIs. In fact, visual feedback and feed-forward are a prerequisite for the proper operation for many of these instruments. This is contradictory to the existing lineage of musical interactions and may cause adaptation problems especially for musicians coming from traditional training/backgrounds.

Wearables (i.e. wearable instruments) and collaborative/collective interactivity are concepts that are gaining more significance in connection to the exploration of further expressiveness and creativity. Software instruments and music ‘apps’, especially in the context of mobile communication devices, are among noteworthy examples of this new species of instruments, which owe their existence partly to the technological progression of every day interactive consumer products.

Exploring these concepts in new musical instrument design also alerted the author to the terminology likely to be used in the research. Many of these key concepts formed the foundation for the dimensions of new musical interactions and product/design qualities which are discussed as the main findings of this thesis.

The following chapters of the thesis focus on the employed research methodology, the user-centred experiment, results and the contributions of the work.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 The Psychology of Personal Constructs

The methodological background of this user-centred research is based on a theory called ‘The Psychology of Personal Constructs’, which was developed by George Kelly in 1955. Kelly suggests that all human beings strive to make sense of the universe and interpret the world of events ‘uniquely’ by construing the world around themselves.

In other words, every person has their own view of the world (theory) and they drive hypotheses (expectations) from their own theories (personal construing). They then subject those hypotheses to experimental testing (behaviour), modify their theory and then the whole process is repeated again, becoming an ongoing cycle (Fransella et al., 2004, p. 6).

This interpretation suggests that the act of construing is a dynamic process. According to Kelly (1955), humans feel the need to constantly re-shape and re-adapt their interpretations of the world to confirm the validity of their interpretations and better fit them to the changing circumstances and environments. The creation and re-creation of this implicit theoretical framework is identified as an individual’s <u>Personal Construct System</u> (Fransella et al., 2004, p. 5). As a personal system is made up of a whole lot of constructs, such a system can be interpreted as a complex conceptual grid, within which, events can be seen in depth (Kelly, 1959, p. 13 as cited in Fransella et al., 2004, p. 7).

3.1.1 The Basic Theory

Kelly (1955) laid down his basic theory through a fundamental postulate: "A person's processes are psychologically channelized by the ways in which he anticipates events"; and then elaborated upon this postulate with the help of eleven corollaries.

Among Kelly's eleven corollaries, construction corollary, dichotomy corollary, individuality corollary, commonality corollary and organization corollary are directly relevant to this research and thus, they will be explored further below.

3.1.1.1 Construction Corollary

Humans look at the world through transparent patterns or templates, which they create and then attempt to fit over the realities of which the world is composed. Regardless of how successful these attempts are; these templates or patterns are called 'constructs' (Kelly, 1955, pp. 8-9). Kelly also refers to constructs as "a way in which two or more things are alike and thereby different from a third or more things" (Fransella et al., 2004, p. 7).

"A person anticipates events by construing their replications". (Kelly, 1955, p. 50).

> Construing. By construing we mean "placing an interpretation": a person places an interpretation upon what is construed. He erects a structure, within the framework of which the substance takes shape or assumes meaning. The substance which he construes does not produce the structure; the person does. (Kelly, 1955, p. 50)

The commonality among all of Kelly's definitions of a construct is that <u>constructs are bipolar</u>. According to Kelly we make sense of our world by simultaneously noting likeness and differences and it is in this contrast that the usefulness of the construct subsits (Fransella et al., 2004, p. 7).

3.1.1.2 Dichotomy Corollary

"A person's construction system is composed of a finite number of dichotomous constructs". (Kelly, 1955, p. 59).

Kelly argues that it is more useful to see constructs as having an affirmation pole and a negative pole rather than see them as concepts or categories of a unipolar pole (Bannister & Fransella, 1986, p. 12). Thus, it is the bipolarity of a construct that distinguishes it from a 'concept' (Fransella et al., 2004, p. 7). Bannister and Fransella (1986, p. 12) also suggest that it is often the opposite pole of a personal construct that gives the clear meaning of a that construct. The bipolarity in constructs allow us to envisage a variety of relationships between them; as they can be correlated or logically interrelated in many ways.

3.1.1.3 Individuality Corollary

"Persons differ from each other in their construction of events". (Kelly, 1955, p. 55).

Bannister and Fransella argue that the fundamental mystery of human psychology is covered by the question: 'Why is it that two people in exactly the same situation behave in different ways?'. The answer lies in the fact that those two people are actually not in the same situation because each of us sees our situation through the 'googles' of our personal construct system and the 'perceived similarity' does not derive from having same experiences, but because people have placed the same interpretations on the experiences they have had (1986, p. 10).

3.1.1.4 Commonality Corollary

Even though the commonality corollary seems to contradict the individuality corollary, they actually complement each other. While people differ from each other, there is a possibility that there may be certain respects in which persons can be construed as being like each other (Kelly, 1955, pp. 91-92).

"To the extent that one person employs a construction of experience which is similar to that employed by another, their processes are psychologically similar to those of the other person." (Kelly, 1955, p. 90)

> If a person's processes are psychologically channelized by the ways in which he anticipates events, and if he anticipates events by construing their replications, it may seem obvious that we are assuming that, if two persons employed the same construction of experience, their psychological processes would have to duplicate each other (Kelly, 1955, p. 90).

3.1.1.5 Organization Corollary

Kelly (1955) suggests that not only do man differ in their construing of events, but they also differ in the ways they organize their constructions of events. While being relatively more stable than the individual constructs themselves, the construction system which is composed of those individual constructs is also dynamic and ever-changing (p. 56).

> Each person characteristically evolves, for his convenience in anticipating events, a construction system embracing ordinal relationships between constructs. (Kelly, 1955, p. 56)

Additionally, Kelly (1955, pp. 57-58) also states that this construct system is of hierarchical nature, where there may be many <u>levels of ordinal relationships between the constructs.</u> People systemize their constructs, by arranging them in hierarchies or abstracting them further, through creating what Kelly calls 'superordinate' and 'subordinate' relationships between the constructs (Kelly, 1955, p. 58; Fransella et al., 2004, p. 9).

This section of the chapter briefly explores Kelly's psychology of personal constructs theory only through the points, which are relevant to this research. The next section of the chapter explores the practical applications of the theoretical framework, which is based on a methodology called 'Repertory Grid Technique'.

3.2 Repertory Grid Technique

Kelly (1955) first introduced the 'Repertory Test' (or Rep Test) as a new diagnostic instrument, *which was an attempt to apply the theoretical thinking behind the psychology of personal constructs to the practical needs of the psychotherapist (*p. 219). Kelly (1955) initially called this methodology 'Role Construct Repertory Test' (or shortly Rep Test) and he stated that the Rep Test was an instrument for eliciting personal constructs; designed to be used in a clinical or preclinical setting. The test soon became to be known as the ‘Repertory Grid’ (Bell, 2003). Bell (2003, p. 95) suggests that repertory grid technique (from hereon RGT) is not independent of the personal construct theory (Bannister & Fransella, 1986); in fact, the theory’s fundamental postulate forms the basis for RGT’s framework:

> Kelly’s Fundamental Postulate says that *a person’s processes are psychologically channelized by the ways in which he anticipates events*. That underpins the repertory grid. The *ways* are the constructs of a repertory grid, and the *events* are the elements. The technique of the repertory grid thus involves defining a set of elements, eliciting a set of constructs that distinguish among these elements, and relating elements to constructs.

In order to further elaborate on the methodology, a definition for the term ‘grid’ (or repertory grid) is required. Fransella et al. (2004) suggest that grid is actually another way Kelly uses to state his theory of personal constructs; “it is personal construct theory in action”.

> Now let us turn to a personal system made up of a whole lot of constructs. Such a system is complex, or, if you don’t mind the term, a conceptual grid within which events can be seen in depth or in their psychological dimensions (Kelly, 1959, p. 13 as cited in Fransella et al., 2004, p. 7)

Feixas and Cornejo (2002) define the repertory grid as “an instrument designed to capture the dimensions and structure of personal meaning”. Rather than being a ‘test’, RGT can be considered as a structured interview (Feixas & Cornejo, 2002; Fransella et al., 2004) which is designed to reveal the constructs with which persons understand, interpret and organize their experience of the world they live in.

In the organization corollary, Kelly (1955) mentions that a person’s constructs are organized as part of a hierarchical and integrated system. Bannister and Fransella (2004) propose that a grid is a way of getting individuals to tell you, in mathematical terms, the coherent picture they have of any given set of elements (p. 48). Furthermore, Bell (2003), suggests that this elicitation may result in both qualitative and quantitative data. “The identity of the elements and the nature of the constructs provide qualitative information while the relationships between the constructs and elements may be interpreted as quantitative data” (Bell, 2003). Thus, repertory grid does not only elicit a person’s constructs within a given context, but also enables the researcher to explore the structure of and the interrelations between those constructs that form any particular construct system.

Regarding RGT's flexibility, Feixas and Cornejo (2002) mention that RGT is not completely standardized like other psychological tests and therefore it must be designed and adapted based on the researcher's objectives, the general aim of the research and the types of assessment that will be carried out. A good understanding of how the RGT is administered and analysed, is required in order to make the decisions which determine the scope or focus of the grid as well as the type of information that will be obtained at the end of the study.

Basically, a full repertory grid consists of three parameters: (i) a series of elements that are representative of the content area under study, (ii) a set of personal constructs that the subject uses to compare and contrast these elements and (iii) a rating system that evaluates the elements based on the bipolar arrangement of each construct (Feixas & Cornejo, 2002). Similarly, Easterby-Smith (1980) define these three parameters as: 'elements' that define the material upon which the grid will be based; 'constructs', which are the ways that the subject is grouping and differentiating between the elements; and a 'linking mechanism' which can show how each element is being assessed on each construct.

Bannister & Mair define 'grid' as: "Any form of sorting task which allows for the assessment of relationships which yields these primary data in matrix form" (1968, p. 136; as cited in Easterby-Smith, 1980). Additionally, Smith's definition proposes to consider elements as being the objects of people's thoughts, and constructs as the qualities that people attribute to these objects (1978; as cited in Easterby-Smith, 1980). Following Kelly's (1955) original grid for his role construct repertory test, the format of the repertory grid is defined by a two-dimensional matrix, where the column data is composed of the elements and the row data is composed of the participant's bipolar constructs, and a 'mechanism' links the bipolar constructs to the elements (Easterby-Smith, 1980). These three parameters; (i) Elements, (ii) bipolar constructs and (iii) linking mechanisms that form a repertory grid are discussed as follows.

3.2.1 Elements

Kelly defines elements as "the things or events which are abstracted by a construct" and considers them as one of the 'formal aspects of a construct' (Kelly, 1955, p. 137, as cited in Fransella et al., 2004, p. 15). In a repertory grid, elements are the components which are evaluated by the participants and they set the context of the grid. Thus, the selection of elements must be based on the aspects of the interviewee's construing to be evaluated (Feixas & Cornejo, 2002).

In the clinical field, elements are usually the people who are representative of the subject's world (e.g. role titles such as teacher, wife, mother, employer, etc.) (Kelly, 1955; Feixas & Cornejo, 2002; Fransella et al., 2004). However, Fransella et al. (2004) suggest that elements can be almost anything such as objects, products, or artwork, etc. Elements can also be specifically designed for the repertory grid. In a study by Fransella (1978, as cited in Fransella et al., 2004) a standard body shape (for both genders) was altered by an artist, specifically for the repertory grid, to range from extreme thinness of a person with anorexia nervosa to extreme obesity.

Regarding the selection of the elements, the common practise is for the investigator to select them for the participant (Fransella et al., 2004). Fransella et al. suggest that there are two important criteria for choosing elements for a repertory grid. The first criterion is that the elements must be homogeneous (Easterby-Smith, 1980); in other words, they must be selected within the same range of convenience or area of interest (Yorke, 1985, as cited in Feixas & Cornejo, 2002). Kelly (1955) mentions this requirement in his range corollary as follows: "*Elements should be within the range of convenience for the constructs used"* (Fransella et al., 2004).

The second criterion is for elements to be representative of the area being investigated (Easterby-Smith, 1980; Fransella et al., 2004), in other words, they should reflect the context (Yorke, 1985, as cited in Fransella et al., 2004).

In addition, Easterby-Smith (1980) propose a third criterion stating that if the same grid is to be completed by a group of people, it is important to ensure that all the people in that group are able to relate directly to the elements specified. Yorke also supports this view, stating that the elements must be easily understood by the subject, must be coherent with those already employed by the subject, and must be within his/her capacity to understand (1985; as cited in Feixas & Cornejo, 2002).

In the context of this research, musical instruments were the obvious choice for ‘elements’ because they fulfil all three selection criteria mentioned above:

1. They are within the range of convenience for musician’s constructs (they will be the basis for the construction of design strategies and guidelines for new musical instruments),
2. The musical instruments, which are used in the study as ‘elements’ are specifically chosen to represent the broader area of new musical instrument design,
3. Thanks to the participant selection criteria, all professional musicians are able to relate directly to the musical instruments.

3.2.2 Constructs

As stated in Section 3.1.1.2, the essential attribute of constructs that allows the construction of a repertory grid is their bipolarity. Kelly (1955) describes poles as follows: “Each construct involves two poles, one at each end of its dichotomy. The elements associated at each pole are like each other with respect to the construct and are unlike elements at the other pole” (p. 137).

There are two main methods to select the constructs to be used in a repertory grid: (a) the researcher provides previously selected constructs to the participants and (b) the constructs are elicited directly from the participants (Feixas & Cornejo, 2002). Feixas and Cornejo state that while providing pre-selected constructs is a more suitable approach for discovering commonalities within a group of respondents, the latter method is more preferable for studies with an idiographic focus, where the elicited constructs are probably more representative of the participant’s personal meanings (Adams-Weber, 1990, as cited in Feixas & Cornejo, 2002). Bell (2003) also suggest that from a purely Kellyian perspective, the technique would seem to demand that the constructs be elicited from the <u>person,</u> since they are <u>personal</u> constructs.

As this research intends to capture musicians' unique personal meanings, the second method, which is based on eliciting constructs directly from the participants is considered to be more suitable for the purposes and context of this thesis. Thus, the approaches and procedures in relation to generating constructs through participant elicitation will be further elaborated.

3.2.2.1 Elicitation of Constructs

There are three approaches for eliciting constructs from participants: (i) triadic eliciation, (ii) dyadic elicitation and (iii) laddering and pyramiding.

3.2.2.1.1 Triadic Elicitation

The classical approach to generating constructs is by triadic elicitation (Easterby-Smith, 1980). This is also the original method used by Kelly (Feixas & Cornejo, 2002). Triadic elicitation method involves simultaneously presenting three elements to the participant and he/she is invited to evaluate in what ways two elements are alike/similar and thereby the third element is different from the other two (Kelly, 1955, p. 222; Easterby-Smith, 1980; Bannister & Fransella, 1986; Feixas & Cornejo, 2002; Fransella et al., 2004). Each time the participant is able to successfully generate an answer, a dichotomous construct with two contrasting poles is created. The procedure continues until the participant is no longer able to generate a new construct based on the existing triad of elements. Then, the researcher replaces the existing triad with a new one in order to elicit new constructs. According to Easterby-Smith (1980), the selection of triads may affect the final grid. Thus, the researcher should either choose the triads on a genuinely random basis or intentionally decide the triads, which have the highest potential to bring out the greatest contrast in the elements available. Easterby-Smith further propose that it is also important to give all elements roughly equal durations in order to avoid distortion on the final grid, since more frequently used elements can dominate the type of constructs being produced.

3.2.2.1.2 Dyadic Elicitation

The alternative approach to the traditional triadic elicitation is through the use of dyads (pairs of elements) instead of triads (Landfield, 1971, as cited in Fransella et al., 2004; Keen & Bell, 1980, as cited in Easterby-Smith, 1980). Dyading becomes preferable when the participants have difficulty generating constructs from triads; when the elements are complex (Easterby-Smith, 1980). Landfield provide a similar view proposing that the elicitation procedure based on two elements is a less confusing task for the participants in psychotherapy research (1971, as cited in Fransella et al., 2004). Dyadic elicitation method involves simultaneously presenting two elements to the participant and he/she is invited to answer *whether they are alike or different, and what makes them alike or different* (Easterby-Smith, 1980). If the participant reports a difference, the opposite poles of a construct are instantly identified (e.g. simple vs complex), where as, if the participant reports a similarity, then the participant is asked for the opposite of that similarity (Fransella et al., 2004). While Yorke suggests that the dyadic procedure is more likely to elicit clear opposite poles on the same semantic or hierarchical level (1985, Feixas & Cornejo, 2002), Easterby-Smith (1980) offers a contrasting view, claiming that the disadvantage of the dyadic procedure lies in the fact that the resulting constructs tend to incorporate logical opposites (e.g. simple-not simple, attractive-not attractive), rather than opposites of meaning (e.g. simple-sophisticated, attractive-dull).

3.2.2.2 Laddering and Pyramiding

Laddering and pyramiding are not stand-alone methods; instead, they are used in conjunction with triadic or dyadic elicitation procedures. As previously stated, Kelly (1955, pp. 57-58) mentions the hierarchical nature of a construct system in the organization corollary, where he explains the ‘superordinate’ and ‘subordinate’ relationships between the constructs (Kelly, 1955, p. 58; Fransella et al., 2004, p. 9). Laddering and pyramiding procedures are used in order to reveal these superordinate and subordinate constructs by moving away from the original construct in opposite directions. First mentioned by Hinkle (1965), laddering is used in order to generate superordinate constructs based on the original construct elicited from the participant. The procedure is as follows: After the construct is elicited in the usual manner through either triadic or dyadic procedures, the participant is asked which pole of the construct he/she prefers. The researcher then asks the question ‘Why?’. The participant’s answer is a new construct, which is superordinate to the original construct and with a higher order of abstraction. The ‘Why?’ question is repeated by the researcher until the participant is no longer able to produce a new superordinate construct (Easterby-Smith, 1980; Fransella et al., 2004).

Pyramiding, suggested by Landfield (1971, p. 135; as cited in Fransella et al., 2004), on the other hand, uses a similar procedure, where the usual elicitation procedure is followed by the researcher asking a ‘What?’ question. The participant’s answer produces a new construct subordinate to the original construct and it is more concrete in nature. Similarly, following the participant’s subordinate construct by asking a secondary ‘How?’ question may generate an even more concrete construct revealing more detail, such as the physical characteristics of the element being elicited. As an example, Honikman (1976; as cited in Fransella et al., 2004) used pyramiding in his study where he investigated people’s views on living-rooms and he was able to elicit constructs involving physical characteristics of the elements of a living-room.

Fransella et al. (2004) suggest that while Hinkle’s laddering takes the person ‘up’ a ladder, Landfield’s pyramiding takes him/her ‘down’ it. Both laddering and pyramiding are equally useful for further understanding the hierarchy and interrelations between a person’s construct system.

3.2.3 Linking Mechanisms

The final parameter of the RGT is the rating system, which acts as a linking mechanism between elements and constructs (Easterby-Smith, 1980). When the elicitation procedure is completed and the repertory grid is constructed, the elements form the columns while the constructs elicited from the participants form the rows. The values placed within the grid originate from the rating system used.

Three main methods (Easterby-Smith, 1980; Feixas & Cornejo, 2002) can be employed for a rating system:

1. Dichotomous method
2. Ranking method (alternatively termed as 'Ordinal method' by Feixas and Cornejo)
3. Rating scale

3.2.3.1 Dichotomous method

The dichotomous method involves the participant to place all elements on either of the contrasting poles of the construct through marking the relevant box with a 'tick' for the left pole and a 'cross' for the right pole (Easterby-Smith, 1980). According to Feixas and Cornejo (2002) dichotomizing, a two-point scale, is the simplest rating system and the method is recommended for use with children or participants with cognitive deficits, where more complex methods cannot be applied. In addition, Kelly suggested the risk of an unbalance, caused when the majority of elements lean towards one pole of the constructs, leaving only one or two elements on the opposite pole; a situation that requires the constructs to be discarded due to their poor discriminative capacity (Feixas & Cornejo, 2002). Easterby-Smith (1980) mentions that dichotomous scales tend to be more useful for hand analysis or if the grid is to be used for discussion purposes. A representation of the dichotomous scale is presented in Table 3.1.

Table 3.1 Example of a dichotomous scale

	Element 1	Element 2	Element 3	Element 4	Element 5	Element 6	Element 7	
Positive Pole	✓	✗	✗	✓	✓	✓	✗	Negative Pole

3.2.3.2 Ranking (Ordinal) method

The ranking (ordinal) grid was first suggested by Phillida Salmon and described by Bannister as being employed mainly in order to avoid the disadvantages of the dichotomous method (Feixas & Cornejo, 2002). The ranking method requires the participant to order all elements from one pole of the construct to the other. Since the elements are ranked and ordered between the two construct poles, the same score cannot be repeated for more than one element (Easterby-Smith, 1980). While the ranking method offers more discriminative power compared to the dichotomous method, the participants may also be forced to score elements differently when in fact there they see no difference between them based on the elicited construct (Easterby-Smith, 1980; Feixas & Cornejo, 2002). Additionally, the application of the ranking method becomes more difficult when the number of elements increases while the mathematical analysis of the grid is also limited to a certain number of elements for some software (Feixas & Cornejo, 2002). A representation of the ranking (ordinal) scale is presented in Table 3.2.

Table 3.2 Example of a ranking (ordinal) scale

	Element 1	Element 2	Element 3	Element 4	Element 5	Element 6	Element 7	
Positive Pole	3(rd)	1(st)	4(th)	2(nd)	5(th)	7(th)	6(th)	Negative Pole

3.2.3.3 Rating scale

The rating scale is the most widely used method among the three alternatives (Feixas & Cornejo, 2002; Fransella et al., 2004). The participants are instructed to rate the elements based on a Likert-type scale where the minimum and maximum values represent the opposite construct poles. Fransella et al. (2004) mention that Bannister developed the rating scale based on Kelly’s original dichotomous scale by expanding the two-point scale to a longer one. While the scales have ranged from Kelly’s 2 points to 20 points, increasing the number of intervals provide the participants more scope to express their views (Fransella et al., 2004) and allow them to make more sensitive discriminations and increase the complexity of their elicitations (Feixas & Cornejo, 2002). Fransella et al. (2004) suggest that a 7-point scale is a commonly used length because it yields more comprehensive data while also providing a mid-point. Feixas and Cornejo (2002) also support this view by suggesting that based on their experience, 7-point intervals are preferable. A representation of the rating scale is presented in Table 3.3.

Table 3.3 Example of a rating scale

	Element 1	Element 2	Element 3	Element 4	Element 5	Element 6	Element 7	
Positive Pole	6	6	4	1	4	3	2	Negative Pole

For the purposes of this research, a triadic elicitation method was selected in order to elicit constructs from the musicians. In addition, the author used laddering and pyramiding in combination with triadic elicitation due to these methods' ability to produce superordinate and subordinate constructs as well as further revealing the hierarchy and interrelations within the musicians' construct systems. Finally, a 7 point Likert-scale was employed for musicians to rate their constructs.

3.3 Personal Construct Theory and Design Research

Even though Kelly developed the 'psychology of personal constructs' theory and its practical applications to be used in clinical psychology, the flexibility of both the theory and the RGT made the personal construct theory a point of interest for many other disciplines such as HCI, education, design, business and marketing, etc.

Especially in the last couple decades, considerable amount of research has been conducted through RGT in industrial design as well.

Sener et al. (2006) used RGT to elicit user expectations from audio products. The study revealed similarities and differences in user expectations regarding physical (portable digital audio devices) and virtual (audio player software applications) audio products. Sener et al.'s study was the first of its kind in regards to utilizing the RGT method to compare products in physical and virtual domains.

In their study, Fallman and Waterworth (2010) note the artificiality of assessing the emotional impact of interactive products in isolation from cognitive judgments. Hence, they present RGT as a candidate for assessing holistic meaning of users' interactive experiences through a study they conducted using both off-the-shelf and research prototype mobile information technology devices. They propose RGT as an open and dynamic technique *on the border between qualitative and quantitative research,* which can qualitatively elicit people's experiences and meanings while also allowing for quantitative analysis of the data. Fallman and Waterworth conclude that RGT is unique in the way that it respects the wholeness of cognition and does not separate the intellectual from the emotional aspects of the user experience.

In their automobile design research Normark and Gkouskos (2012) combined RGT with a series of four workshops, in order to propose an alternative method for capturing user's needs and experiences of human machine interface design in automobiles. According to Normark and Gkouskos, today's highly technological cars, highlight an emergent need for the careful selection of added functionality and of features that can fulfil the driver's needs without compromising safety and driving enjoyment. They suggest that RGT takes into consideration both the intellectual and the emotional dimensions of user experience and thus reveal a broader picture regarding user's needs.

To investigate the perceived qualities of on-body interactive products, Kuru and Erbuğ (2013) used the RGT in order to determine what will lead users to avoid or approach these new technologies. The authors used conceptual designs for wearable phones in order to capture the meanings and relative importance of the qualities, which were elicited from the users through RGT.

In her PhD dissertation, Akbay (2013) employed RGT in order to shed some light on the idiosyncrasy and peculiarity of individuals' colour perception. According to Akbay, the results of the research can be actionable for design professionals who make use of colour samples in colour design and colour planning.

Baxter et al. (2014) discuss the usefulness of RGT as a method used in new product development to help uncover customers' hidden needs. They base their discussions on three case studies from their own work to show that RGT can be applied effectively at different stages of product development process; resulting in entirely new products, product improvements and new approaches to marketing.

3.4 Features of PCT and RGT in the Context of Design Research

There are many underlying reasons for employing personal construct theory and RGT in the context of design research. The most important advantages of RGT are:

- Its ability to gather design-relevant information,
- Its ability to illuminate important topics without the need to have a pre-conception of these,
- Its relative efficiency
- The wide variety of analysis methods that can be applied to the gathered data (Hassenzahl & Wessler, 2000; pp. 455-456).

While the main data captured through the RGT is qualitative in its nature, a variety of coding and analysis methods that can be applied to the repertory grids enable the researcher to interpret this data both qualitatively and quantitatively.

Additionally, RGT's flexibility makes it an ideal method to address diverse design problems in various areas of interest in the greater field of design research.

> There is no fixed form or content. It is called repertory grid *technique* and not *test* advisedly and the selection of the form and content is related to each particular problem. (Bannister & Fransella, 1986).

This flexibility in 'form and content' is one of the main aspects of RGT, which makes it a suitable method for the purposes of this research.

Another important feature of RGT which sets it apart from other structured interview forms is the role of the researcher in the whole process. While traditional interview techniques require the researcher to ask specific questions (providing both the context and the particular topics related to that context) in order to generate knowledge, in the case of RGT, <u>as long as the constructs are elicited directly from the participants at the time of the experiment</u>, rather than being pre-selected by the researcher, (Feixas & Cornejo, 2002), the researcher has no influence over the participants regarding *which constructs* are elicited. However, once a construct is elicited by a participant, the researcher may elaborate on the construct through laddering and pyramiding. While the context of the study is still pre-determined by the selection of the elements, the constructs are elicited solely based on the perceived evaluation of the participants and they are representative of *only their idiographic and idiosyncratic views*. For the purposes of this research, this particular feature of the RGT is essential because this research aims to find only the dimensions of new musical instruments and interaction experiences, which matter to the musicians rather than providing specific contexts, themes or topics for discussion.

In addition, RGT takes into consideration both the intellectual and the emotional dimensions of user experience (Fallman & Waterworth, 2010; Normark & Gkouskos, 2012). This point is especially important in the context of music (and musicians) because being an art form, intellectual and emotional aspects of music-making paradigms are of equally critical value. Thus, this feature of RGT ensures that the findings of this research are actionable for design professionals for not only the ideation and conceptualization of pragmatic issues, but hedonic (i.e. dimensions of 'design and emotion') ones as well.

3.5 Methodological Approach

The general philosophy of the methodology employed for this research to reach the aforementioned design strategies can be described as follows:

In order to make the findings practicable (i.e. actionable) for designers and instrument makers, the research employs a divergence-convergence-divergence model (Figure 3.1) in three consecutive steps:

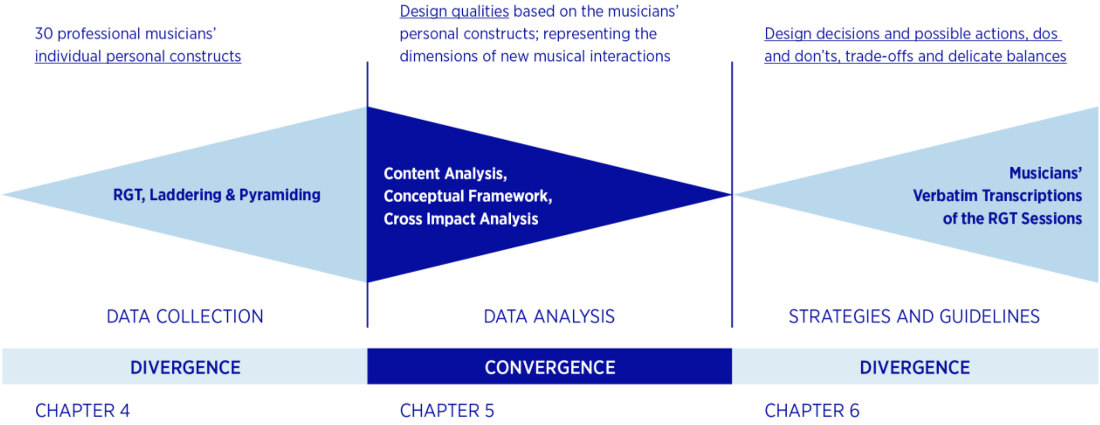

Figure 3.1 Methodological approach

Firstly, divergence in data collection through RGT to capture a diverse, detailed and rich set of unique personal constructs from 30 professional musicians.

Secondly, convergence in data analysis by using a hybrid analysis methodology (content analysis, a conceptual framework and cross impact analysis) to reach the main findings as well as translating them to a size that is manageable for communication.

Finally, for the construction of design strategies and guidelines, returning to divergence by referring to the RGT data from the original experiment transcriptions, where, the verbatim anecdotes examples suggestions and comments provided by the participants are used to create the detailed explanations in the strategies; which include design decisions and possible actions, dos and don’ts, trade-offs, and delicate balances that are essential for designing new musical instruments and their surrounding interactions.

CHAPTER 4

EXPERIMENT SET-UP AND PROCEDURE

4.1 Overview of the Experiment

This thesis aims to generate strategies and guidelines for designers to consider while designing for new generation electronic musical instruments to improve interaction, user experience and live performance. In order to construct the aforementioned strategies and guidelines, a user-centred experiment was carried out with professional musicians. This Chapter presents a detailed walk-through of this experiment, which includes the selection of participants, selection of stimuli, equipment and venue considerations, the Protocol of the experiment, (detailed steps regarding how the experiment was executed), a pilot study and the main study as well as the actual data collection procedures.

Repertory grid technique (RGT) has been chosen as the methodology for data collection. RGT enables each participant to evaluate and interpret any given element in their own words. This is particularly essential because it is the individual and personal interpretations of the identical elements that create the grid. Especially when the participants are knowledgeable and experienced in the given context and come from different backgrounds, it is reasonable to expect more diversity in terms of their elicitations, thus creating more complex grids. The research also aims to explore these differences in musicians' interpretations and whether if the diversity points out to different routes and directions regarding the subject matter. However, for this particular research, exploration of similarity, as emphasised in Kelly's (1955) commonality corollary, is equally important as diversity because similarities in the elicited constructs belonging to participants with diverse backgrounds have a higher chance to lead to more 'actionable' design strategies; thus becoming useful for a wider spectrum of musicians.

4.2 Selection of Participants

As previously stated, this research intends to conduct a user-centred experiment with professional musicians. The reasoning behind this selection is based on the idea that if the same grid is to be completed by a group of people, it is important to ensure all participants of that group are able to relate to the elements specified (Easterby-Smith, 1980).

Additionally, selecting professional musicians for the experiment was further justified by two more criteria:

1. The author argues that a musical instrument, by definition, is first and foremost intended for a professional musician (Contrary to historical context, this statement has exceptions due to new research being carried out to design musical instruments specifically for amateurs)

2. Professional musicians' skillsets and experience enable them to evaluate a musical instrument with a deeper level of understanding compared to amateur musicians, thus, it is expected that the resulting grids elicited by professional musicians would be more complex and detailed. Yorke (1985, as cited in Feixas & Cornejo, 2002) states that the elements must be easily understood by the subject, must be coherent with those already employed by the subject, and must be within his/her capacity to understand. Even though Yorke's suggestion is aimed at the element rather than the participant, it is possible to arrive at the same conclusion by arguing that a professional musician can understand the elements more easily compared to an amateur.

Music itself is a very abstract concept, and the very definition of a 'musician' is an ongoing discussion based on multiple points of view. For the purposes of this research, the author needs to propose a definition and 'selection criteria' for 'professional musicians' to be employed during the recruitment process of the participants. Thus, the author defines 'professional musician' as a person whose actual profession is related with the composition, conduction, direction, arrangement, recording, editing, production, performance or education of music in a theoretical and/or practical context. Music school and conservatory students have also been included in this definition due to their educational activities that involve participation in professional and academic concerts. From this point onwards, the term *musician* is used to refer to the specialist user group defined as: ‘professional musicians’. Examples of a ‘professional musician’ as proposed by the author are:

- Composer (acoustic and/or electronic-digital music)
- Performer (singer (vocalist), instrumentalist and/or virtuoso)
- Conductor
- Music theorist
- Music historian, musicologist, ethnomusicologist
- Arranger
- Producer
- Mixing/Mastering engineer
- Sound designer
- Sound engineer
- Disc Jockey (i.e. club DJ, hip hop DJ, turntablist, resident DJ)
- Conservatory or music school professor (i.e. lecturer)
- Conservatory or music school student (undergraduate and graduate level)

As stated in the Introduction Chapter, this research aims to generate design strategies and guidelines only in the context of <u>live musical performance</u> due to the differences in music-making paradigms and music-composition paradigms in regards to the way they ‘treat’ the musical instrument. Thus, for the recruitment process, a second criterion was set as: ‘a musician who can play a musical instrument on a proficient level’.

4.2.1 Selection Criteria

Based on Kelly's (1955) individuality corollary, different musicians with diverse backgrounds may have different construing and interpretation regarding their conception of music. Thus, the collective sum of their individual attitudes towards musical instruments and music making paradigms create a rich and diverse pool of knowledge. It was essential to represent this spectrum as widely as possible in order to create richness in findings and avoid bias, which might have occurred if the experiment was conducted with only a specific group of musicians (e.g. classical violinists) where the full spectrum of musicians is not represented.

Therefore, in order to recruit a more comprehensive and diverse participant profile, a framework was created based on a simple scale involving 3 levels of experience in music technology.

The framework defines music technology in relation to i- music making (performance, conducting), ii- music production (sound engineering, sound design, recording, mixing, mastering) and iii- music composition.

The 3 levels of experience in music technology are defined as:

1- <u>No experience:</u> Music technology is not part of participant's professional competence
2- <u>Some (moderate) experience:</u> The participant has from time to time used and/or experimented with music technology
3- <u>High experience:</u> Music technology is part of participant's core competence

Some example profiles, which represent musicians belonging to the three levels of technology experience are as follows:

<u>No experience:</u> Musicians who only perform with traditional acoustic instruments (e.g. stringed instruments, brass winds, wood winds, percussions). Orchestra, chamber music and ensemble musicians.

<u>Some (moderate) experience:</u> Musicians who perform with acoustic and electric instruments, also using effects modules, effects pedals and similar electronic devices. Musicians who use a variety of workstations, synthesizers, samplers. This profile has

some experience with cables, communication protocols, compatibility, and device set-up.

High experience: Musicians who not only use electronic instruments and devices as part of their set-ups, but also invent, design, customize and modify their instruments on both software and hardware domains. Musicians who can create/synthesise their own ‘sounds’. Musicians who have advanced experience with programming skills and coding languages, basic engineering principles, practical engineering work (welding, soldering and similar craftsmanship).

Through this framework, it became possible to represent the full spectrum of musicians rather than a single homogeneous group in relation to technology experience. However, exploring the diversities between the participant group’s attitudes is not within the scope of this research. Similar research could be undertaken if the concern was to identify the individual construings of participants belonging to one of the 3 levels of experience but than the participant recruitment would have to be made specifically for that group. This issue can be considered as a limitation of the research that specific user groups’ constructs are not identified independently of the needs of the full group of participants covering all experience levels.

4.2.2 Participant Profile

For the selection and recruitment of musicians, the author consulted the aforementioned 3-level framework for music technology experience. A total of 30 musicians were recruited based on voluntary participation. Equal number of musicians were successfully recruited based on i- no music technology experience (10 musicians), ii- some (moderate) music technology experience (10 musicians) and iii- high music technology experience (10 musicians). Even though this classification was not a methodological prerequisite of the experiment, representation of a broader spectrum of musicians with different levels of technology experience in the study was decided with the intention of creating a rich and diverse pool of knowledge based on the musicians’ personal constructs. The demographic and profession-related details concerning the participants of the study are presented in Table 4.1.

PARTICIPANT	MUSIC PROFESSION	MUSICAL INSTRUMENT	TECHNOLOGY EXPERIENCE None (I) Moderate (II) High (III)	LOCATION of THE EXPERIMENT	AGE	NATIONALITY
P01	Music Professor, Composer, Performer	Guitar, live electronics	TE III	Ankara, METU BILTIR-UTEST Product Usability Unit	38	Turkish
P02	Composer, Performer	Bass guitar	TE II	Istanbul, Bilgi University Dept. of Music	45	Turkish
P03	Music Professor, Composer, Performer	Guitar	TE II	Istanbul, ITU MIAM Centre for Advanced Studies in Music	36	Turkish
P04	Music Professor, Music Theorist, Composer, Performer	Piano, keyboard	TE II	Istanbul, ITU MIAM Centre for Advanced Studies in Music	36	Turkish
P05	Music Professor, Composer, Performer	Guitar	TE I	Istanbul, Bilgi University Dept. of Music	34	Turkish
P06	Music Professor, Producer, Arranger, Composer, Performer	Piano, keyboard, live electronics	TE III	Istanbul, Bilgi University Dept. of Music	40	Turkish
P07	Music Professor, Composer, Performer	Flute, Live electronics	TE III	Istanbul, Musician's Residence	35	Turkish
P08	Music Professor, Composer, Performer	Guitar	TE I	Ankara, Bilkent University Dept. of Music	39	Turkish
P09	Composer, Performer	Piano	TE I	Istanbul, Musician's Residence	38	Turkish
P10	Sound Engineer and Sound Designer, Composer, Performer, Instrument Maker	Live electronics, sonic gloves	TE III	Istanbul, ITU MIAM Centre for Advanced Studies in Music	29	Turkish
P11	Music Professor, Sound Engineer, Performer	Guitar	TE II	Istanbul, ITU MIAM Centre for Advanced Studies in Music	36	Turkish
P12	Music Professor, Music Theorist, Composer, Performer	Piano, keyboard, live electronics	TE II	Ankara, Bilkent University Dept. of Music	35	Turkish
P13	Music Professor, Sound Engineer, Composer, Performer	Guitar, live electronics	TE III	Istanbul, ITU MIAM Centre for Advanced Studies in Music	37	Turkish
P14	Music Professor, Sound Engineer, Multimedia Artist, Performer	Drums, live electronics	TE II	Istanbul, ITU MIAM Centre for Advanced Studies in Music	37	Turkish
P15	Music Professor, Sound Engineer, Composer, Performer, Instrument Maker	Live electronics	TE III	Istanbul, Musician's Residence	32	Turkish
P16	Music Professor, Composer, Performer, Instrument Maker, Inventor	Guitar, Microtonal Guitar	TE I	Istanbul, ITU Turkish Music State Conservatory	33	Turkish
P17	Music Professor, Sound Engineer and Sound Designer, Composer, Performer	Live electronics	TE II	Istanbul, Bahcesehir University. Dept. of Communication Design	32	Turkish
P18	Sound Engineer, Composer, Arranger, Performer	Piano, keyboards	TE III	Istanbul, Saran Digital Studios	36	Turkish
P19	Music Professor, Composer, Performer	Piano, violin	TE I	Istanbul, ITU MIAM Centre for Advanced Studies in Music	32	Turkish
P20	Sound Engineer and Sound Designer, Composer, Performer	Guitar, live electronics	TE III	Istanbul, ITU MIAM Centre for Advanced Studies in Music	33	Turkish
P21	Sound Engineer and Sound Designer, Instrument Maker, Inventor	Live electronics	TE III	Istanbul, ITU MIAM Centre for Advanced Studies in Music	28	Turkish
P22	Music Professor, Sound Designer, Conductor, Composer, Performer	Piano, live electronics	TE III	Ankara, METU BILTIR-UTEST Product Usability Unit	30	Turkish
P23	Composer, Arranger, Performer	Piano, keyboard	TE II	Istanbul, Musician's Residence	47	Turkish
P24	Music Professor, Composer, Performer	Piano	TE I	Istanbul, Istanbul University State Conservatory	35	Turkish
P25	Sound Engineer, Performer	Saxophone	TE I	Istanbul, ITU MIAM Centre for Advanced Studies in Music	30	Turkish
P26	Composer, Performer	Violoncello, live electronics	TE II	Istanbul, ITU MIAM Centre for Advanced Studies in Music	27	Turkish
P27	Music Professor, Arranger, Performer	Guitar, piano	TE II	Istanbul, Musician's Residence	36	Turkish
P28	Music Professor, Composer, Performer	Piano	TE I	Istanbul, Musician's Residence	32	Turkish
P29	Music Professor, Performer	Piano	TE I	Istanbul, Halic University Dept. of Music	33	Turkish
P30	Music Professor, Music Theorist, Composer, Performer	Piano	TE I	Istanbul, Author's Residence	35	Turkish

Table 4.1 Participants of the study

The recruitment process has been carried out through telephone calls, actual face to face conversations, e-mails and social media. Among the 30 participants, 22 were male and 8 were female, with an age range between 27 and 47. The mean age of the participants was 35. Since the research did not involve gender studies, male and female participant numbers were not adjusted equally.

4.3 Selection of Stimuli (Elements)

In order to carry out the RGT experiment with professional musicians a set of elements, which will be used as ‘stimuli’ is required for the participants to evaluate. It became evident that it would not be possible to carry out the experiment with actual working musical instruments due to limitations regarding budget, logistics and timing. In most optimistic scenarios each individual session would take days to complete and it is both financially or logistically beyond the reach of this research to acquire all of the selected new musical instruments. However, it was decided that the disadvantages of conducting the experiment with the simulation of these musical instruments could be overcome thanks to the experience and skill-sets of professional musicians. It is argued that a professional musician would be able to understand and evaluate an instrument if its features can be presented with sufficient detail, as will be explained in this section. From hereon, the term ‘musical instrument’ is used to replace ‘element’.

4.3.1 Selection of Musical Instruments

The decision process regarding the quantity and features of new musical instruments was based on the specific criteria for the selection of elements in a repertory grid. According to Easterby-Smith’s (1980) first suggestion on grid design (see Section 4.7) it is important to keep the grid small because larger grids (e.g. with 10 elements) take substantially longer time to complete. Thus, it was decided that 5 musical instruments would be sufficient to provide enough diversity while enabling the grid to be completed in a reasonable time.

Regarding the selection of elements, the musical instruments need to be homogeneous (Easterby-Smith, 1980), within the same area of interest (Yorke, 1985, as cited in Feixas & Cornejo, 2002) and representative of the area being investigated (Easterby-Smith, 1980; Fransella et al., 2004). The final selection of five all elements;

1. are new generation electronic/digital musical instruments
2. embody diverse and contrasting features (e.g. product architecture, feedback modes, interaction models) in order to represent the full spectrum of new musical instrument design

all have easy to access and easy to understand audio-visual media with an optimum level of detail regarding sound generation and musician-instrument interaction.

4.3.2 Description of Selected Musical Instruments for the Experiment

The five new generation electronic musical instruments, which were selected based on the abovementioned criteria are as:

1. Percussa 'AudioCubes'
2. 'Reactable'
3. Yamaha 'Tenori-on'
4. Wizdom Music 'MorphWiz'
5. Massachusetts Institute of Technology (MIT) Media Lab 'Beatbugs'

1. Percussa 'AudioCubes' (2007)

AudioCubes (Figure 4.1) is a modular audio-visual instrument designed and developed by Bert Schiettecatte; founder and director of Percussa. According to Percussa's description on its official website, AudioCubes are defined as smart wireless objects sensing location, orientation, and distance.

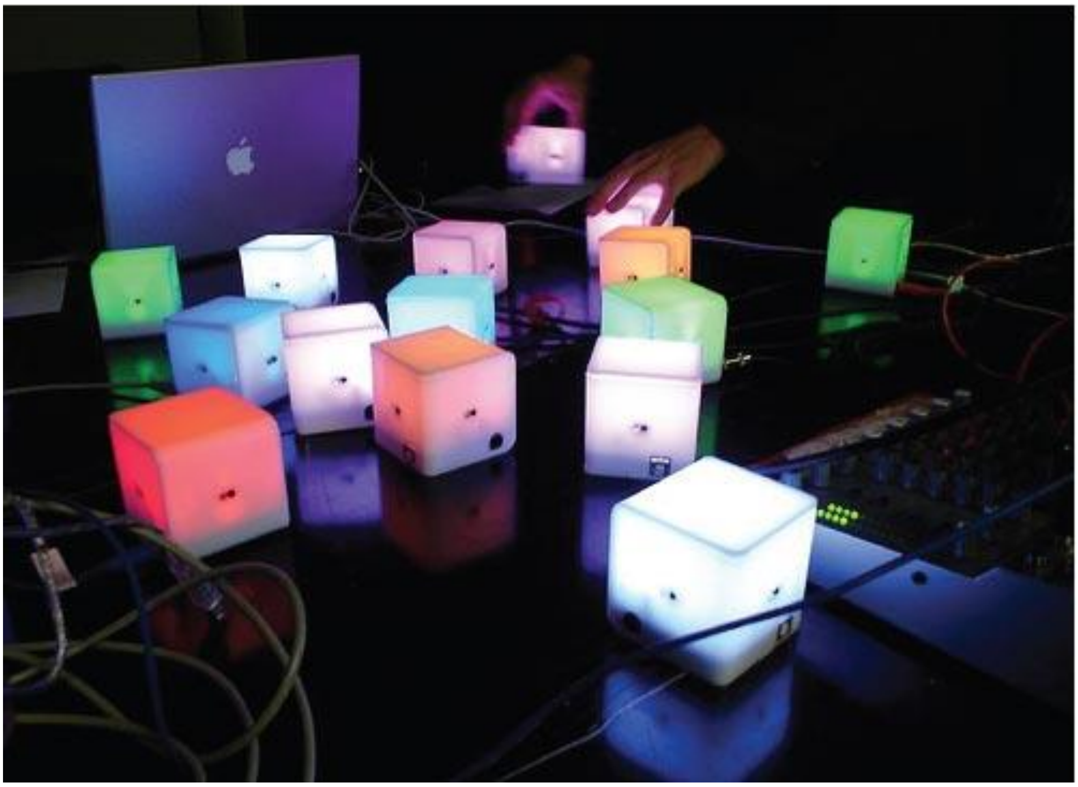

Figure 4.1 Percussa 'AudioCubes' (Schiettecatte and Vanderdonckt, 2008)

The instrument is aimed at professional artists and they allow people to easily make music and perform live using smart wireless blocks. Musicians can upload audio files and sound samples to the cube components sthrough a computer and then playback and modify these pre-recorded sounds, loops and musical textures through moving and rotating the cubes. The AudioCubes were launched in January 2007 at NAMM (Anaheim, US). Currently, AudioCubes are mass-manufactured and sold as physical instruments (Percussa, 2016).

2. Reactable Systems SL ‘Reactable’ (2005)

Reactable was conceived and developed since 2003 by a research team at the Pompeu Fabra University in Barcelona. Reactable (Figure 4.2) was presented to the public for the first time by its creators Sergi Jordà, Günter Geiger, Martin Kaltenbrunner and Marcos Alonso at the International Computer Music Conference 2005 in Barcelona.

Figure 4.2 Reactable Systems SL ‘Reactable’ (Jordà, Geiger, Alonso, and Kaltenbrunner, 2007)

Reactable uses a tangible interface where the musician controls the instrument by manipulating physical objects. Musicians can control and combine different elements of music-making such as synthesisers, effects and samples through placing the physical objects on the smart Reactable surface and manipulating or combining them with each other. The sound output is represented graphically on the Reactable’s surface, turning the music into a visible and tangible entity (Reactable, 2016). Currently, the instrument is being mass-manufactured and sold both as a physical musical instrument and also as a software application, compatible with multiple platforms on mobile smart products.

3 Yamaha 'Tenori-on' (2007)

Tenori-on is an electronic musical instrument designed and created by the Japanese artist Toshio Iwai and Yu Nishibori of the Music and Human Interface Group at the Yamaha Centre for Advanced Sound Technology. Tenori-on (Figure 4.3) is designed as a hand-held pad with a large screen in which a sixteen-by-sixteen grid of LED switches are used in order to generate sound. Tenori-on offers a dual-view through the LEDs placed on the reverse face of the instrument.

Figure 4.3 Yamaha 'Tenori-on' (Nishibori and Iwai, 2006)

Tenori-on was demonstrated at SIGGRAPH 2005 held in Los Angeles, in 2005.

The instrument was launched in London in 2007 and is being mass-manufactured and sold as a physical instrument with two alternative models.

4 Wizdom Music 'MorphWiz' (2010)

According to the Wizdom Music official website, MorphWiz (Figure 4.4) is a soft-instrument (software musical instrument) designed and developed by Dream Theater keyboardist Jordan Rudess and Kevin Chartier in 2010.

Figure 4.4 Wizdom Music 'MorphWiz'

MorphWiz runs on multiple platforms on mobile smart products and is advertised as both an expressive musical instrument and an exciting visual experience. MorphWiz is being sold as a downloadable digital application.

5 MIT Media Lab Hyperinstrument Group 'Beatbug Network' (2000)

Designed and developed by Weinberg, Aimi and Jennings in 2000, The Beatbugs (Figure 4.5) are hand-held percussive instruments, that allow the creation, manipulation, and sharing of rhythmic motifs through a simple interface. The design is based on a concept called Interconnected Musical Networks (IMNs), which are live performance systems that allow players to influence, share, and shape each others' music in real-time (Weinberg et al., 2002). Multiple Beatbugs can be connected in a network, allowing multiple players to form large-scale collaborative compositions by interdependently sharing and developing each other's motifs. Beatbugs were premiered in 2002 as part of Tod Machover's Toy Symphony Project's concert with the Deutsches Symphonie Orchester Berlin (Weinberg et al., 2002) Beatbugs are prototypical musical instruments and are not commercially available.

Figure 4.5 Beatbugs played by Tod Machover (Weinberg, Aimi and Jennings, 2002)

Each of these aforementioned musical instruments showcase unique features, which cover different aspects of the taxonomy of new generation electronic/digital musical instruments mentioned in Chapter 2. The market and pre-market review was also consulted to identify potential candidates and select the examples most suitable for the purposes of this research. Thus, the combination of their diverse features represent the full spectrum of new musical instruments and novel music-making paradigms; creating a rich source to be evaluated by the participants.

Presented below is a ‘sample’ of features functions and specifications, which reveal the diversity the selected musical instruments represent regarding the research area under investigation.

- Modular vs. compact product architecture
- Tangible vs. virtual interaction
- Contact vs. non-contact gestural interaction
- Organic vs. geometric design
- Continuous vs. discrete pitch (frequency) space
- Repeatability of musical actions vs. random sound generation
- Visual guidance vs. no visual guidance
- Single user interaction vs. multiple user/collaborative interaction
- Embodied musical instrument vs. decoupled controller
- Traditional interaction references vs. novel interaction model
- Visual feedback vs. vibro-tactile feedback
- Instantaneous sound generation vs. triggering pre-recorded sounds
- Multifunctional instrument vs. single-function instrument

It is important to note that the five musical instruments chosen are used as ‘probes’ to trigger a discussion. In other words, they are representative of a wide spectrum of instruments, which define new musical interactions and new music-making paradigms. Hence, the experiment could have been carried out by replacing these instruments with a different set of five; they are important for what they represent, not for the specific products that they are.

4.3.3 Presentation Strategy for the Selected Stimuli

As previously mentioned, conducting the experiment with actual musical instruments was financially and logistically not possible. Thus, a special ‘presentation strategy’ (as illustrated in Figure 4.6) was employed in order to overcome the possible hardships, which would occur due to representing actual instruments through other media. The first part of this strategy involved designing special templates to visually present the musical instruments in detail. However, even for professional musicians, it would prove too difficult to understand or ‘guess’ the features and functions of a new musical instrument just by looking at images. Thus, the second part of the strategy was based on supporting the visual cards with short video clips, which presented the actual musical instruments in a live musical performance context.

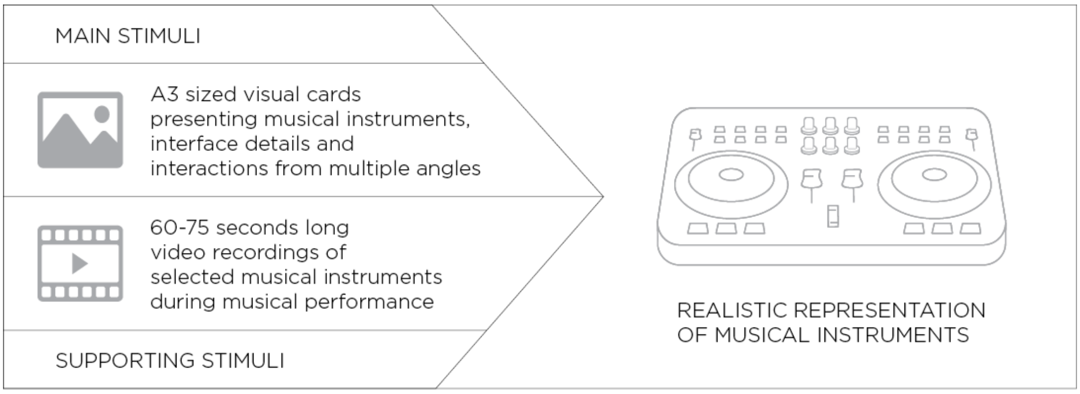

Figure 4.6 Presentation Strategy for the Selected Stimuli

For the design and production of the main stimuli, high resolution images of the musical instruments were gathered through Google image search and the official web sites of the musical instruments. The images were optimized and arranged in Adobe Creative Suite 4 Photoshop for Mac software in order to create the A3 sized print templates for the experiment. The design template is composed of four sections and it was used in an identical manner for each musical instrument. Design template’s sections are: One large area for the main photograph of the musical instrument and three identical-sized smaller images, which reveal specific details of the user interface as well as user-product interaction. The image templates were labelled with unique identifiers A, B, C, D and E. Example of a completed template for one of the musical instruments (Reactable) is presented in Figure 4.7.

Figure 4.7 Final version of the template for Reactable (Element B)

Finally, five A3 sized image templates were printed digitally on 240 gr paper with glossy finish in order to closely match the colour saturation as seen on the computer screens. The original image templates of the five RGT elements can be found in Appendix A.

For the design and editing of the supporting stimuli, the video clips of the selected musical instruments were downloaded from YouTube and the official web sites of the respective musical instruments. The exporting and editing of the videos were done by Jdownloader software for Mac. The following selection and editing criteria were set in order to achieve coherency among the videos:

1. There should be no spoken narrative to explain the musical instrument
2. Each video should be of similar duration, which is 60 to 75 seconds
3. Each video should clearly demonstrate how the musical instrument works

The audio-visual resolution should be high enough for the participant to clearly see hear and understand the videos

4.4 Experiment Equipment

In order to address time management concerns related with the availability of the participants and their diverse geographical locations, a modular and portable experiment set-up was designed. An Apple MacBook Pro 17” laptop computer with matte screen was used in order to display videos of the electronic musical instruments. VideoLAN-VLC Media player for Mac software was used to playback the videos to the participants on the MacBook Pro laptop computer. A SONY DCR-TRV25E digital video camera recorder, which was mounted on a professional tripod was used to record the sessions. The empty grid data sheet templates have been prepared in Microsoft Excel and printed on standard A4 papers. The same laptop, videos and prints were used in all the sessions, to ensure each participant viewed the visual and audio media in identical resolution and quality. The tools, equipment, software and online services used for the experiment is listed in Table 4.2

Table 4.2 List of experiment equipment

NAME	FUNCTION	TYPE
Google	To search product images	Online Services
Adobe Creative Suite 4 Photoshop	To edit product images and create print templates	Software
YouTube	To search product videos	Online Services
JDownloader for Mac	To export and save embedded Youtube videos	Software
Apple MacBook Pro 17” Laptop Computer with matte screen	To display product videos	Hardware
VideoLAN VLC Media Player for Mac	To playback product videos	Software
SONY DCR-TRV25E Digital Video Camera Recorder	To record the RGT sessions	Hardware
Professional Tripod	To mount the SONY camera	Hardware
5 A3 sized 240gr prints (RGB digital print on glossy paper)	To display the product images	Hardware
Pre formatted grid data sheet (Excel)	To note participant elicitation	Hardware

4.5 Data Collection Method

As discussed in Chapter 3, the preferred data collection and analysis method for the research study was the repertory grid technique (RGT). In this section, the practical implementation of the method is explained on a step-by-step basis referred to as the 'Protocol' for the experiment.

4.5.1 The Protocol

The experiment was carried out in five main phases as illustrated in Figure 4.8.

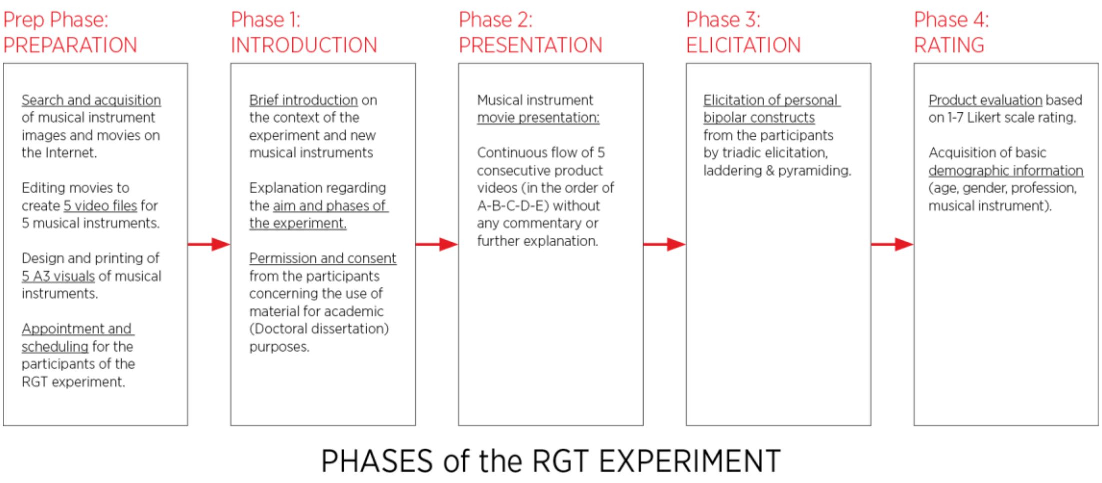

Figure 4.8 Phases of the RGT experiment

<u>Preparation Phase</u>

The preparation phase consisted of the general planning of the sessions, selection of elements, design of the experiment setup, production of audio-visual media (representation of the elements), selection and recruitment of participants as well as the arrangement of interview dates and locations.

Phase 1: Introduction

The introduction phase was composed of a brief conversation made with the participants at the beginning of each session. The author briefly introduced the area of research and gave a definition of new generation electronic musical instruments. Then, he explained the interview procedure to the participants verbally and walked them through all the phases of the experiment. During this phase the participants were asked for their consent to be recorded on video for the entirety of the session. The participants were also given reassurance that the video recording would be kept strictly confidential and used only for academic purposes; more specifically in order to inform the PhD research. The introduction phase ended when the author asked the participants whether if they had any questions about any particular aspect of the experiment. A transcription of the verbal explanation, which was given to the participants at the beginning of the sessions can be found in Appendix B.

Phase 2: Product Presentation

Following the introductory conversation, the author played the videos of the elements to the participants on the laptop computer. All 5 product demonstration videos were presented sequentially, without interruption nor any explanation. The order of video playback (A, B, C, D, E) was identical for all 30 participants. The author also reminded the participants that any video could be replayed partially or fully upon their request at any instance during the interview.

Phase 3: Construct Elicitation

As mentioned in Chapter 3, the traditional approach for construct elicitation in the RGT is *triading*. Triading is a procedure where a triad of elements are either systematically or randomly selected from a pool of larger number of elements (in the case of this experiment; five) and presented to the participant simultaneously. During the construct elicitation phase, the author initiated the procedure by presenting a random triad of elements to the participants. The author then asked the participants to identify *'in what way(s) two of the elements are alike and the third element is* *different from the other two?'* (Easterby-Smith, 1980, p.6). In many instances, the participants produced the opposite poles immediately (e.g. 'These two instruments are portable but the third one is not portable'). After receiving the participant's construct, the author asked the participant which of the bipolar construct was preferable/positive for them. When the participant did not produce an opposite construct immediately, the author asked the participant to produce a bipolar opposite of the initial construct.

However, especially for dyadic procedures, elicitation of an opposite attitude tends to produce logical opposites rather than opposites in meaning (Easterby-Smith, 1980). When the participant identifies a musical instrument being 'not portable' as the opposite attitude for 'portable', the elicitation is straight forward because this is a logical opposite. On the other hand, when the participant identifies 'frustrating' as the opposite attitude for 'portable', this is an opposite in meaning and it reveals a deeper understanding on the representation of the construct. Furthermore, it also becomes possible to investigate the interrelations between different dimensions. Regarding this example, there is clearly a correlation between the dimensions 'portability' and 'pleasure in use', where the former attitude is affecting the latter. During the course of the experiment, some of the participants became confused when asked to provide an 'opposite' of a construct. Thus, an important part of the data collection process was to clarify to the participants that they are completely free to provide the opposites of their constructs 'in their own words'.

Throughout the process, the author noted down the preferred/positive constructs on the left pole and not preferred/negative constructs on the right pole on the grid data sheets. This procedure was intended to generate a new set of individual bipolar constructs every time the participants grouped the elements to identify a new similarity and difference.

During the construct acquisition process, the author also carried out a laddering and pyramiding procedure in order for the participants to elicit superordinate and subordinate constructs. In regards to laddering, when the participants produced the bipolar constructs, the author asked the questions *'which one of these constructs is important for you?'*, *'which one of these constructs do you prefer?'* or *'which one of* *these constructs is positive for you?'*. The author then immediately followed the participants' preferences by asking *'Why?'* (or *'Why is it important to you?'*). Laddering was completed when the participant was no longer able to give an answer to the *'Why?'* question.

Similarly, pyramiding was used constantly throughout the 30 sessions. After the participants successfully elicited a set of bipolar constructs, the author followed up the participants' comment by asking *'What is it about this construct that is important to you?'*

The author argues that in order to achieve <u>actionable</u> design strategies and guidelines, both laddering and pyramiding were equally critical for the reasons stated as follows:

1. The generation of superordinate constructs through laddering enables the researcher to understand the hierarchy of the personal construct system as well as the interrelations between the elicited attitudes. Designers need to understand not only 'what' matters for the musicians but also why how and when these dimensions are affecting each other.

2. The generation of subordinate constructs, on the other hand, reveal more concrete detail and physical characteristics (Fransella et al., 2004) for designers to incorporate into their design activity. The dimensions, which matter to the musicians and the interrelations between these dimensions cannot be actionable on their own without sufficient detail. Pyramiding generates enough detail that can be used for actual product design.

The author ended both laddering and pyramiding procedures when the participants were not able to produce a superordinate or subordinate construct anymore.

When the participants could not elicit any new constructs based on the existing triad of elements, the author replaced the triad with a new random triad. The same cycle was repeated with different sets of random triads until the participants decided that their evaluations of the musical instruments were completed. It was ensured that all 30 participants were exposed to as many random triads as needed until they were not able to produce any new bipolar constructs.

Phase 4: Product Rating

In the final phase of the interview, the participants were given the grid data sheet, which had been pre-prepared expediently by the author, using the bipolar constructs elicited by the participants. The author explained the rating procedure to the participants as follows:

“Now, may I ask you to rate all five musical instruments based on your own elicited constructs? I want you to use this grid template to rate these instruments. The rating scale is between 1 to 7, where 7 represents the positive attitude and 1 represents the negative attitude. In other words, 7 means the product strongly embodies your construct on the left pole and 1 means the product strongly embodies your construct on the right pole. After you finish this rating procedure our interview will be completed.”

For the Product Rating Phase, ‘grid data sheets’ (i.e. empty grid sheet templates) were pre-formatted in Microsoft Excel and printed separately for each participant. Each grid daha sheet template is composed of 20 rows and the mean value of grid data sheet usage for the interviews was two. The author used the sheets to note down the bipolar attitudes where as the participants used the same sheets to rate the five electronic musical instruments based on their elicited bipolar constructs. After the participants completed rating the musical instruments, the author noted the participants’ basic information (profession, age, musical instrument) and concluded the interview session. An original grid data sheet sample from one of the interview sessions (Participant 20) is presented in Figure 4.9. Additionally, an empty RGT grid data sheet template can be found in Appendix C.

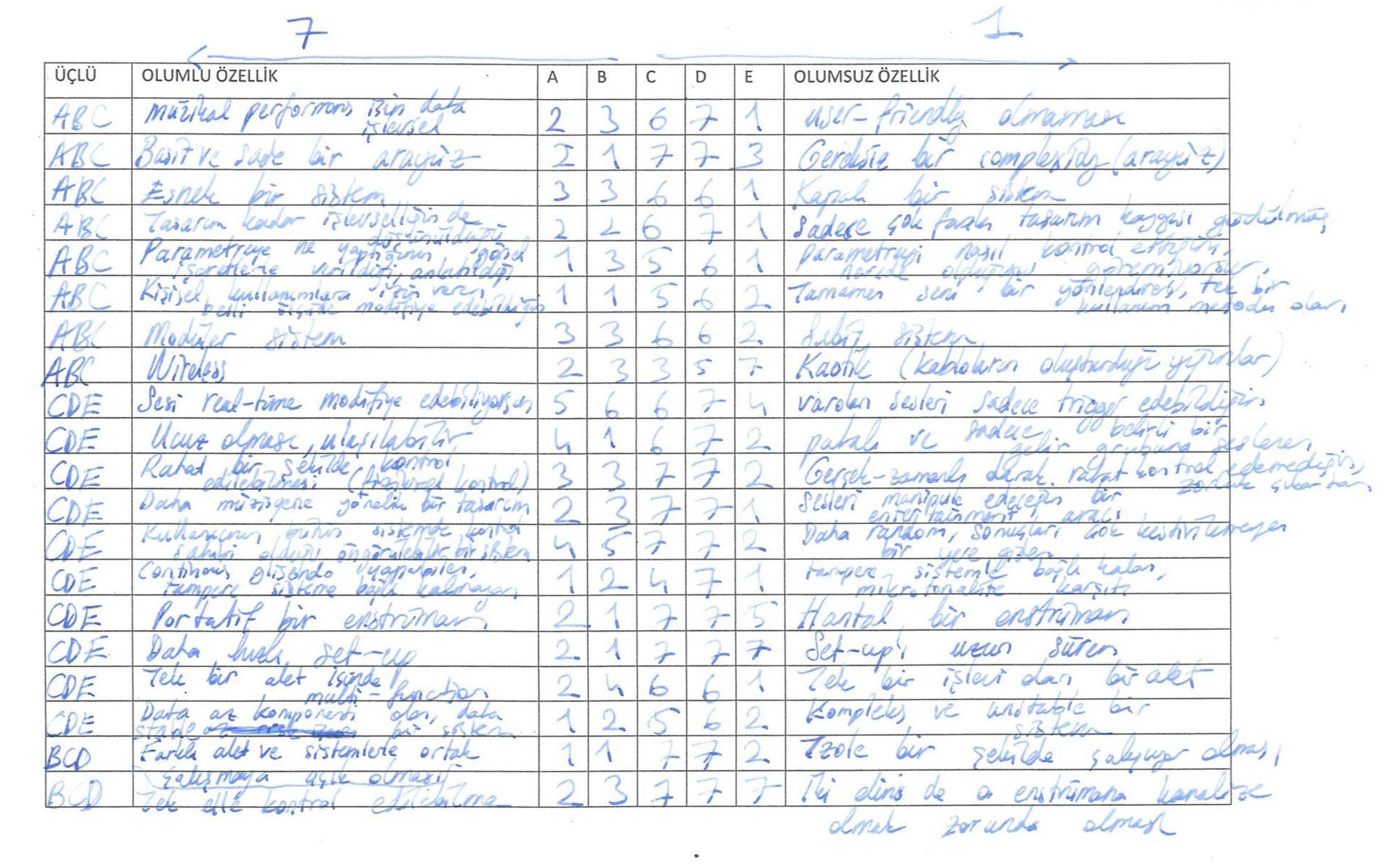

Figure 4.9 An original grid data sheet sample from the RGT sessions.

4.6 Pilot Study

A pilot study was carried out in order to evaluate the implementation of RGT data collection, prior to committing to the substantial main study. Additionally, a pilot study was considered an essential phase of the whole research because it enabled the author to simulate the actual experiment and confirm or improve the efficiency of the set-up and tools. Thus, two individual experiments were organized with locally available participants to form the pilot study.

4.6.1 Pilot Study Venue

The pilot study was conducted at the METU/BILTIR U-Test Ankara, Turkey in a private interview space specifically designed to accommodate various empirical experiments. Basically, the space is an isolated room, which has a large table and two chairs. One wall of the room is mounted with double-mirrored glasses to enable the researchers in the adjacent control room to view the experiments without disturbing the sessions. A photograph of the METU/BILTIR U-Test interview room is presented in Figure 4.10.

Figure 4.10 METU/BILTIR U-Test Interview Room

4.6.2 Pilot Study Set-Up

The experiment set-up (illustrated in Figure 4.11) is as follows: A table wide enough to accommodate five A3 sized prints and a laptop computer, a digital video camera recorder mounted on a tripod and placed behind the researcher and participant, which is adjusted to capture the gestures and voice of the participant as well as the A3 prints and the laptop screen.

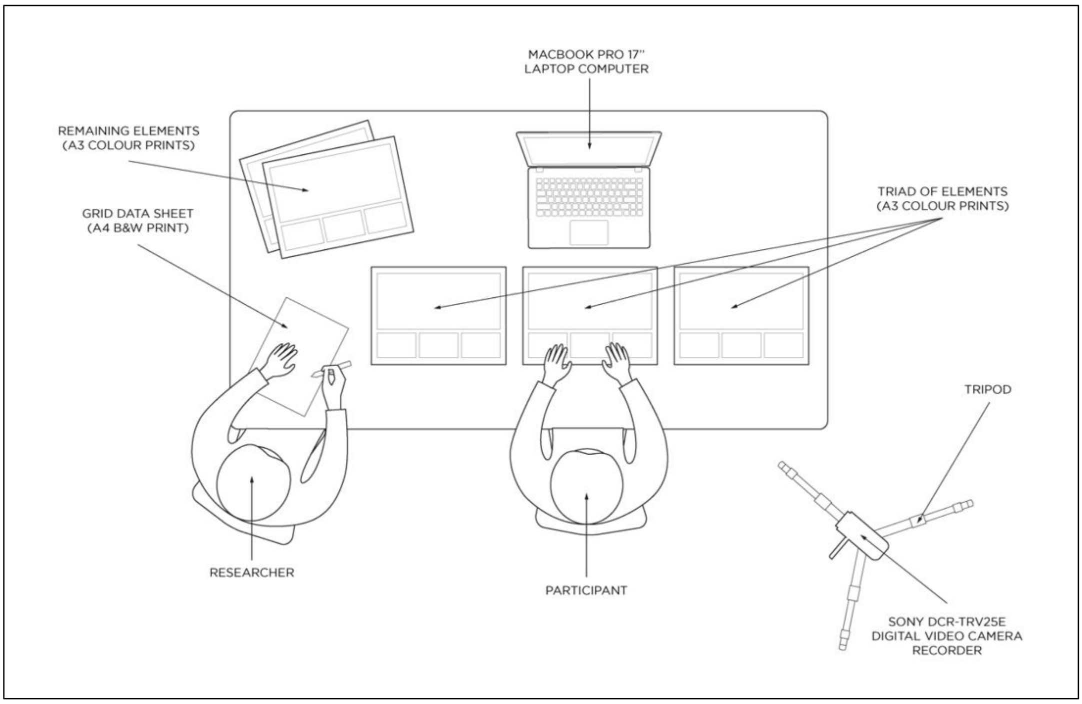

Figure 4.11 Visual representation of the experiment Set-Up

4.6.3 Pilot Study Equipment

Since the pilot study was designed to replicate a precise simulation of the actual experiment, the author used the identical equipment (see Section 4.4) and set-up, which were used during the main study. However, METU U-Test interview room was already equipped with a permanently mounted audio-visual recording system on its walls. The system was composed of a camera and a microphone. The audio-visual data, which was being captured in the room was directly streamed to a computer that was in the adjacent 'control room'. Thus, the Sony camera and the tripod were not used during the pilot studies but this alteration did not have any effect on the outcome of the experiments conducted within the pilot study. A photograph of the control room is presented in Figure 4.12.

Figure 4.12 METU/BILTIR U-Test Control Room

4.6.4 Participants of the Pilot Study

As a pilot study serves as a 'test' of the selected methods, this testing is partly procedural and partly to observe the ability of the participants to 'participate'. Thus, while the recruitment of professional musicians was not necessary, some experience with a musical instrument was desirable in order to understand the 'ease' of eliciting constructs. Hence, the pilot studies were carried out with locally available participants; two students from the METU Faculty of Architecture who also happened to be amateur musicians. The first participant was a pianist and an undergraduate student from the Department of Architecture. The second participant was a guitarist and graduate student from the Department of Industrial Design. They were both male and aged 19 and 26 respectively. Both participants volunteered to take part in the pilot study and their consent was taken to record the interviews for reflection purposes.

Regarding musical performance, professional musicians have a superior understanding of the context and content of music-making paradigms. Thus, it was decided that if the pilot studies confirmed the efficiency and suitability of the proposed research strategy and methodology, it would be reasonable to expect an even higher level of efficiency for the actual experiments, which were set to be conducted with professional musicians.

4.6.5 Data Collection with the Pilot Study

Both of the experiments in the pilot study were carried out precisely through the five phases as described by the 'Protocol' (see Section 4.5.1). The participants were first given an introduction on new generation electronic musical instruments and the experiment procedures. Following the introductory conversation, the participants viewed the five videos of the musical instruments without interruption.

During the construct elicitation process, both participants were able to successfully elicit 21 and 23 bipolar personal constructs respectively. Following the construct acquisition phase, both participants managed to rate the five musical instruments based on their elicited bipolar individual constructs. The first experiment lasted around 80 minutes and the second experiment lasted 100 minutes. Before completing the sessions, the author had a short conversation with both participants to obtain feedback regarding their overall experience and any particular detail regarding the interviews.

4.6.6 Reflections and Discussion on the Pilot Study

In addition, short conversations with the participants of the pilot study after the sessions were completed, provided invaluable feedback regarding their experiences and the procedure as well as the tools employed for presenting the musical instruments. Both participants requested to view the musical instrument videos multiple times during the construct elicitation process. This behaviour confirmed the necessity/decision to support the printed images with moving-images and sound. The participants openly stated that without the videos it would have been very difficult for them to understand the features and functions of the musical instruments as well as the user-product interactions if they were shown only the printed musical instrument cards.

Additionally, during the rating phase one of the participants requested the author to repeat the explanation regarding how to associate the bipolar attitudes with the polar ends of the 7-point rating scale. Based on the participant's question it became clear that rather than associating 'point 7' with the positive attitude (left pole) and 'point 1' with the negative attitude (right pole), the participant associated 'point 7' (left pole) with the positive attitude and 'point 1' with the product 'not having' that positive attitude (again left pole). Thanks to this feedback the author was able to adjust the verbal explanation for the rating phase to clarify any confusions regarding the mapping of the rating points to the elicited attitudes.

The author's personal observations also led to significant improvements on the overall procedure. During the construct acquisition phase both participants constantly pointed on specific parts of the printed images while talking. The author realized that the camera needed to be placed at a specific angle in order to visually capture all hand movements of the participants. This information was later used in the cases of inconsistencies or contradictions between the participant's evaluation and ratings of the musical instruments. In such cases, the author cross referenced the video recordings with the written session transcriptions and confirmed the correct interpretation with the help of the visual information captured on the recording.

Apart from the aforementioned issues the construct acquisition and rating procedures were carried out successfully and the participants were able to generate a sufficient quantity of bipolar individual constructs based on their elicitation of the musical instruments. The diversity of the elicited constructs also confirmed the suitability of the selection of the particular set of musical instruments as stimuli for the experiment. As a result, the efficiency of the research strategy was confirmed by the complexity and detail of the collected data.

4.7 Main Experiment

As confirmed by the pilot study, the nature of the experiment did not require a specific laboratory environment or a controlled climate. However, an indoors set-up with adjustable lighting conditions was preferred to obtain visibility for the computer screen as well as to provide isolation for the experiment in order to avoid external disturbances such as noise. As the participants resided in different cities in Turkey, the sessions for the main study were carried out in the following locations: METU/BILTIR U-TEST Product Usability Unit, Bilkent University Faculty of Music and Performing Arts, Bilgi University Faculty of Music, İstanbul Technical University Turkish Music State Conservatory, İstanbul Technical University Dr. Erol Üçer MIAM Centre for Advanced Studies in Music, İstanbul University State Conservatory, İstanbul Haliç University Faculty of Music, İstanbul Bahçeşehir University Faculty of Communication, İstanbul Saran Digital Studios and the private residences of the musicians and the author.

In all of the mentioned locations, it was possible to adjust the room lighting conditions to ensure that the laptop screen visibility was at optimum levels. In addition, all facilities had access to private rooms, which enabled noise and disturbance free sessions. Apart from the experiment locations, all remaining aspects of the experiment were carried out in procedures identical to the Pilot Study. The author used the same experiment equipment during all sessions of the main study with the exception of the Sony Digital Camera and the tripod (inbuilt recording system in METU BILTIR U-TEST). All experiments were carried out without any issues and with the identical step-by-step procedures, precisely following the phases, which were defined by the 'Protocol' (see Section 4.5).

The session durations varied between 90 to 150 minutes and all 30 participants were asked for their consent before the experiments to be recorded on video for the entirety of the sessions. During the sessions, all participants were able to successfully elicit a sufficient number of bipolar personal constructs. Following the construct acquisition phase, all participants managed to rate the five musical instruments based on their elicited constructs without any issues. The statistical information regarding elicited constructs is discussed in detail in Chapter 5: Analysis Structure and Procedures.

4.8 Reflections on the Experiment and Data Collection

The author acknowledges certain notable hardships in terms of implementing RGT to run the experiment. First and foremost, the elicitation of personal constructs from 30 musicians was a very time consuming activity. It is important to note that despite its flexibility in adapting to various design problems, RGT is not a quick or simple procedure. Further more, the subject matter being music – as opposed to more conventional user/product profiles – resulted in personal constructs not only high in volume, but also very complex and rich in semantics. It is a common known fact that musicians express themselves in diverse ways through music. It is no surprise that their verbal expressions and elicitations can become at least equally diverse and thus complex in nature. Additionally, as music itself is arguably the most abstract and subjective of all art forms, the participants use a lot of metaphors and analogies even when describing more concrete or tangible concepts. As a result, the coding and analysis procedures become at least as overwhelming as the data collection process.

However, in the context of this research study, despite the hardships mentioned above, RGT's advantages and benefits as a research method surpasses its disadvantages, because, employing:

a. Quantitative research methods would result in semantically blind data, which would in turn be not actionable for design professionals,

b. Other qualitative research methods such as in depth interviews or mental models would require the researcher to set the 'tone' of the experiment by providing context topics and themes, or asking direct questions. Thus, the perceived evaluations of the musicians might have been biased as a result of the researcher's priorities, prejudgements and intervention.

c. Similarly, methods such as shadowing and observation might have generated data, which is based on the researcher's personal interpretations (and thus, personal constructs) rather than the musicians'.

CHAPTER 5

DATA ANALYSIS AND RESULTS

This chapter presents the analysis structure and coding procedure, which were carried out based on the repertory grids collected from the 30 participants. The first part of the chapter explains the data preparation, the coding procedure and the initial content analysis where as, the second part of the chapter presents the background and analysis procedure of cross impact analysis in detail, and interprets the results of the analysis through individual discussions for each construct.

5.1 Content Analysis, Coding Structure and Conceptual Framework

The first step in analysis involves processing the participants' repertory grids through content analysis in order to group the constructs and standardize construct names (Hassenzahl & Wessler, 2000; Jankowicz, 2004; Tomico et al. 2009).

As this study lies at the intersection of music and design, the literature (Chapter 3) concerning new musical instrument design was consulted in order to create a preliminary list of constructs for a comprehensive terminology, which was used for the coding procedures (Miles & Huberman, 1994). The terminology was iteratively developed until all of the 30 participants' constructs were identified.

For data preparation, each individual repertory grid sheet was transcribed and coded into Microsoft Excel including the 'word for word' transcriptions of the video recordings of the interview sessions. 30 participants' RGT sessions combined for a total of 966 rows of individual repertory grids. The number of repertory grids per session ranged between 19 to 42 with a median of 26.

The content analysis led to the development of a 3-level coding procedure, which was used for clustering and interpreting the participants' repertory grids.

The first step of coding involved translating the bipolar constructs into English. At the end of this process, a total of 357 unique bipolar construct pairs were identified. For each bipolar construct pair, both positive and negative constructs proved equally valuable in further understanding the meaning of the dimension that was elicited from the participant. Table 5.1 is a sample of the aforementioned unique bipolar constructs in English highlighted in green colour and labelled as Level 0 (L0) codes.

Table 5.1 Repertory Grid Sample with Level 0 (L0) codes.

Unique Participant Identifier	Product Triplet	Positive Pole Construct (7)	PRODUCTS					Negative Pole Construct (1)
			A	B	C	D	E	
		PARTICIPANT 01						
P01L01	ABC	**Modüler - Parçalardan oluşuyor** **Modular (L0)**	7	7	1	1	2	**Fixed form** **Fixed Form**
P01L15	ABC	**Sound-synthesis / kendi seslerini üretebiliyor** **Sound-synthesis (L0)**	7	7	1	1	2	**Kendi soundlarını üretemiyor, pre-set sound ile çalışıyor** **Pre-set sounds**
P01L26	BDE	**Alet benim bildiğim gibi çalışıyor** **Familiar interaction (L0)**	2	5	6	6	1	**Nasıl kullanacağımı anlamıyorum** **Incomprehensible interaction**
P01L32	BDE	**Learning curve daha kısa** **Short learning curve (L0)**	2	3	6	6	5	**Learning curve daha uzun** **Steep learning curve**

The English translations of these bipolar construct pairs have been triple checked and approved by two design researchers, who are the supervisors of this thesis. In some instances, the participants mentioned their constructs directly in English. Those constructs have also been checked by the author and the above mentioned thesis supervisors in regards to consistency in meaning and terminology. Occasionally, what the participant said and the English term she/he used had different meanings. For these instances, the author consulted the raw transcription data in order to clarify the construct's translation and his translation/correction proposal of the user construct has been triple checked by the supervisory team as well. The complete list of the musicians' 357 unique bipolar construct pairs can be found in Appendix D.

For the second step of coding, 357 unique L0 codes were grouped into 123 Level 1 (L1) codes based on their semantic similarity. This procedure provided a more holistic view of the pool of dimensions while bringing down the constructs to a more manageable scale. A sample of L1 codes based on semantic similarity is presented in Table 5.2.

Table 5.2 Sample of Level 1 codes based on semantic similarity.

Level 0 (L0) Raw Construct	Level 1 (L1) Semantic Similarity
Gestures observable by audience (L0)	**Visible to Audience (L1)**
Interface visibility for audience (L0)	**Visible to Audience (L1)**
Performance visible to audience (L0)	**Visible to Audience (L1)**
Visibility to audience (L0)	**Visible to Audience (L1)**

The L1 codes were then entered on a separate column on the Excel document named as the 'defining dimensions' of the relative constructs. Table 5.3 is a sample, which illustrates the placement of the L1 codes in the participants' repertory grids.

Table 5.3 Repertory Grid sample displaying L0 and L1 codes.

Unique Participant Identifier	**Product Triplet**	**Positive Pole Construct (7)**	**PRODUCTS**					**Negative Pole Construct (1)**	**Defining Dimension**
			A	**B**	**C**	**D**	**E**		
		PARTICIPANT 24							
P24L17	ABC	Çalgıcının performansının seyirci tarafından görülebildiği **Performance visible to audience (L0)**	1	7	2	2	1	Çalgıcının performansının seyirci tarafından görülemediği **Performance not visible to audience**	**Visible to Audience (L1)**

The third and final step in coding is an attempt to further structure the semantically similar codes in light of a conceptual framework. The framework is created for two reasons: Firstly, a conceptual framework has the ability to elaborate on the key factors; in other words, constructs or variables, as well as the presumed relationships among them (Miles & Huberman, 1994). Secondly, in order to bring down the number of codes to a qualitatively and quantitatively manageable scale.

According to Miles and Huberman (1994) *frameworks can be rudimentary or elaborate, theory driven or commonsensical, descriptive or casual* (p. 18).

As this research is primarily structured around musicians' (and the audience's) musical interaction experiences, Verplank's (2009) framework for designing interactive products (Figure 5.1) has been adopted in order to provide the foundation for the conceptual framework of this study.

According to Verplank (2009), the central concern in regards to designing interactions is how to design for people’s physical, emotional and intellectual needs. Thus, Verplank believes that interaction designers answer three questions: *How do you DO? How do you FEEL? How do you KNOW?*

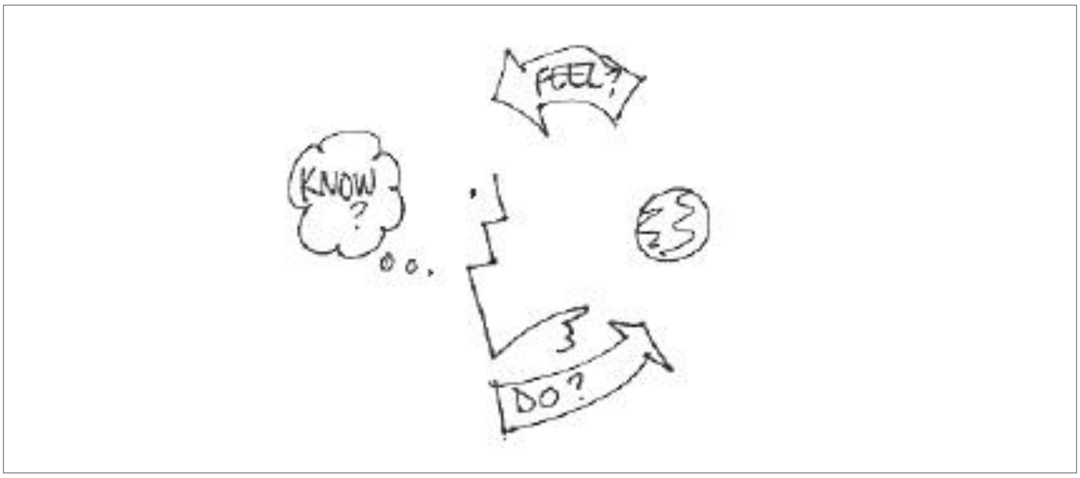

Figure 5.1 Bill Verplank’s Framework for Designing Interactions (2009).

Verplank (2009) elaborates on these three questions as follows:

How do you do? How people do things with interactive products presents designers a chance to provide users choices; i.e. analogic control vs. the ‘machine’ taking over (e.g. continuous control (expressive) with a handle vs. discrete control (precise) with a button).

How do you feel? Sensorial information (visual, auditory, tactile, etc.) in other words, sensorial qualities of the interactive product determines users’ feelings about the interaction experience.

> Designers are continually faced with this choice of suggestion or clarity, metaphor or model, poetry or law (Verplank, 2009).

How do you know? As emerging technologies increase the complexity of interactive products’ behaviours, the current challenge for interaction designers is to consider the level of comprehension they are expecting from users whom they design for. Different types of situations may call for different types of ‘knowledge’ (e.g. step by step i.e. path knowledge, immediate interaction, map-like knowledge, etc.)

Verplank (2009) concludes that the choices for interaction designers are arranged around these three questions and best products or systems support not one or the other but all three of these parameters.

> Good interactions are the appropriate styles of doing, feeling and knowing plus the freedom to move from one to the other (Verplank, 2009).

The first step in constructing the conceptual framework rephrases Verplank's three questions to: How does the musician do? feel? and know? The variables belonging to this aspect are categorized as: Musician's interaction experience; i.e. **'Musician IX'.**

Secondly, the framework is expanded through the capabilities of the interactive products. The variables belonging to this aspect are categorized as: Musical instrument specification; i.e. **'Instrument Specs'.**

Finally, a third aspect was created for the framework in order to address what the participants consider to be an indispensable element of any live performance; the audience, and their overall experience of the musical performance. The variables belonging to this aspect are categorized as: Audience's performance experience; i.e. **'Audience PX'.** As a result, a Framework for Musical Interaction (Figure 5.2) is constructed in order to discuss and interpret findings concerning the design of new musical instruments from an interaction design and user experience perspective.

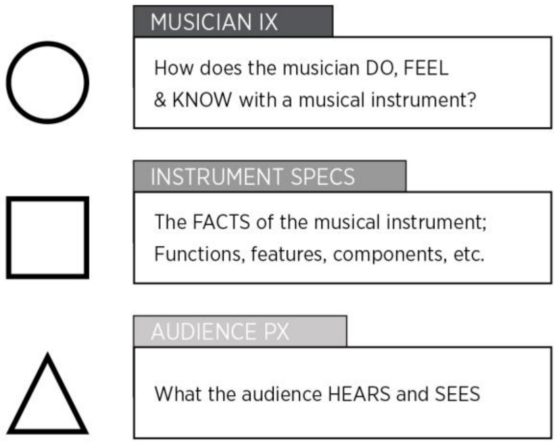

Figure 5.2 Framework for Musical Interaction in the context of Live Musical Performance.

The conceptual framework uses Verplank's (2009) terms collectively to define the scope of Musician IX, but does not use the sub-divisions; DO, FEEL and KNOW as a structure for the content analysis.

The musical interaction framework clusters the 123 L1 codes into 31 Level 2 (L2) codes (Figure 5.3).

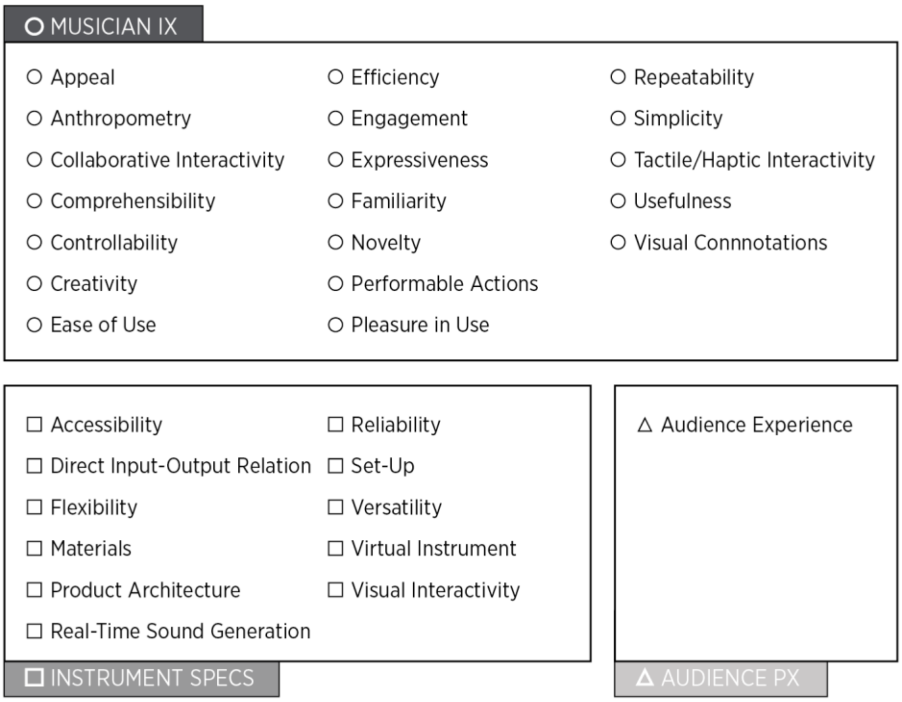

Figure 5.3 Framework for Musical Interaction with L2 Codes.

Both of the aforementioned thesis supervisors have examined the entirety of the coding process and the construction of the conceptual framework in order to maintain reliability for the coding procedures. All necessary revisions were iteratively carried out based on their comments and suggestions.

These codes are presented as the main qualities to be discussed in this study. The detailed breakdown of the musical interaction framework, which presents the hierarchy of L1 and L2 codes is illustrated in Figure 5.4. The line widths and numbers are based on the number of participants, who mentioned that specific L2 quality.

As different researchers may name the identical constructs with different terms, a glossary of terms is needed in order to achieve clarity in meaning and consistency of the results across different studies. A comprehensive glossary of terms for all L1 and L2 codes is presented in Appendix E.

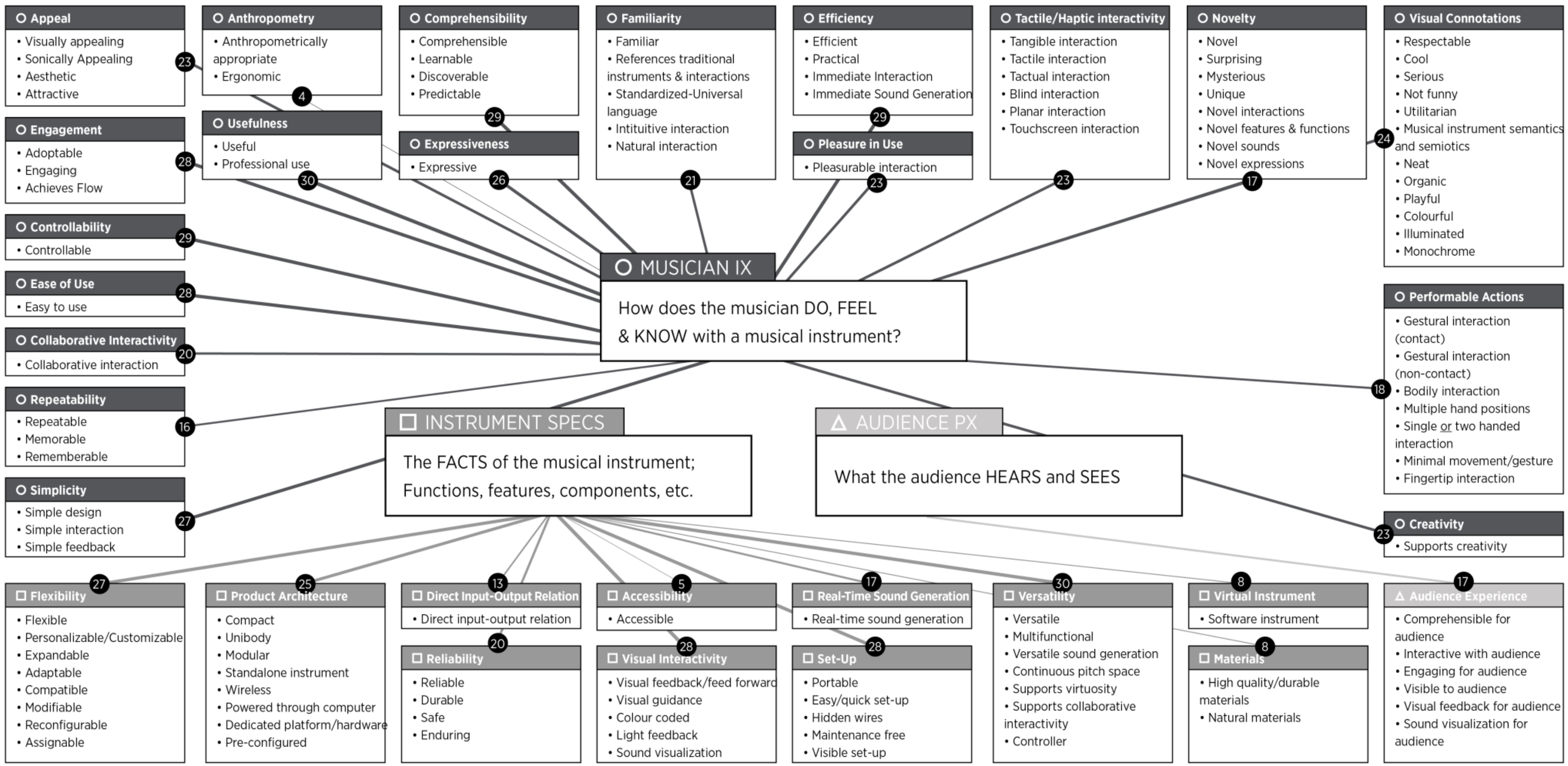

Figure 5.4. Framework for Musical Interaction; L1 and L2 codes.

The L2 coding process has two steps:

First, the L2 code is entered directly on a new column next to the relevant L1 code. This quality is named as the 'Active' quality and it directly refers to 'What the musician wants' (Table 5.4). In other words, the 'Active' quality is the 'affecting construct' described by the participant.

In the case of the sample below, the participant elicits 'visual representation of interactions' on the instrument interface. This construct is grouped under Visual Guidance L1 code based on semantic similarity. The related L2 code, in other words, the active quality is Visual Interactivity (red).

Table 5.4 Repertory Grid sample with L0, L1 and Active L2 codes.

Unique Participant Identifier	Product Triplet	Positive Pole Construct (7)	PRODUCTS A	B	C	D	E	Negative Pole Construct (1)	Defining Dimension	ACTIVE (Affecting Quality)
		PARTICIPANT 03								
P03L07	ABC	I can see the complex relationships. Dechipers not only sonically but also visually. **Visual representation of interactions (L0)**	3	5	5	6	1	Interactions are not visible at first glance. They are understood only by paying attention to their effect on the sound. **No visual representation of interactions**	**Visual Guidance (L1)**	**Visual Interactivity (L2)**

As previously mentioned in Chapter 3 (Section 3.2.2.3) and Chapter 4 (Section 4.5.1) understanding the reasons behind people's expectations or needs reveals, what Kelly defines as the superordinate and subordinate relationships between the elicited constructs (Kelly, 1955, p. 58; Fransella et al., 2004, p. 9). Thus, asking a 'Why?' question after learning the participant's preference (laddering) (Hinkle, 1965; Crudge & Johnson, 2007) or a 'What?' or 'How?' question (pyramiding) (Landfield, 1971 p. 135; as cited in Fransella et al., 2004) is necessary for exposing the hierarchy of interrelationships in a user's personal construct system.

Thus, a second column is created for the 'Passive' quality. In the sample (Table 5.5), the passive quality indicates the 'affected construct', which reveals 'why the musician wants visual guidance'.

Participant's comments in the negative construct (highlighted in red) give a very clear reference to comprehensibility. Thus, the participant associates visual interactivity with comprehensibility.

Table 5.5 Repertory Grid sample with L0, L1 and Active and Passive L2 codes.

Unique Participant Identifier	Product Triplet	Positive Pole Construct (7)	PRODUCTS A	B	C	D	E	Negative Pole Construct (1)	Defining Dimension	ACTIVE (Affecting Quality)	PASSIVE (Affected Quality)
		PARTICIPANT 03									
P03L07	ABC	I can see the complex relationships. Dechipers not only sonically but also visually. **Visual representation of interactions (L0)**	3	5	5	6	1	Interactions are not visible at first glance. They are **understood** only by paying attention to their effect on the sound. **No visual representation of interactions**	**Visual Guidance (L1)**	**Visual Interactivity (L2)**	**Comprehensibility (L2)**

All repertory grids were completed with the active and passive L2 codes as explained above. The final code-count of the 3-level coding structure is presented in Table 5.6.

Table 5.6 Final code-count of the 3-level coding structure

Level 0 (L0) **Raw Construct**	**Level 1 (L1)** **Semantic Similarity**	**Level 2 (L2)** **Framework for Musical Interaction**
357	123	31

Additional Coding Procedures

A final step involving an addition/reduction procedure has also been carried out during the coding of the repertory grids of the participants. The details of this procedure is presented below:

Data Reduction Procedures

Two types of repertory grids are deleted from the final repertory grid table:

1- <u>Participant constructs which are not in context/scope of the study</u>

Since the aim of the thesis study is to investigate new musical instruments from an interaction and user experience perspective, constructs relating to affordability or pricing are beyond the scope of this study. Thus, after the repertory grid data is completely transcribed to Microsoft Excel, the author has deleted all rows of repertory grids, which includes the above mentioned constructs.

2- <u>Re-phrased participant constructs with identical meaning</u>

Participants sometimes elicited the identical dimensions by phrasing them differently. After checking each participant's repertory grid table, the author carefully identified and deleted the re-phrased rows with identical bipolar construct pairs. This is considered a necessary intervention because the inclusion of identical bipolar pairs would have caused miscalculation during the analysis.

Data Addition Procedures

During the interview sessions, while appraising a product triplet relating to a particular dimension, in certain instances participants engaged in multi-dimensional discussions associated to a single bi-polar construct pair.

As the application guidelines of the RGT does not allow nor recommend the interviewer to intervene with the participant's discussion for any reason, ignoring the multi-dimensional information inevitably causes data loss critical for the study. Data addition procedure was carried out through only <u>duplicating the repertory grids</u>. In order to correctly identify the grids that require duplication, the video recordings of the complete interview sessions and their word-for-word transcriptions have been reviewed again. A sample from the repertory grids is presented below in Table 5.7 in order to explain the duplication process in detail.

Table 5.7 Sample of duplicated repertory grids

Positive Pole Construct (7)	PRODUCTS A	B	C	D	E	Negative Pole Construct (1)	Related Raw Data (Session Transcription)	Defining Dimension	ACTIVE (Affecting Quality)	PASSIVE (Affected Quality)
PARTICIPANT 03										
Organic materials such as wood or metal **Natural materials (L0)**	1	1	3	3	1	Plastic instrument (or its derivatives) **Synthetic materials**	We have adopted these materials as 'musical instrument materials' through the musical instruments that have been used for many years. Secondly, naturally it gives the feeling of sturdiness and durability.	**Natural Materials (L1)**	**Materials (L2)**	**Familiarity (L2)**
Organic materials such as wood or metal **Natural materials (L0)**	1	1	3	3	1	Plastic instrument (or its derivatives) **Synthetic materials**	We have adopted these materials as 'musical instrument materials' through the musical instruments that have been used for many years. Secondly, naturally it gives the feeling of sturdiness and durability.	**Natural Materials (L1)**	**Materials (L2)**	**Reliability (L2)**

Highlighted in red in the session transcription; the participant's comment "we have adopted these materials as *'musical instrument materials' through the musical instruments that have been used for many years"* indicates <u>familiarity</u>. However, the participant continues with his appraisal by saying: *"Secondly, naturally it gives the feeling of sturdiness and durability"* (highlighted in red in the duplicate grid) which is a reference related to <u>reliability</u>. Thus, the repertory grid is duplicated in order to capture the interrelationship between materials and reliability.

Frequency Count of the Elicited Constructs

Using the framework for musical interaction, a hierarchy of importance was established through a frequency count of each individual quality (L2 codes) among the 30 participants.

Figure 5.5 is a visual representation of the frequency counts of the qualities in a descending order from maximum (30) to minimum (4) number of participants, colour coded to the framework for musical interaction mentioned in the previous section.

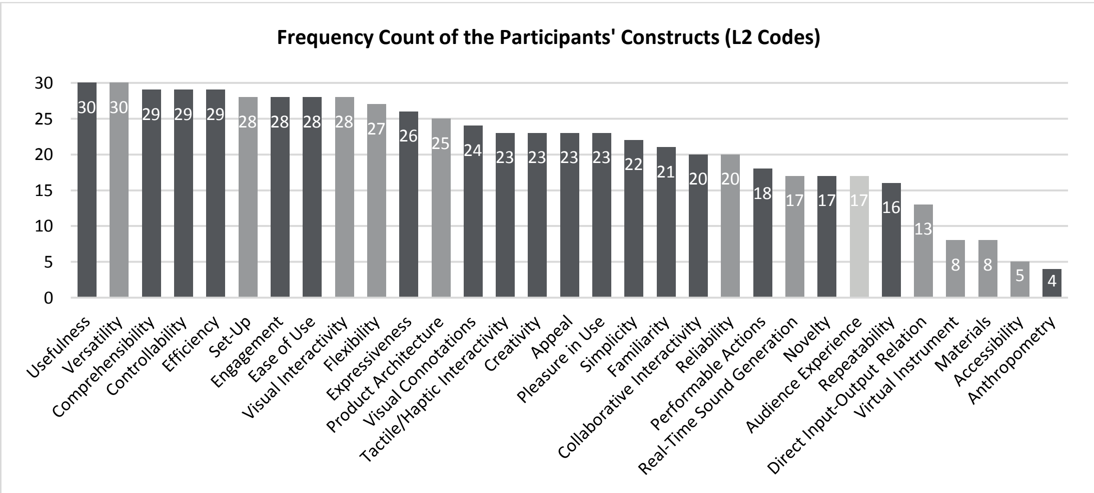

Figure 5.5 Frequency Count of Participants' Constructs (L2 Codes)

The results of the frequency count reveal two important findings: Firstly, 26 out of 31 qualities have been mentioned by more than 50% of the participants. This finding points to an overwhelming similarity between what musicians consider important in relation to the dimensions of new musical interactions. Secondly, the high rate of similarity between musicians with different levels of technology experience also proves that regardless of technological fluency and musical background, musicians' minds work in similar ways when exposed to new musical interactions. Hence, further individual analyses of the three participant groups (for participants' framework of technology experience, see Section 4.2.1) and cross-comparisons were not carried out.

The isolated frequency orders of qualities belonging to Musician IX and Instrument Specification are presented in Figure 5.6, Figure 5.7 respectively. Audience PX is a single quality (L2 code) and it has been mentioned by 17 participants.

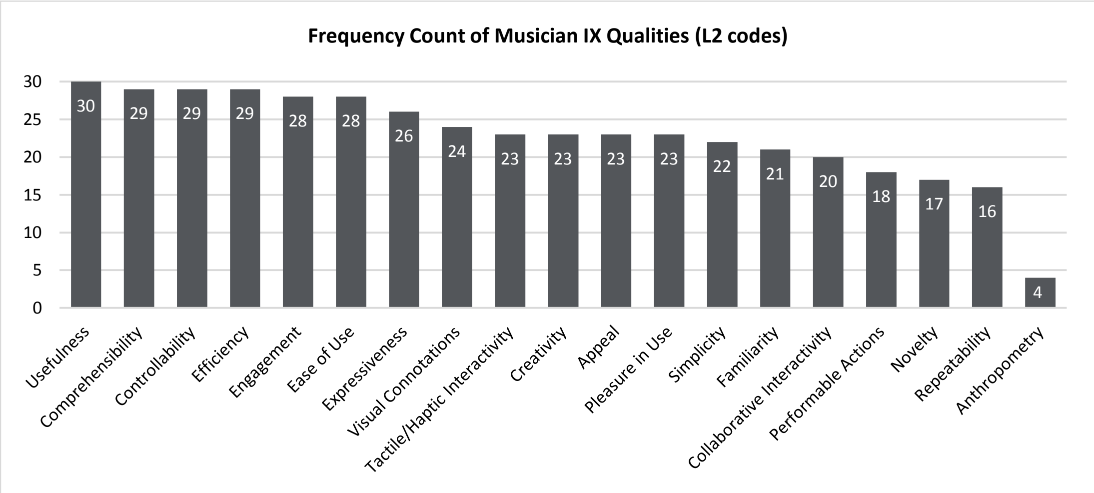

Figure 5.6 Frequency Count of Musician IX qualities (L2 Codes)

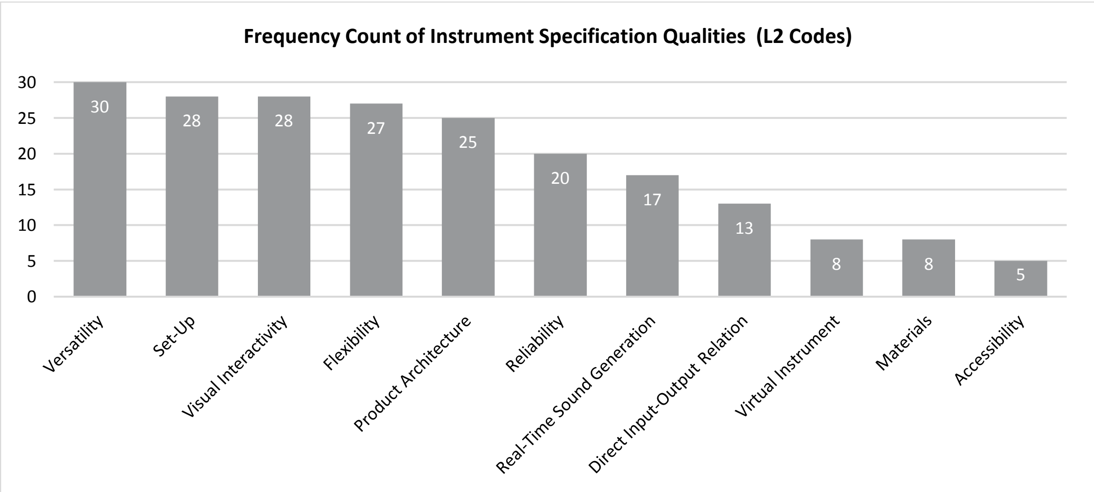

Figure 5.7 Frequency Count of Instrument Specs qualities (L2 Codes)

The results of the frequency count suggest that usefulness, comprehensibility, controllability, efficiency, engagement, ease of use and expressiveness are the leading Musician IX qualities in the study. In regards to Instrument Specification; versatility, set-up, visual interactivity and flexibility are the most frequently mentioned qualities by the participants. Audience PX is represented as a single quality.

Appendix F illustrates the frequency distribution of the 31 L2 codes among the 30 participants of the study. Thus, the highest frequency count for any quality is 30. The duplicate rows of participants' repertory grid tables have been excluded from the frequency count to ensure the same dimension is not calculated twice for any participant.

The frequency count also reveals the diversities between the participants' perceived evaluations. It is interesting to note that virtual instrument, materials, accessibility and anthropometry have been mentioned by less than ten participants (below 30%); making them the least frequent qualities in the research. These qualities are not necessarily unimportant and their rating frequency may be related with the limitations of the research.

Materials and anthropometry in particular are considered important topics, especially in design research. Hence, a few reasons can be speculated in relation to why these qualities were not higher-up in musicians' evaluations despite the author's expectations. None of the five RGT elements (instruments) featured wooden materials. This might be one of the reasons materials was not picked-up more often during the interview sessions. Further more, as the stimuli of the experiment were visual cards and videos, the sense of touch and physicality, which are strongly linked to materials, were missing. Similarly, if the participants were given actual musical instruments for a 'hands-on' evaluation, dimensions related with ergonomics (and anthropometry) could have been noticed immediately.

The 'sound' itself was also expected to be a topic of great discussion. The author proposes that especially concerning new generation electronic musical instruments, musicians take it for granted that all the instruments can deliver good sound quality, thinking that this is a matter of price tag and technology. Further more, the quality and nature of the sound itself, generated through synthesis or sampling, is beyond the scope of the research; as its dimensions are more suitably claimed by various engineering domains.

5.2 Cross Impact Analysis

As previously mentioned in the Introduction Chapter, this study aims to find answers to the following research questions:

RQ 1: What are the dimensions of new musical interactions, which matter to musicians?

RQ 2: Why do these dimensions matter to the musicians?

RQ 3: How can these dimensions be utilized to improve musicians' interaction, user experience and live performance with new generation electronic musical instruments?

RQ 3.1: What are the similarities and diversities between the elicited dimensions?

RQ 3.2: How/In which ways are these dimensions interrelated?

The primary analysis answers the first (RGT) second (laddering and pyramiding) and partially the third (RQ 3.1) (semantic similarity and conceptual framework) research questions through the empirical experiment, content analysis and the framework for musical interaction. Further investigation is required in order to understand and interpret the interrelationships (RQ 3.2) between the elicited dimensions.

RGT is a theoretically grounded, structured and empirical approach. However, it is not restricted or limited to already existing, pre-prepared or researcher-generated categories (Fallman & Waterworth, 2010). RGT's open approach puts it on the border between qualitative and quantitative research, (Fallman & Waterworth, 2010) which Tomico et al. (2009) similarly describe as *a hybrid, quali-quantitative approach*. Especially in the context of design research, RGT's versatility allows for both qualitative and quantitative data collection, either or both of which can be utilized based on the design researcher's purposes. The qualitative data collected from the participants can be used for exploratory and generative research. Additionally, the participants' constructs reveal which qualities they use when they evaluate a certain set of products. Additionally, participants' rating of the RGT elements (quantitative data) can be used to statistically evaluate the products that are used for the study.

Kuru (2015) suggests that while RGT data is traditionally analysed through quantitative data, design researchers can decide to use alternative analysis methods because reasons behind users' expectations and needs are too intricate and rich to be simplified through quantitative analysis (Kolko, 2011). Running conventional factor analysis for the RGT data excludes some of the participants' constructs (Kuru, 2015). However, the multidimensional nature of product design forces the designers to consider all factors simultaneously, including their interrelations. Thus, having to delete constructs during quantitative analysis inevitably causes high amounts of data reduction (Tore-Yargin & Erbuğ, 2012; Kuru, 2015).

Fallman and Waterworth (2010) suggest that quantitatively analyzing participants' ratings of the RGT elements through relational statistical methods is 'semantically blind'. On the other hand, qualitatively analyzing the individual participants' constructs is 'statistically blind' because it is driven by an interpretation of the semantic content rather than the participants' ratings (Fallman & Waterworth, 2010). Kuru (2015) and Kuru and Erbuğ (2013) propose that cross impact analysis (CIA) can potentially show the most important construct groups within the data. According to Kuru, CIA can simultaneously solve both problems (of blindness) because while CIA depends on the numerical relations (statistical) between construct groups, it also depends on the semantic analysis (qualitative) of the individual constructs. In other words, CIA can be used to *quantify the qualitative data analysis*.

Cross impact analysis is a method developed for futures research. The concept of Cross impact analysis was originally developed by Gordon and Helmer in 1966 and the first experiments with the 'Cross-Impact Method of Forecasting' were programmed and reported in 1968 by Gordon and Hayward. According to Gordon (1994), the development of the method was based on a simple question: *Can forecasting be based on perceptions about how future events may interact?* (p. 1). Thus, rather than projecting future events one by one in an isolated manner, (Serdar Asan & Asan, 2007) CIA forecasts future scenarios through exploring the interactions and influences between future events that form these scenarios (Stover &

Gordon, 1978; Gordon, 1994; Schlange & Jüttner, 1997; Scholz & Tietje, 2002; Bradfield et al., 2005). CIA is a very flexible method and thus, it has been applied to a wide variety of problems including market and product opportunities, communication, education, natural resource and many other subjects. (Stover & Gordon, 1978).

Since its development, several versions of CIA have been developed by researchers, which can be classified into three groups: quantitative, qualitative, and mixed CIA (Serdar Asan & Asan, 2007). Serdar Asan and Asan state that the aim of the qualitative CIA is to reduce the complexity of the system and to identify what they term as 'key variables' that should be studied first. A key variable's importance is determined by the number and intensity of its relationships inside the system. Schlange and Jüttner (1997) propose that as the changes in key variables affect the whole system, they deserve more attention in the future.

The first step of qualitative CIA involves a problem analysis, which defines the scope of the analysis, the scenario field, and the modelling work. Then, experts are consulted to estimate the interrelationships; or 'cross-impacts', between a set of key variables on a specific subject, usually through a matrix of conditional probabilities or impact values (Serdar Asan & Asan, 2007; Wiek et al., 2008). The experts fill the cells of this matrix on a rating scale between 3 to 7 points (Scholz & Tietje, 2002).

In the context of this thesis, the above mentioned experts are replaced by the professional musicians who participated in the research. Rather than asking them to estimate and rate the interrelations, the cells of the matrix are filled directly based on their personal evaluations which reveal the interrelationships between the variables.

The essential tool of the CIA method is a cross impact matrix (CIM). Schlange and Jüttner (1997) consider a cross-impact matrix as *a tool for systematic description of all potential modes of interaction between a given set of variables and the assessment of the strength of these interactions*. In other words, CIM defines how variables influence each other (Bradfield et al., 2005; Wiek et al., 2008). CIM also ensures that no interrelations are omitted between any defined variable because, for every single pair of variables, the intensity of the impact that one has on the other is examined (Schlange & Jüttner, 1997).

Concerning this research, the CIA was carried through the following steps:

First, a 31x31 impact matrix (CIM) is formed based on the 31 qualities (L2 codes from the framework of musical interaction) elicited from the participants (Table 5.8). The influence strength of any quality is determined by the numbers placed at the intersection cells of the related qualities. Any participant's single mention of a relationship between two qualities (through the why? (laddering) and what? (pyramiding) questions) is counted as '1' in the intersecting cell. The final number in each intersecting cell indicates the number of times that specific interrelationship was mentioned by the participants.

To give an example; if a participant states an interrelation between simplicity and ease of use, the number '1' is placed in the intersecting cell between these two qualities. If 22 more participants mention the same interrelation, the number at the cell is replaced as '23'. The total sum of the rows (active sum) indicate the quality's activity, in other words how strongly it influences other qualities. The total sum of the columns (passive sum) indicate the quality's passivity; i.e. how strongly it is influenced by other qualities. For any particular quality; the active sum represents the participant's construct where as, the passive sum represents the other qualities, which the participant perceives in relation to the active quality. Thus, in addition to numerically identifying the importance levels of constructs, CIM can also reveal which factors affect people's perceptions when they think about a specific quality (Kuru, 2015).

		MUSICIAN IX																			INSTRUMENT SPECIFICATION											AUDIENCE UX	
		Anthropometry	Appeal	Collaborative Interactivity	Comprehensibility	Controllability	Creativity	Ease of Use	Efficiency	Engagement	Expressiveness	Familiarity	Novelty	Performable Actions	Pleasure in Use	Repeatability	Simplicity	Tactile/Haptic Interactivity	Usefulness	Visual Connotations	Accessibility	Direct Input-Output Relation	Flexibility	Materials	Product Architecture	Real-Time Sound Generation	Reliability	Set-Up	Versatility	Virtual Instrument	Visual Interactivity	Audience Experience	ACTIVE SUM
MUSICIAN IX	Anthropometry					3				1																	2						6
	Appeal																																0
	Collaborative Interactivity					1	7			4					9				1													1	23
	Comprehensibility					1		3	9	5									2														20
	Controllability						11		3	3					2				16								1						36
	Creativity		1																														1
	Ease of Use					2			5	3					4				3		1												18
	Efficiency						2			4					2																		8
	Engagement																																0
	Expressiveness									19									25														44
	Familiarity				16	2	1	4	1	5	2				2				7													2	42
	Novelty		10	1			2				2				2				7				1								1	5	31
	Performable Actions					11	2		9	2	6				3				6				15									3	57
	Pleasure in Use									7																							7
	Repeatability								1	1									15														17
	Simplicity		1		12	1	2	14	11	4	2				5	2			1	1			3				2						61
	Tactile/Haptic Interactivity					18	1	6	6	10	3	1			7	1			5				1				1		1			1	62
	Usefulness								1	14					1																		16
	Visual Connotations		22		1					10		1	4		3				1								1					12	55
INSTRUMENT SPECIFICATION	Accessibility																																0
	Direct Input-Output Relation				11	2				3		2				1																3	22
	Flexibility		2	2		2	12	3		2	12		1						23		1											1	61
	Materials		1			1				1		1			2				1								6						13
	Product Architecture		2			3	1	4	26	1					2				6				8				9						62
	Real-Time Sound Generation					9	12			3					1				17													2	44
	Reliability																																0
	Set-Up			1					30	1					1				1		1						5					7	47
	Versatility		1	10		5	11	1		9	23				3				30								2	1				1	97
	Virtual Instrument																				4		3				1	3					11
	Visual Interactivity		2		26	4	1	14	3	4		3	1		3	15			7			1										7	91
AUDIENCE UX	Audience Experience																																0
	PASSIVE SUM	0	42	14	66	65	65	49	105	116	50	8	6	0	52	19	0	0	174	1	7	1	31	0	0	0	30	4	1	0	1	45	

Table 5.8 Cross Impact Analysis – Cross Impact Matrix.

The next step involves the construction of a ‘system grid’ (Figure 5.8) in order to visualize and further understand a quality’s significance in the whole system (Wiek et al., 2008). Each quality is placed on the system grid based on their total active and passive sums, which represent their influence strengths. The horizontal line on the system grid represents the arithmetic mean of the activity scores for each quality where as, the vertical line represents the arithmetic mean of the respective passivity scores. These lines separate the system grid into four main sectors, i.e. active, passive (reactive), ambivalent (critical) and buffering, each of which embody specific system significances. The characteristics of the sectors (Wiek et al., 2008; Scholz and Tietje, 2002, p. 99) are explained as follows:

Active Sector (orange): The qualities in the active sector strongly affect other qualities but they are only slightly influenced by them. These qualities essentially act as the ‘means’ to achieve the system goals. In this study, versatility, visual feedback, product architecture, tactile/haptic interactivity, simplicity and flexibility are the leading qualities which have strong impacts on the system.

Ambivalent/Critical Sector (purple): The qualities in the ambivalent sector have strong influences on other qualities and they are also strongly affected by them. These are the most critical qualities which deserve primary attention because of their bidirectional impact on the system. Expressiveness and controllability are the two qualities in this sector and they have a critical influence on the overall system.

Reactive/Passive Sector (green): The qualities in the reactive sector are strongly affected by other qualities but they have only a slight influence on them. These variables are very important because they represent the ‘end goals’ of the system. Usefulness, engagement, efficiency, comprehensibility and creativity are the primary qualities that are most affected in the system.

Buffering Sector (blue): The qualities in this sector slightly affect other qualities and they are only slightly influenced by them. Since design is a multidimensional phenomenon, these qualities should not be completely ignored because they are still an important part of the entire system. Collaborative interaction, direct input-output relation and repeatability stand out as moderately important qualities in this sector.

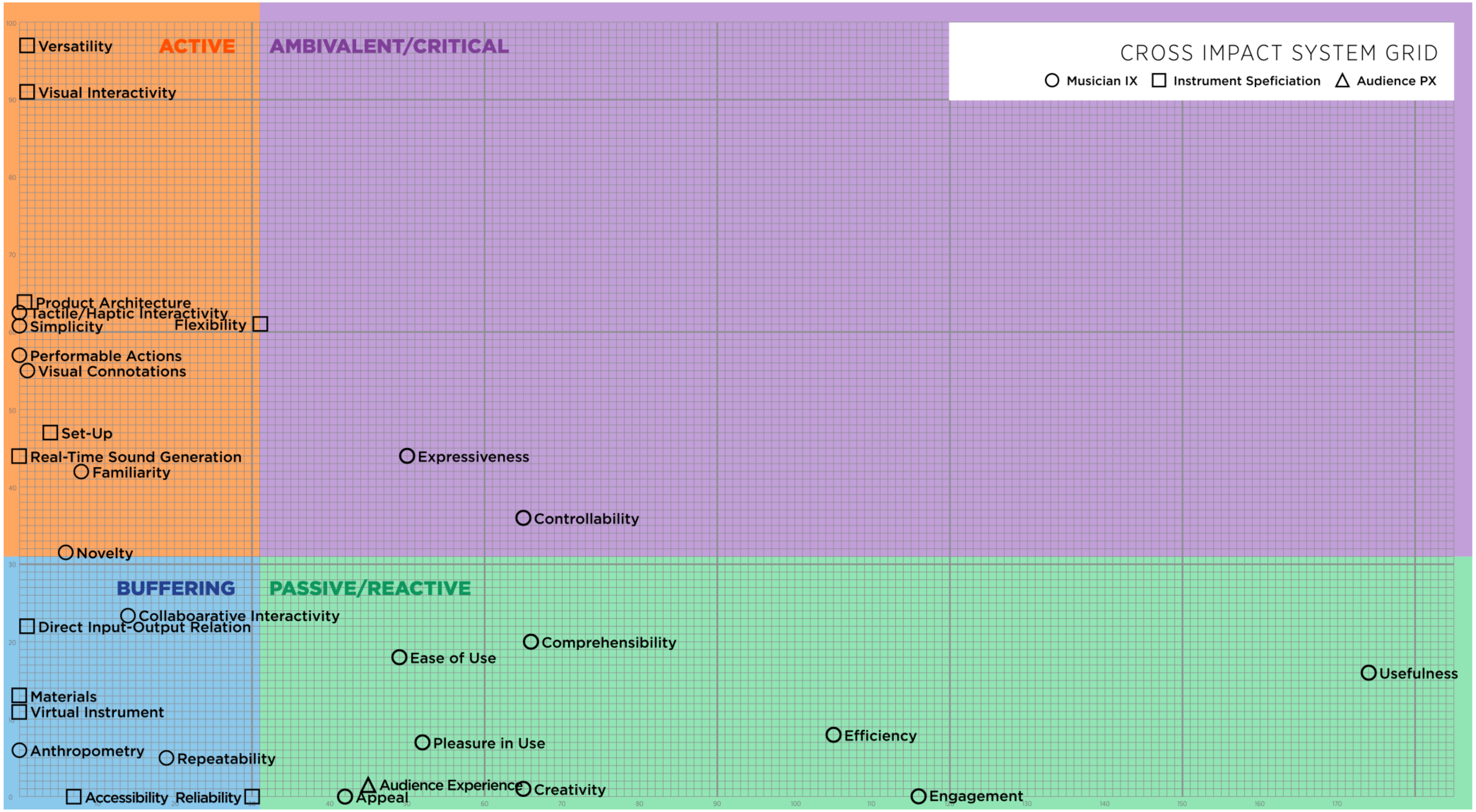

Figure 5.8 Cross Impact Analysis – Cross Impact System Grid

A complete breakdown of the sectors based on the distribution of qualities is shown in Table 5.9.

Table 5.9 Distribution of Qualities in the System Grid.

System Grid Sector	Affects other Qualities	Affected by other Qualities	Qualities
Active	Strong	Weak	Familiarity, Flexibility, Novelty, Performable Actions, Product Architecture, Real-Time Sound Generation, Set-Up, Simplicity, Tactile/Haptic Interactivity, Versatility, Visual Connotations, Visual Interactivity
Ambivolent (Critical)	Strong	Strong	Controllability, Expressiveness
Passive (Reactive)	Weak	Strong	Appeal, Audience Experience, Comprehensibility, Creativity, Ease of Use, Efficiency, Engagement, Pleasure in Use, Usefulness
Buffering	Weak	Weak	Accessibility, Anthropometry, Collaborative Interactivity, Direct Input-Output Relation, Materials, Reliability, Repeatability, Virtual Instrument

The next step in the CIA involves the construction of a 'system graph' (Scholz & Tietje, 2002, p. 99). System graph is a structured network, which visualizes how all the variables in the study are interlinked. Scholz and Tietje (2002) suggest that if only a few variables are present, the strengths of impacts can be displayed by varying the line weights and arrows. However, as there are 31 individual qualities in this study, the system graph (Figure 5.9) is presented with identical line weights in order to prevent information overload. Additionally, only the strong impacts (for each individual quality) are presented for the same reason. In order to further enhance the readers' conception of the system model, each quality's activity score (CIM active sum) is noted on the top right where as, the passivity score (CIM passive sum) is noted on the top left (Scholz & Tietje, 2002, p. 101). Furthermore, the qualities are colour coded to the system grid and arrows indicate the direction of influence.

While the system graph provides insight into the relative importance and mutual interactions of the variables, it is still too complex for readers to see the interrelationships for individual qualities. Hence, the final step of the CIA involves the construction of individual egocentric networks (Hansen et al., 2010; Töre Yargın & Erbuğ, 2012; Töre Yargın, 2013; Kuru & Erbuğ, 2013) in order to visualize interpret and discuss the specific system of interactions surrounding each individual quality.

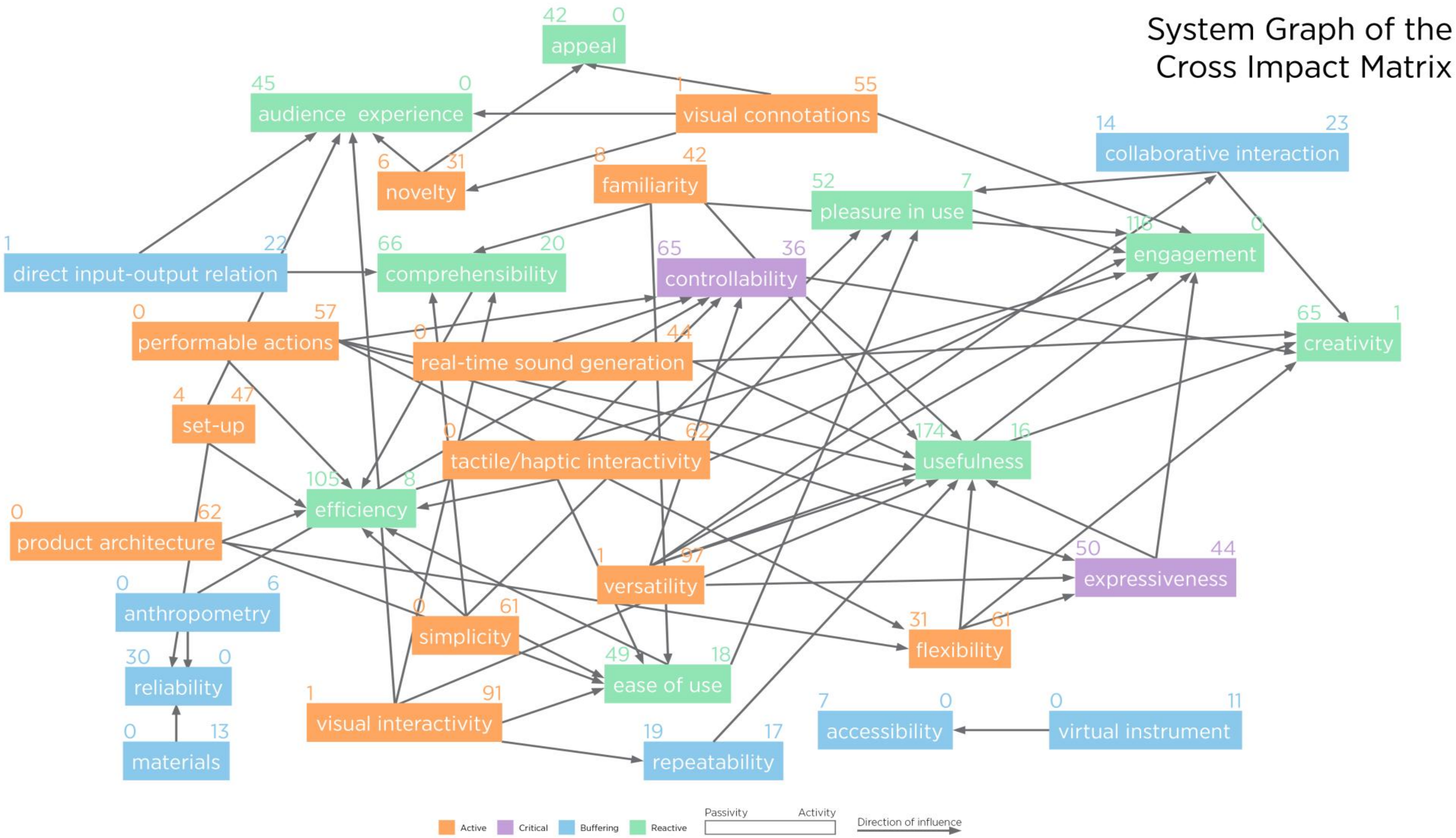

Figure 5.9 A System Graph of the Cross Impact Matrix

5.3 Interpretation of Interrelationships between the Qualities

This section presents the individual interpretations of each quality, based on their interrelationships within the system. The qualities will be presented based on sector (active, ambivalent, buffering, passive) and ordered from high to low importance within the respective sector they belong to. For each quality the discussion will focus on the stronger interrelations while intentionally leaving out the qualities, which have minor or very little effect on the central quality. Relevant participant comments (P) are quoted in order to enrich the discussions. In the participant quotations, elements (musical instruments) used in the RGT are referred to as (A), (B), (C), (D) and (E).

The visual specifications of the egocentric networks (Table 5.10) are as follows:

- The large shape (circle, square, triangle) at the centre indicates the quality under discussion.
- The surrounding shapes represent the interrelating qualities.
- All shapes are colour coded to their respective system grid sector.
- The line weights indicate the strength of interrelationship (the sum of the number of mentions by the participants for that particular interrelationship) between the surrounding quality and the central quality.
- Direction of arrows indicate the direction of impact between the qualities. If the central quality affects the surrounding quality, the arrow points to the surrounding quality. When the central quality is affected by the surrounding quality, the arrow points to the central quality. A double arrow indicates a mutual (i.e. bidirectional) impact between the qualities.
- The faded (light grey) qualities represent interrelationships with very small impacts; hence, they are left out of the discussions.
- The size of the central shape does not represent any numerical value; it is only for visualization purposes.

Table 5.10 Visual Specifications of the Egocentric Networks.

GRAPH FEATURE	INFORMATION
	Strength of interrelationship
	Direction of impact (Tip of the arrow points to the affected quality)
CONCEPTUAL FRAMEWORK	○ Musician IX ☐ Instrument Specs △ Audience PX
SYSTEM GRID SECTOR	Active Critical Buffering Reactive

5.3.1 Interpretation of Qualities in the Active Sector

The qualities in the active sector strongly influence the other qualities in the system and they are only slightly affected by them. These qualities are: versatility, visual interactivity, product architecture, tactile/haptic interactivity, simplicity, flexibility, performable actions, visual connotations, set-up, real-time sound generation, familiarity and novelty.

5.3.1.1 Versatility

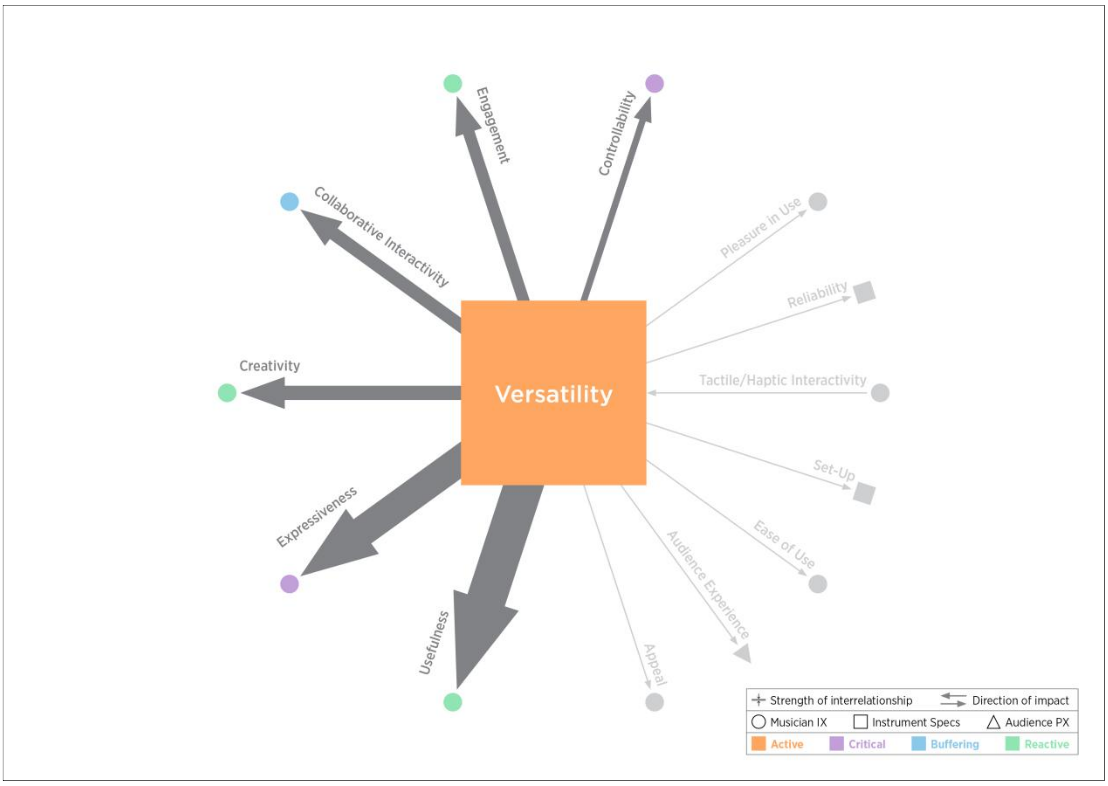

Figure 5.10 Egocentric Network Graph for Versatility.

Versatility is the highest ranking active quality in the study because it embodies many important dimensions, which the musicians require in order to achieve a useful, expressive and creative performance. Musicians believe that versatile instruments are more controllable and engaging, and they can also lay the foundations for collaborative performances (Figure 5.10).

Musicians expect a musical instrument to feature as many of the basic musical functions (sound synthesis, sequencing, sampling, live/signal processing) as possible. Thus, having unlimited musical possibilities affect both perceived usefulness and creativity. Diversity and quality of the generated sounds strongly impact the perceived usefulness of an instrument. Musicians also expect the instrument to be versatile enough to allow the performance of different music styles and genres. Additionally, being able to use the instrument as a ‘controller only’ positively contributes to both its usefulness and creative potential.

> Here (D) there are things that are not found in a guitar or a harp. You can’t make a vibrato on a harp but in (D) certain controllers activate and alter the sound. Electronic musical instruments should exist for this in the first place; they should enable me to do things, which can’t be done on acoustic instruments due to their limitations. (P 03)

Musicians also believe that versatile musical interfaces empower them to play more expressively. A continuous pitch (frequency) space, high resolution gesture sensors, and multi-touch enable the users to perform musical articulations, nuances, microtones and timbral modifications; dimensions, which strongly enhance the perceived expressiveness of a musical instrument.

> In the musical sense (D) can do portatos or vibratos, I mean it looks like an ‘articulated’ instrument. Both in terms of dynamics and articulation. Besides, as far as I understand it is also touch sensitive, you can make nuances. I mean it doesn’t generate something mechanical, definitely no MIDI sound, it is beautiful in that aspect. (P 12)

Musicians expect versatile instruments to embody a high ceiling of virtuosity. In other words, the instrument should allow a ‘growth’, during which, after sufficient practise musicians will be able to express themselves uniquely.

> You know they say ‘grows on you’ in English? The more you practise on something, the more diverse things it starts to offer you. I am talking more from a perspective parallel to acoustic instrument; As you keep working and become skilled with an instrument, you’ll be able to create things, which are different and more sophisticated than the ones created by people who haven’t practised that instrument as long as you did. (P 21)

5.3.1.2 Visual Interactivity

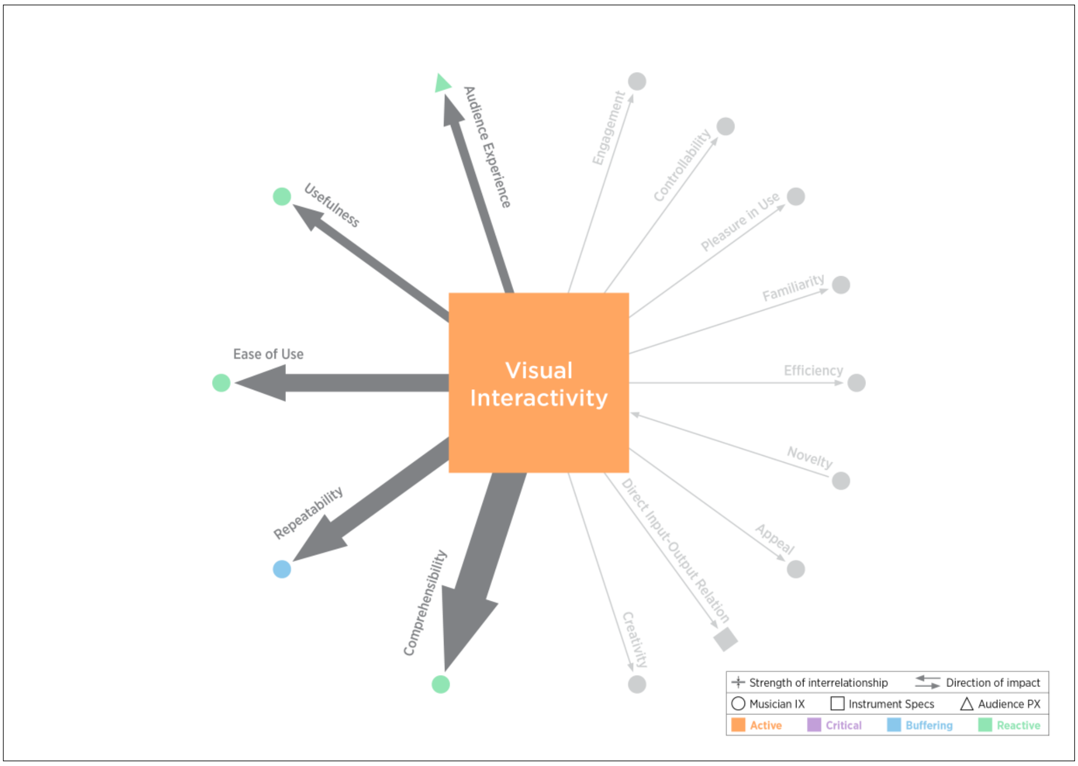

Figure 5.11 Egocentric Network Graph for Visual Interactivity.

Visual interactivity is one of the highest ranking active qualities in the study. Musicians mainly associate visual interactivity with comprehensibility, repeatability and ease of use. This quality also impacts an instrument's perceived usefulness as well as the audience's live performance experience (Figure 5.11).

Musicians expect new musical instruments to be easy to understand. In this sense, colour coding, light feedback and visual guidance and graphical signifiers are the frequently mentioned dimensions of visual interactivity, which help performers understand and memorize the features and functions on the user interface.

> (C) is what you look and what you see 'graphically'. You can 'see' the music in (C). (P 07)

Similarly, musicians believe that graphical guides and signifiers such as icons, origin points, grids and lines help the performers play melodies and modify parameters more easily. These signifiers are also essential for enabling the repeatability of musical actions (e.g. playing melodies, intervals, chords, configuring parameters)

> (D) is a 'real' instrument. Musical notes are apparent, which note I will hear is apparent, when they will come out is apparent. Here which sound comes out of which string is apparent. (P 23)

Especially concerning instruments with novel designs, visual interactivity also helps the audience to engage with the performance. Musicians believe that colours, lights and sound visualization enhance the overall 'on-stage show' experience.

> It would be interesting to visually project the frequencies generated by (C). Frequency is a very powerful thing. A visual, which can evoke its power I mean the power of music. (P 26)

5.3.1.3 Product Architecture

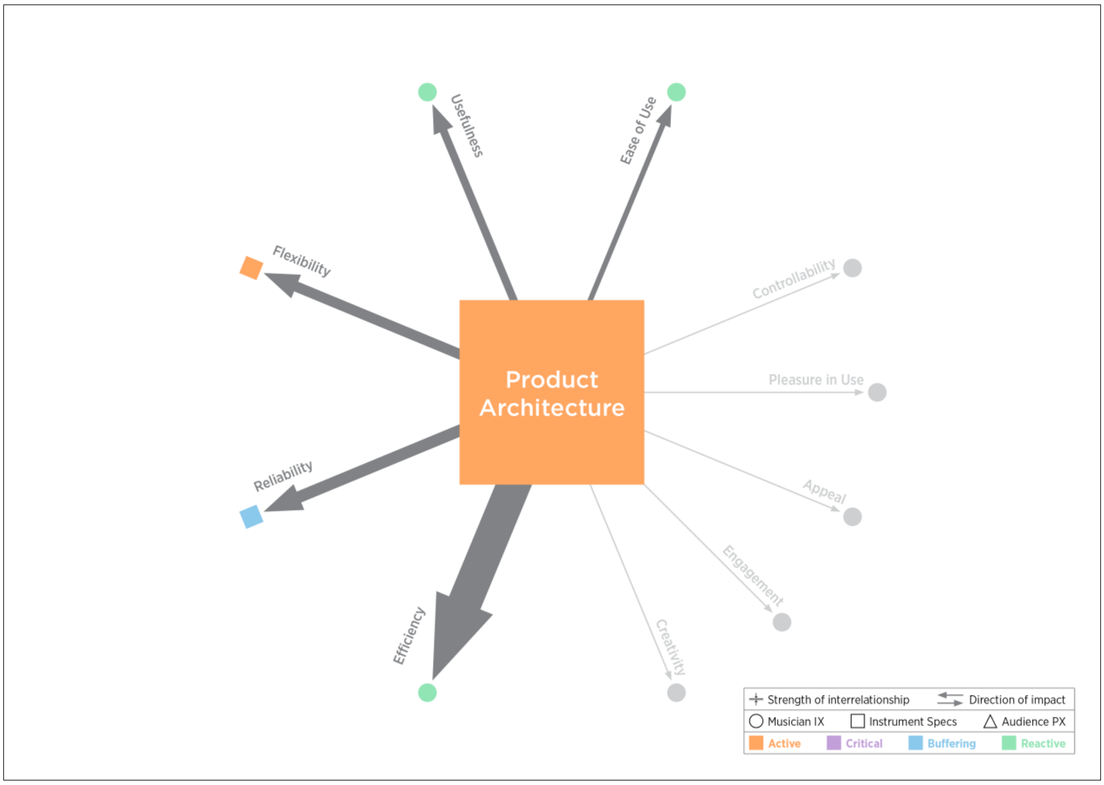

Figure 5.12 Egocentric Network Graph for Product Architecture.

Product architecture is an active quality which affects an instrument's efficiency, reliability and flexibility (Figure 5.12).

Musicians believe that this quality affects a performer's efficiency pre-, during and post live performance. Compact or uni-body product design, stand-alone instruments with inbuilt sound generators and wireless instruments are the most frequently mentioned dimensions of product architecture, which significantly improve the musicians' rehearsal, transportation and performance activities.

> I can play this without connecting it somewhere or requiring an extra equipment (P 10)

Musicians overwhelmingly consider cables the most important problem in a live performance. Thus, wireless instruments are also directly associated with reliability as well as flexibility of movement on stage.

> You have higher mobility without cables. (On the stage), you are limited to the length of the cable, you cannot take your instrument wherever you want to. (P 04)

While compact instruments are perceived more reliable than modular instruments, musicians believe that modular designs allow performers more flexible use scenarios.

> (A) and (B) are modular, (C) is a single unit, and hence, it is rigid. (P 01)

5.3.1.4 Tactile/Haptic Interactivity

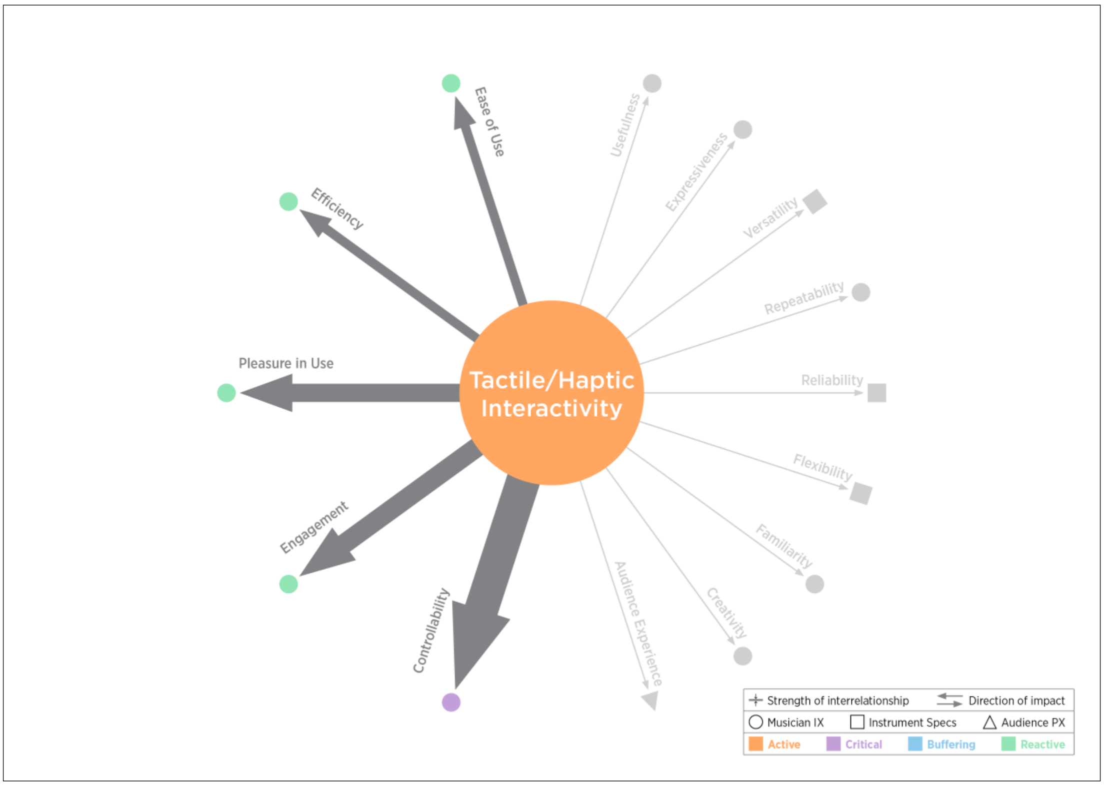

Figure 5.13 Egocentric Network Graph for Tactile/Haptic Interactivity.

Tactile/haptic interactivity is one of the essential active qualities in the study and it has remarkable impacts on perceived controllability, engagement, pleasure in use, efficiency and ease of use (Figure 5.13).

Musicians believe that tactile and haptic feedback plays a critical role in controlling a musical interface. While tangible interactivity provides multi dimensional control opportunities, planar interfaces offer better parameter control. However, touchscreens and similar homogeneous interfaces are criticized for lack of tactile feedback and thus perceived negatively.

> Complete hand contact is very important… Not small and with just fingers but tangible; through the use of all of the hand. Just as I think colours will have a more positive effect on the audience, I believe tangibility is a more efficient use for the musician. In (C) there are just the thumbs. We are at such a 'touch-based' stage that we use just our thumbs while texting or playing games as if we don't have any other limbs. (B) is like kneading dough… This is important… it allures me more… I want to play more with (B)… … After all this is 'electronic music' the name tells it all. Electronic music... what you do here provides you with a mechanical 'bond'. It helps you create a process where you combine electronic with mechanical. Where as (C) is completely electronic. (P 28)

Musicians believe that physicality of feedback provides added controllability and pleasure (in use) for the performer. Physical resistance of the user interface components (e.g. spring loaded mechanisms) and vibro-tactile feedback are favoured highly in relation to more engaging, pleasurable and efficient playing.

> For example, I feel the resonance; that resonance touches my skin. I mean, being able to 'become one' with the instrument is an important thing I cannot 'become one' with (D). (P 26)

5.3.1.5 Simplicity

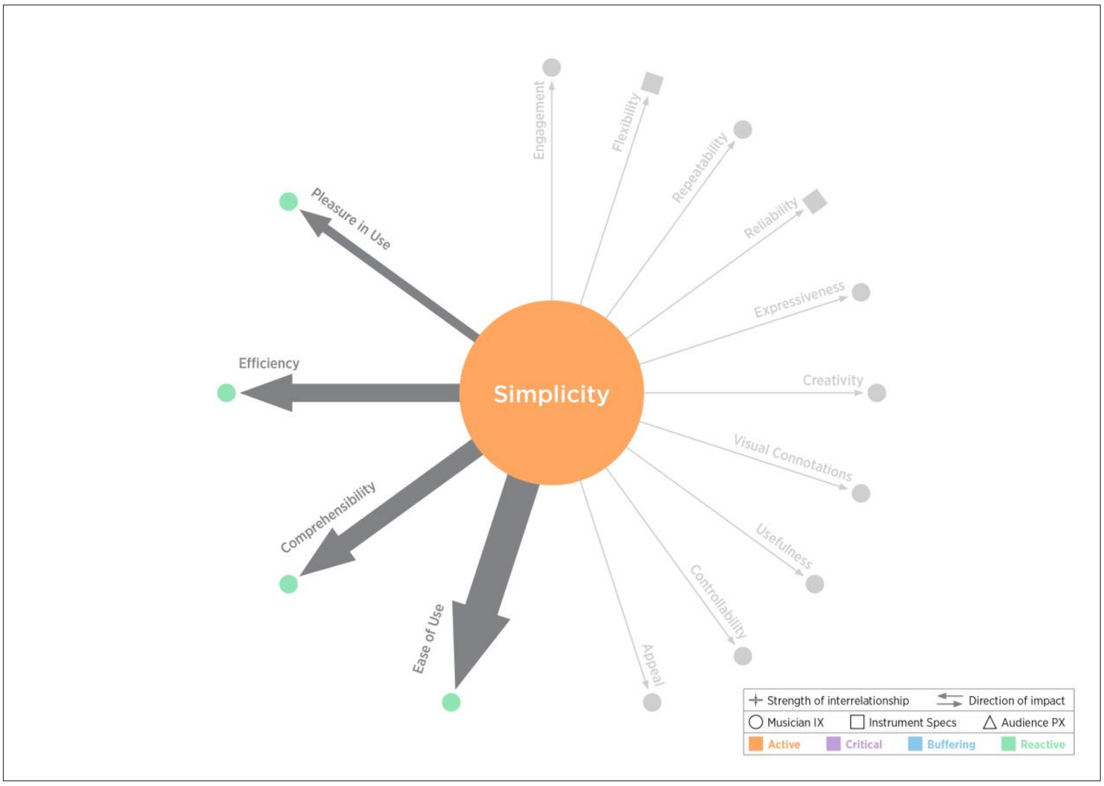

Figure 5.14 Egocentric Network Graph for Simplicity.

This active quality is mainly associated with ease of use, comprehensibility and efficiency (Figure 5.14).

In the context of musical instruments, musicians interpret simplicity as stripping down the instrument to its bare essentials needed to function properly. They want to be able to reach their intentions immediately. Unnecessary complexity of the user interface, a difficult 'narrative' for interactions and a garish visual design are all negatively associated with comprehensibility and performance efficiency. Musicians expect new musical instruments to feature simple user interface designs and simple interactions. A clean and simple product design, fewer interface components and parameters, clear visual feedback and simplicity of sound generation are dimensions that are associated with easier to understand and easier to use musical instruments.

> I am talking in terms of visual feedback again; (A) and (B) are more colourful, based on colour and a little more tiring. (C) seems like something easier, something I can focus better. (P 15)

According to the musicians, simplicity also affects their perceived performance efficiency because it leads to immediate interactivity and immediate sound generation. Additionally, this quality is associated with more enjoyable and pleasurable interactions.

> When you step into the sound business, what is the first problem? ‘there is no sound, mate!’. Let’s not waste time trying to generate sound. There is an instrument, I press all its buttons and stuff, tampered with it, no sound. (P 07)
>
> In my opinion immediate interaction is an important thing. Because you shouldn’t start by reading a 200-page manual. This is a musical instrument. It’s directly related to imagination and stuff like that… As soon as you pick it up, whether you practise for five days or not practise for even five minutes, there has to be a sound… and you need to be able to begin ‘playing’ immediately. (P 17)

5.3.1.6 Flexibility

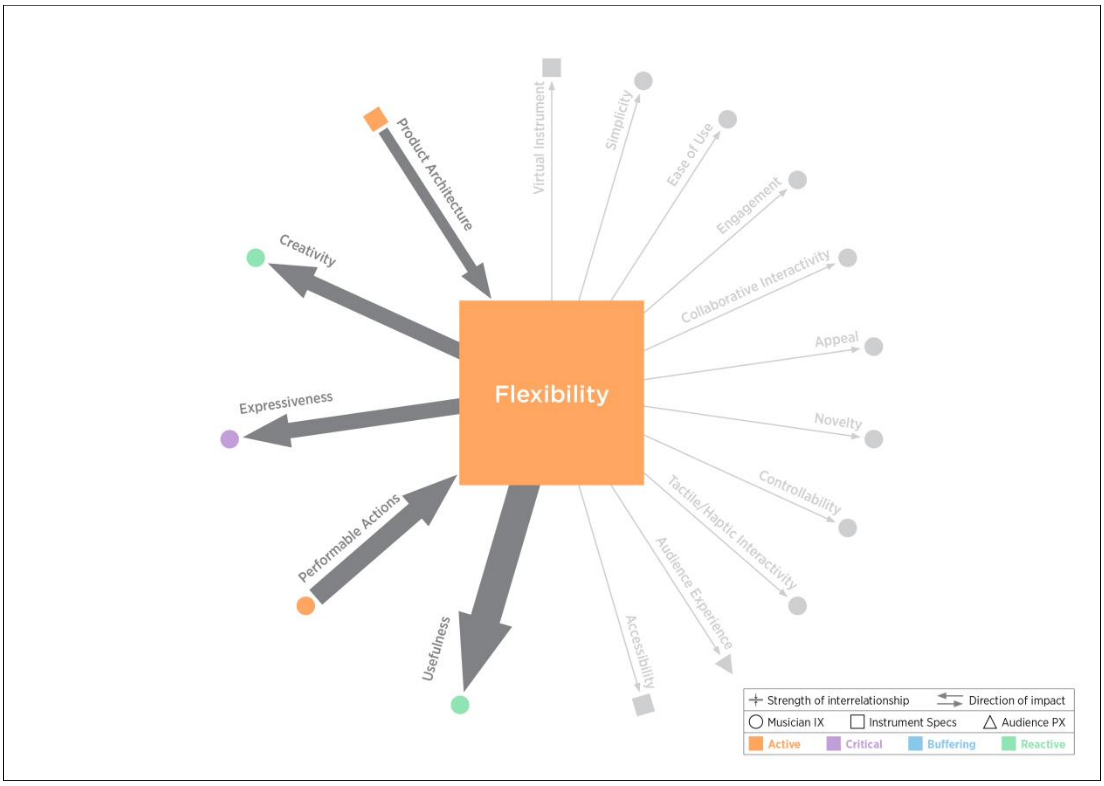

Figure 5.15 Egocentric Network Graph for Flexibility.

Flexibility is a quality, which has a remarkable impact on a musical instrument’s usefulness, expressiveness and creative potential. Musicians believe that performable actions and product architecture are the main qualities that affect the flexibility of a musical instrument (Figure 5.15).

The main dimensions that define flexibility are: customizability, personalizability, expandability, adaptability, compatibility and reconfigurability.

> There is the case where the range is wide and then there is the case where the range is 'expandable'. Thus, I can play in the range I want to play. If I want, I can play in a narrow range; if there were three notes in this range I can play all microtones. Or, I can move inside a five-octave range. (P 05)

> I like to connect these instruments to the effects I design on my computer. If I cannot configure that instrument to my computer, for instance I use Ableton®, if Ableton® does not recognize that instrument or I cannot enter it as an insert it would be absurd… I cannot achieve integrity. (P 07)

Musicians primarily expect freedom of movement and gesture from musical instruments.

> The playing style which the form (design) suggests is open, unpredictable, irrational. A scenario, which doesn't suggest what you have to do. (P 06)

Interfaces, which do not restrict performers to specific/fixed gestures, larger and wider movement space (on stage, with the instrument), non-contact (spatial) gestural interactivity (e.g. Theremin), single or two handed playability and bodily interactivity (i.e. using whole of the body to perform) are the dimensions of performable actions, which improve perceived flexibility.

> The meeting of 'dance' and 'sound' is striking… (P 08)

> The instrument should allow a 'theatrical' performance. You are physically 'fighting' with the instrument; bodily gestures should reflect the generated sound. (P 10)

Musicians believe that modular instrument and interface designs provide much higher flexibility for a variety of purposes: firstly, modules empower the performers to personalize and customize the instrument based on their specific needs. Secondly, being able to add new modules to the system improves its capabilities.

> […] but come tomorrow, as you add new modules to (B) it will start to do things, which it cannot now; you start to generate new sounds that you can't now […] (P 23)

5.3.1.7 Performable Actions

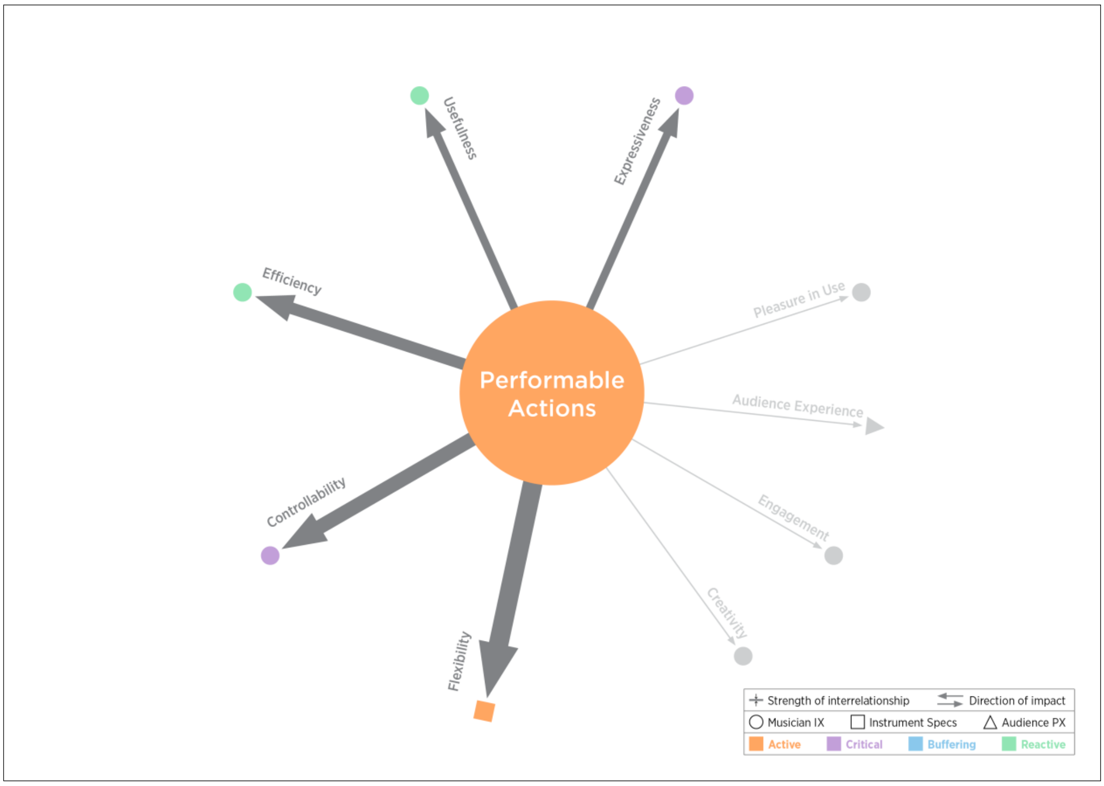

Figure 5.16 Egocentric Network Graph for Performable Actions.

Musicians mainly associate performable actions with other active qualities such as flexibility, controllability and efficiency. This quality also affects the perceived usefulness and expressiveness of a musical instrument (Figure 5.16).

Musicians believe that unrestrictive gestures, bodily interaction (e.g. wearable instruments, feet, breath), non-contact gestural interactivity and multiple/alternative hand positions remarkably increase the flexibility of the performance.

Being able to play an instrument with single or two hands improves control and empowers the musician to perform more efficiently. In contrast, musicians also associate minimal performance gestures and fingertip interactivity with better control for certain musical contexts (e.g. playing melodies in higher speeds, microtonal control).

> I want to be able to control all of my instruments without having to swing my hands and arms around too much. (P 07)

Musicians believe that non-contact (spatial) gestural interfaces open new doors for them to perform more expressively. Similarly, different gestures translate to subtle variations in expressions and thus, the sound.

> Gestures for instance... You can't use many gestures on (D). Imagine doing sforzando with a gesture… When I touch the pad like this or like that gives the same result. That 'gesture' is an important thing. The difference between two different hand/arm movements. These are very fundamental things for us, composers, this is how we write music. (P 08)

5.3.1.8 Visual Connotations

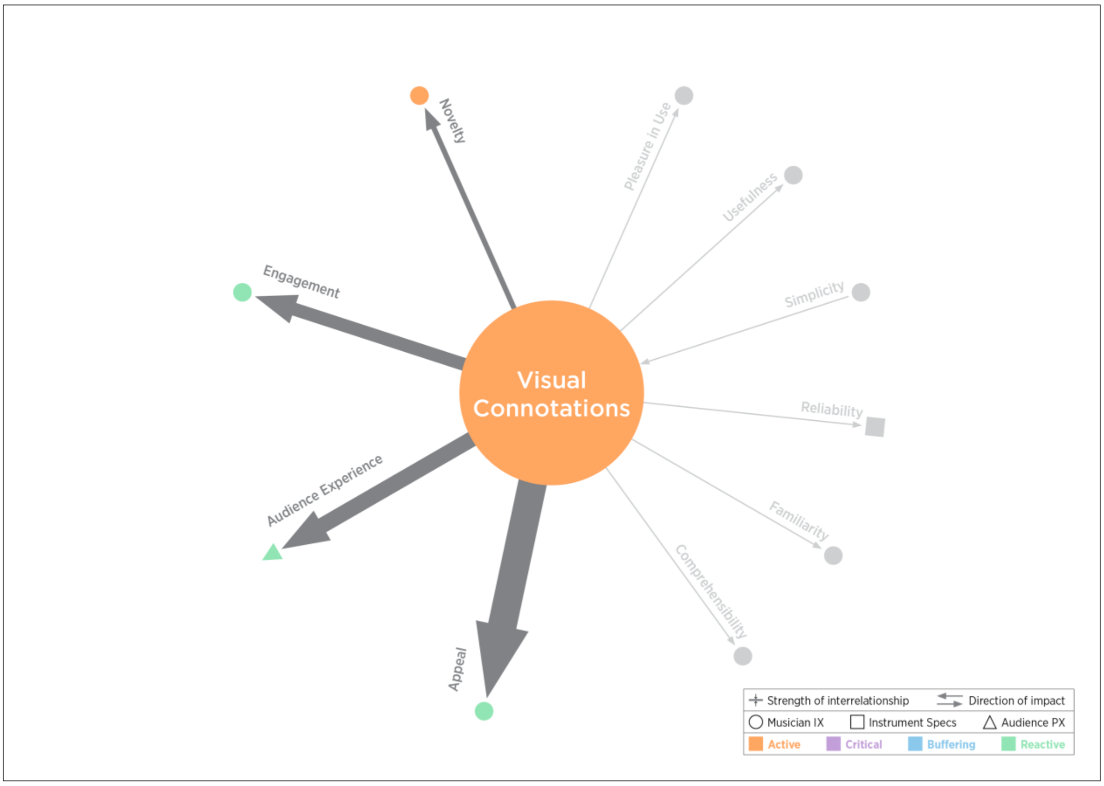

Figure 5.17 Egocentric Network Graph for Visual Connotations.

Musicians believe that a musical instrument's visual design is as important to the performer as it is to the audience. Visual connotations mainly affect the (visual) appeal, audience experience and engagement with a musical instrument. Visual character of a musical instrument is also associated with perceived novelty (Figure 5.17).

In regards to visual character of a musical instrument, different musicians mention many different preferences. Colourful, playful, organic, utilitarian, simple and serious are among many diverse visual characteristics musicians positively associate with an appealing visual design.

> Every successful design has a 'taste' just like a good meal from start to end. If you cannot taste that, it doesn't draw you in. (P 17)

While musicians do not propose a 'definitive' route regarding the visual design of an instrument, they expect the design to evoke respect and support the performer's on-stage presence. Funny looking designs and instruments, which resemble everyday consumer products also negatively impact engagement because musicians clearly state that they would never perform with an instrument that may be mocked by the audience.

> I think that how an instrument looks on you, what it 'adds' to you on stage are also important… It shouldn't take anything away from you on stage. (P 22)

> It's very important for an instrument to evoke respect. When you see an oboe or a bassoon, you feel something, regarding its complexity. It evokes respect in you. But when I see (E) I don't feel the same thing. I don't want to play it. (P 19)

Musicians believe that new, unique and intriguing designs that evoke discovery, increase the perceived novelty of a musical instrument.

> (B) is also visually appealing. This is very favourable. (C) doesn't intrigue me, it looks like a common computer tablet. (P 28)

> (B) appeals me. Hmmm how do I play it? You know, when a young child sees corns popping for the first time is intrigued? Same kind of effect. It intrigues me and I want to understand it. (P 25)

5.3.1.9 Set-Up

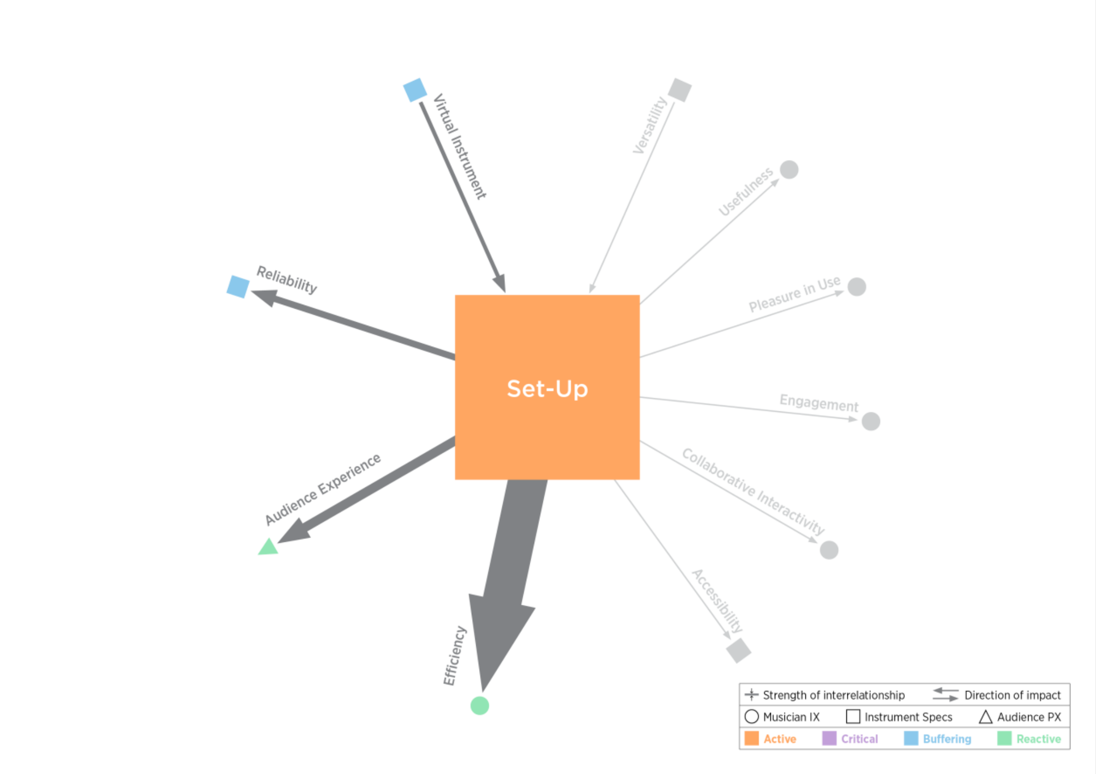

Figure 5.18 Egocentric Network Graph for Set-Up.

This quality is predominantly related with pre, post and actual live performance efficiency. Set-Up also critically affects the audience's performance experience and the perceived reliability of a musical instrument (Figure 5.18).

Musicians mention portability of the musical instruments, practicality and speed of the stage set-up and wireless connectivity as the primary facilitators of an efficient rehearsal and live performance. Similarly, practicality of the set-up procedures also increases the perceived reliability of the performance. Musicians believe that the fewer steps are in a set-up, the lower the risks of malfunction pre or during the performance.

> I don't think (A) and (B) are very practical. Even if they are cheap, they are big and difficult to carry. I am not Björk, I carry my instruments myself. At first I was using a six-octave MIDI keyboard now I am using something this small. (P 07)

> Like in (C) you will learn so many functions, connect that, load sounds here, do this and this and this… When I sit at the table if I am going to work with an electronic instrument I want

> to generate sound as soon as possible... I have something in my mind... I want to take that step as soon as I can so that I will achieve something close to what's in my head. If I do preparations for an hour or two, I get bored. I don't want my creativity to be hindered. It's important to be able to generate sound immediately. At home I sometimes place my guitar on the guitar stand, connected to the amp and the amp is on. It stays like that all day long. I want to keep it, to leave it as something always ready to play. Fewer steps, easier access. (P 17)

> You need to bring two engineers with you just to play this instrument (B) because when something goes wrong, who will you consult? What will you do? If your guitar's string breaks, you just replace it mate… Look at this (B)… Imagine you lose this. What will you do now? (P 27)

Especially regarding new generation musical instruments, musicians are more concerned about the audience's overall concert experience and immersion to the performance. The visibility of the musical instrument and the performer's gestures play a crucial role in the audience's perception of and engagement to the performance. When the audience has difficulty in seeing the instruments or the performer's movement and actions, the performers don't feel interacting with the audience.

> During electronic music performances, the audience is already being exposed to unfamiliar sounds. Thus, it is important for the audience to be able to see what the performer is doing in order to generate sound. How the sound is generated, through which method... this is important. (P 21)

> Is that guy sitting over there? What's he doing? Is someone else playing instead? Because, we need to be convinced that the performance is actually taking place at that moment. Or are we being fooled? Is there a playback? There shouldn't be any doubts. (P 24)

> Previously, we performed a live gig when Alp had built a small Theremin. While we were actively playing our instruments Alp appeared as if he was doing his homework. To tell the truth (C) has such a look, it's not appealing from my point of view. You cannot interact with the audience. (P 24)

5.3.1.10 Real-Time Sound Generation

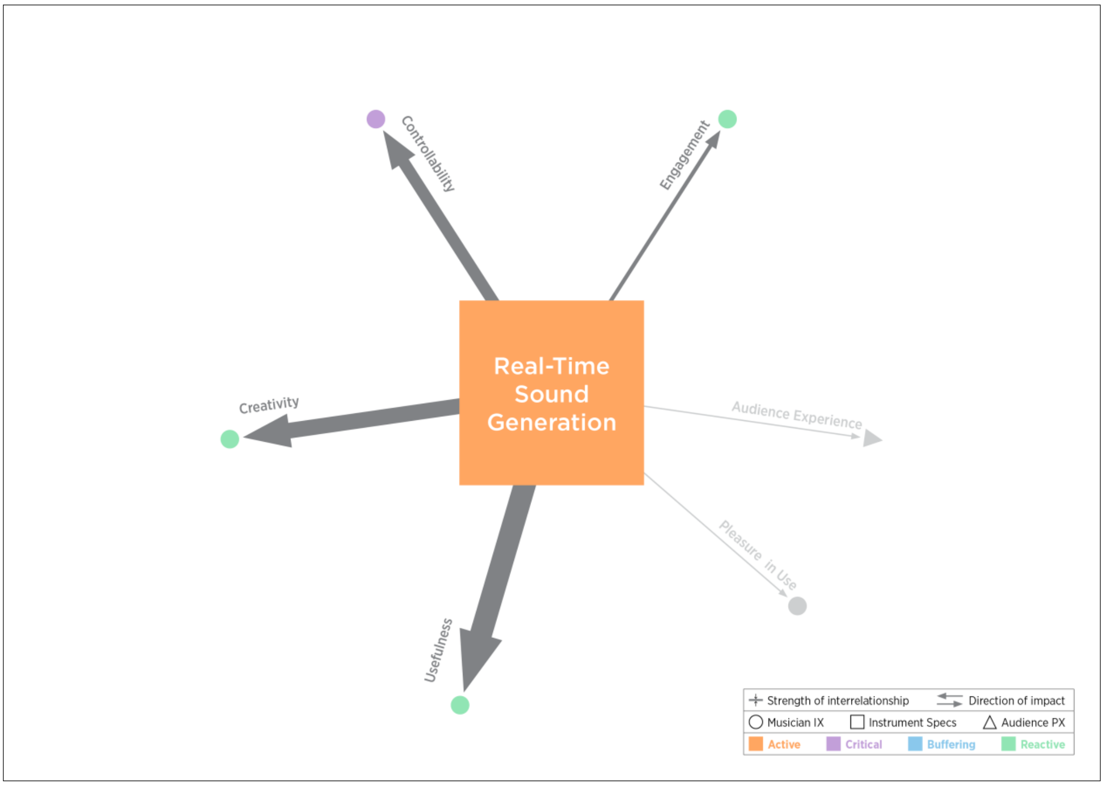

Figure 5.19 Egocentric Network Graph for Real-Time Sound Generation.

This quality mainly affects the usefulness creativity and controllability of a musical instrument (Figure 5.19).

Especially for musicians who come from traditional backgrounds or who play certain music styles or genres, being able to generate and modify sounds instantaneously becomes a prerequisite of perceived usefulness.

> Everything in (A) is preprepared. However, (B) and (D) does everything ‘on the spot’. (P 08)

> Actually, all three of these have a common negative attribute; they run on a loop-based principle. We call it ‘layering’: there is something there and you add or take out something else, etc. I think this is very restrictive, a very negative feature for me. (P 08)

Similarly, when musicians are not able to generate or modify sound ‘on the spot’, they believe that the ‘musical creation’ does not belong to them entirely because they are working with pre-programmed sound materials. Inevitably, the lack of this quality also affect the musicians’ perceived control over both the instrument and the final output, in other words the musical performance itself.

(A) and (B) are actually pre-programmed things with obvious and predictable outputs. You put this one here like this and the whole thing ends there, wanders about on its own. It ceases to be an instrument because I can no longer control it. (P 10)

5.3.1.11 Familiarity

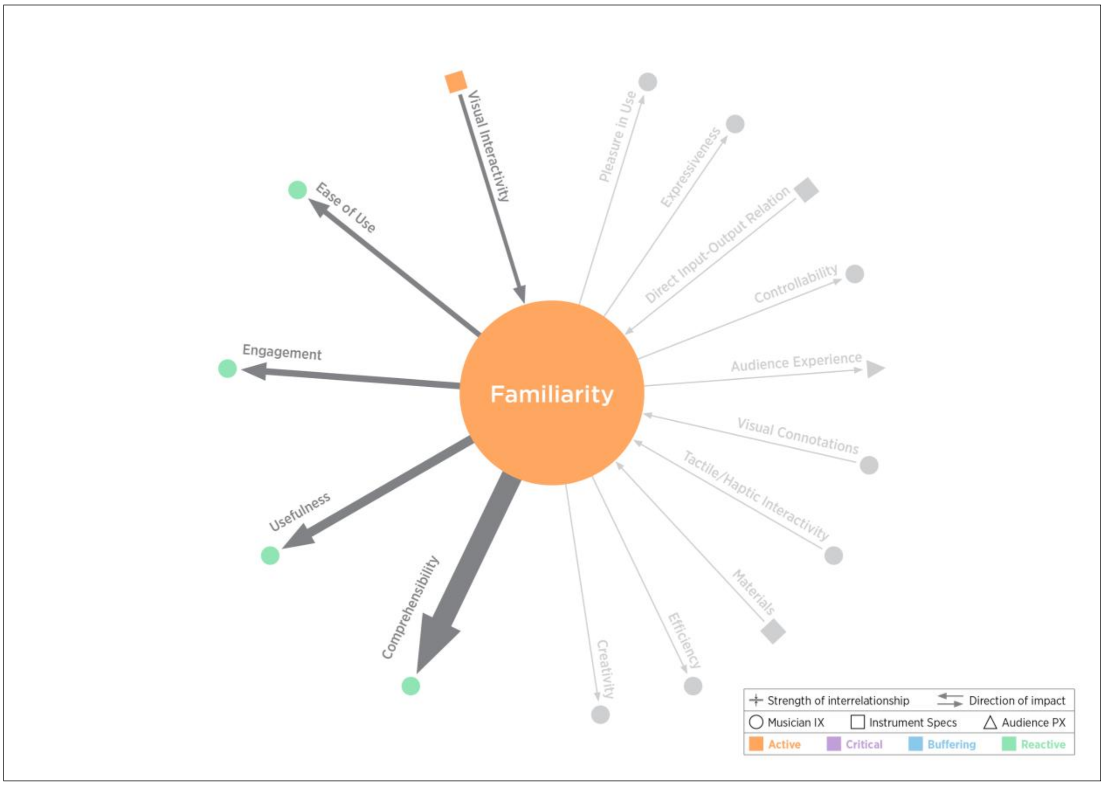

Figure 5.20 Egocentric Network Graph for Familiarity.

Familiarity is a quality, which is perceived through familiar and traditional references concerning the design, visual language or interaction model of a musical instrument. While positive transfer (of experience) is the primary dimension that creates familiarity, this quality also embodies musical instruments and interfaces that feature intuitive or natural interactivity. Musicians believe that familiarity makes an instrument easier to understand and use as well as more engaging and useful (Figure 5.20).

References to traditional acoustic musical instruments in regards to both design and sound generation model (gesture-sound relation) and a universally accepted/conventional visual language (e.g. icons, shapes, colour or music terminology (text)) on the user interface, are the primary dimensions of familiarity that facilitate comprehensibility upon first contact with the instrument. Similarly, musicians believe that positive transferability from traditional acoustic instruments makes an instrument also more engaging.

> I can understand this (D) through the knowledge I have gathered from the instruments that I have previously used. (P 25)

> When someone who can play a traditional instrument looks at this, he or she can understand how to play it. (P 10)

Similarly, musicians believe that musical instruments which feature references to traditional acoustic instruments or intuitive interactions are more engaging and easier to use.

> Since I am a violinist, as the Century and the times change, it is easier for me to adapt to (D). C is not appealing and actually I want to stay away from it because it gives me the feelings that I won't be able to understand its electronic structure. If you asked me, which one I'd prefer, I'd go and play with (D) and try to understand it. (P 28)

> (D) is actually different from (C) and (E), it mimics an acoustic instrument electronically. In this sense, (D) is more primitive, more retrogressive but compared to the others, it is more similar to an acoustic instrument. For example, you can play melodies with the frequencies we are used to. (P 24)

Musicians also emphasise the importance of traditional musical notation, as it is the common and familiar way of communication between all musicians. Thus, a musical instrument's playability with traditional music notation increases its perceived usefulness.

> When we speak of 'instruments', I usually think about musical instruments that are like traditional instruments. I think of this not as a reflex but by choice. An instrument, which can be 'practised' like traditional instruments. When you say 'used' people only think about picking it up and playing. When you say 'practised' you can perform it, you can improvise with it or you can make a notation of what you play. (P 15)

> You may consider notating the music that comes out of this. (P 09)

5.3.1.12 Novelty

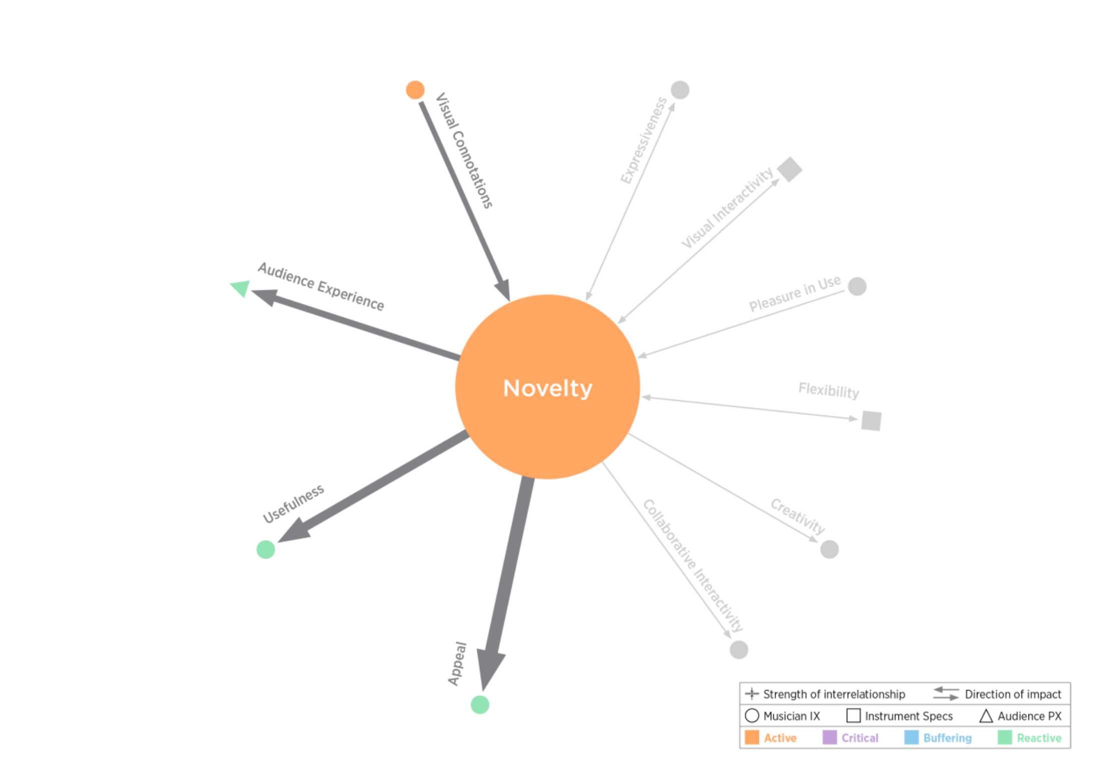

Figure 5.21 Egocentric Network Graph for Novelty.

This quality embodies dimensions such as novelty of product design, novel features, novel interactions (i.e. novel sound generation techniques) and novelty of the generated sounds themselves. Musicians associate novelty mainly with appeal, usefulness and audience's experience (Figure 5.21). From a design standpoint, an instrument's visual character and interactions are its primary features that immediately affect its perceived novelty.

> An instrument which suggests novel sound generation methods… […] Wouldn't you get excited when you see something like (B)? You would want to touch it and play with it wouldn't you? I mean you would want to interact with it… (P 13)

> It doesn't resemble anything, a completely new instrument. It doesn't have an ancestor. This is very engaging. (P 19)

> Among all, (B) is the one I want to experience the most. The things it can do as well as the 'way' it does those things are interesting. It is possible to re-visit certain concepts in ways which were not possible before… They have totally nailed it! (P 23)

Furthermore, Novelty also influences the Usefulness and Creative potential of a musical instrument.

> When I am already using an acoustic instrument why would I prefer these ((C) and (D))? It wouldn't matter if I played an acoustic instrument or these… Besides, you need to spend extra time to be able to play these instruments. However, I cannot do what (B) can do with an acoustic instrument. (P 05)

> If we are to talk about free improvisation here… 'what came out (music) was different in each rehearsal, also different in the concert but the concert was better than all rehearsals'. Instruments like (A) are more favourable for such circumstances. (P 05)

5.3.2 Interpretation of Qualities in the Ambivalent (Critical) Sector

The qualities in the ambivalent sector strongly influence the other qualities in the system and they are also strongly affected by them. The qualities in this sector are controllability and expressiveness.

5.3.2.1 Controllability

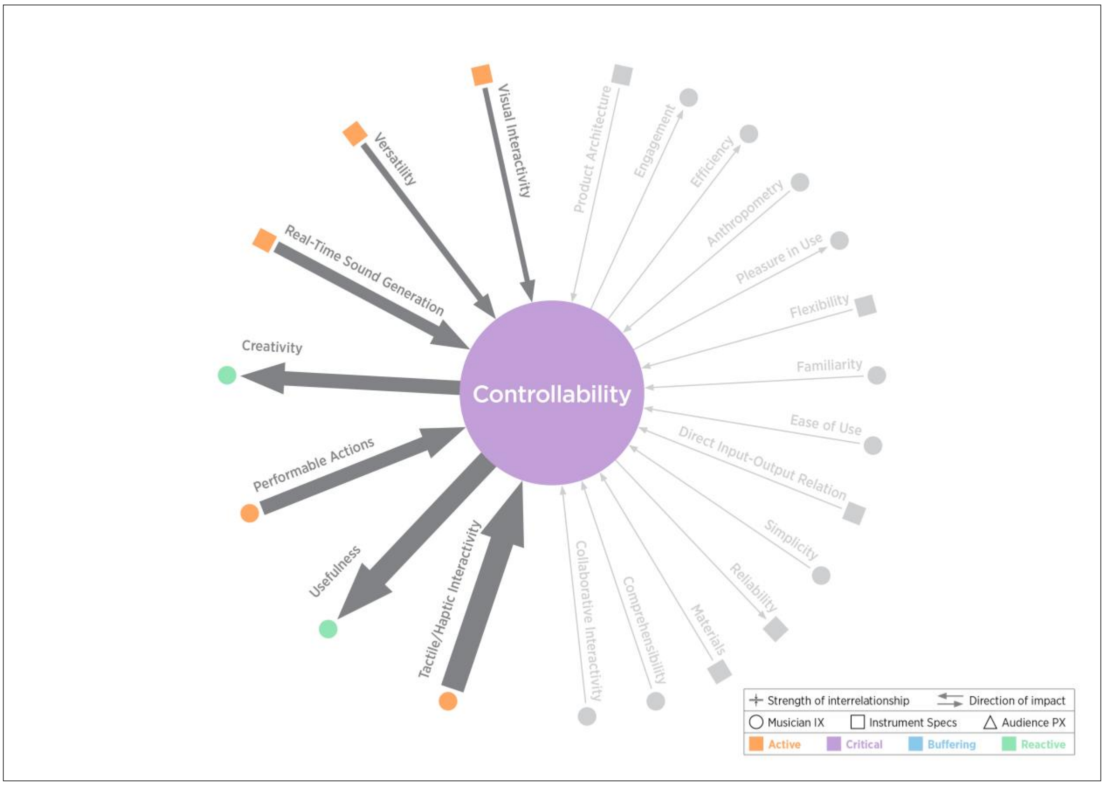

Figure 5.22 Egocentric Network Graph for Controllability.

Musicians consider controllability to be an essential quality for realizing their musical intentions on both creative and technical contexts. This quality is strongly affected by tactile/haptic interactivity, performable actions and real-time sound generation. Controllability improves perceived usefulness while also facilitating a creative performance (Figure 5.22).

> A good instrument is always played by a musician; a bad instrument 'plays' the musician. There is a case where a guitar plays you, and then there is a case, where you play the guitar. (P 02)

Musicians expect new musical instruments to empower them with a level of control similar to that of acoustic instruments. Tangible interfaces, physically responsive (e.g. vibro-tactile feedback, physical resistance) feedback and multi-dimensional interface elements (e.g. protrusion, indentation) are among the most frequently mentioned dimensions facilitating better control. Musicians believe that the 'physicality' of tangible and tactile interaction enables them to have a more precise control over their performance.

> Even the way you hold it is different. It has three dimensions and you turn it and hold it in your hand. Distance, proximity, angles… Even when you play an electric guitar, the strings vibrating underneath your hand or the whole body of the guitar – even if it is wood – vibrating is a very important thing. Being three dimensional is a similar feeling. The other instruments lack a dimension. (P 02)

> The instrument offers feedback to you. A touch, something, a movement. In (C) what you play remains a little abstract but in (A) and (B), there is a physical rotation, a movement and it helps you to concentrate on it. For example, in (E) there is a flex-sensor, when you touch it, it makes you feel a 'bending' sensation. I mean you 'bend' something. The exact opposite is Kinect where there is a camera and a 'range'. I enter that range and I touch the 'air'. I can't feel anything from it. In '(C) you touch something but it is a flat surface. It doesn't bend, or twist. I can't squeeze it or hold it. (Participant grabs and squeezes a PET bottle) When I bend the bottle, it makes a sound and I can completely 'feel' it. (Participant runs his finger over the table) Imagine this gesture makes the exact same sound, but I just make this gesture. A state where the instrument does not make me feel anything in a physical way. (P 10)

While some musicians propose that parameter manipulation may be relatively easier to achieve on a single axis, (e.g. touchscreens, ribbon controls, xy pads) lack of tactile feedback on touchscreens cause serious control problems especially for performances involving higher speeds and agility (e.g. playing melodies at high speeds).

> In (D) the digital knob doesn't feel reliable to me. It feels very antipathetic. See this digital slider here? I think it reduces control. I don't like digital knobs. 'my finger did not touch completely' etc. The opposite: A non-digital or protruding knobs. A physical knob. (C) has protrusions so you can understand whether if you touched the button or not. (P 25)

> They never consider people with sweaty hands! Touchscreens… Believe me this is a very important thing. (P 12)

Physically responsive and reactive interfaces also facilitate better controllability. Physical resistance, force feedback and vibration offer valuable clues to the musician for higher levels of control.

> While controlling (D)… In (D) maybe the timbre-related possibilities are less limited but control? Its response to you is also limited because for instance when you press somewhere, you want 'action-reaction'. When you press a key, you want it to push back in return. (P 22)

Musicians propose that 'bodily interfaces' offer new control opportunities for different parts of the human body. Musical instruments which can be played through multiple/alternative hand positions provides better control for performers with different performance habits. Similarly, single-handed interactivity gives the performer freedom for controlling either additional functions and features or different instruments simultaneously.

> These three have something in common: they are all used by hand; no breath, no feet, restricted. Many people would immediately install 'expression pedals' to these. Human body… Think about Leonardo da Vinci's human silhouette drawing… Drums are such instruments. I claim anywhere I can reach with my hands or feet… More limbs or communication types from human body… It is a tremendous advantage to include the feet in a rhythmic instrument. (P 14)

> While you are doing something here, you can also do something on an external processor at the same time, you can control both. But in (B) you need to constantly concentrate on these shapes and gestures. Even if you could connect to something else, (B)'s system doesn't really allow you deal with something else much. You could control (D) with one hand, and at the same time do something else with the other. (P 20)

Musicians consider real-time sound generation to be a critical dimension that empowers the performers to exercise complete control over their musical creations.

In this sense, being restricted to pre-recorded sound material negatively affects perceived controllability.

> It is not like my creation… As if you touch and press something and it begins to playback… Like a tape or something... The opposite, something I form concretely. An instrument, which I feel in control of, by touching and actually feeling that I play it… not like an alarm clock. An instrument such as (E) has no respectability for me. (P 19)

Musicians praise versatile user interfaces that allow precise pitch (frequency) control; a 'must-have' feature for performers who perform musical genres and styles that require continuous sound generation and manipulation.

> In (D) pitch control is really good. I could play a solo on (D) with great precision. This is very very positive for me and it is a 'must have' for many instruments. (P 03)

Especially concerning new musical instruments that feature un-orthodox interaction models and user-interfaces, musicians expect visual guidance to facilitate precise control on the user interface.

> In (D) these lines help you find your way... Origin… In (B) for example centre point. I think this is very important. Considering the user, we have the need to reference something to somewhere while playing an instrument. (P 10)

5.3.2.2 Expressiveness

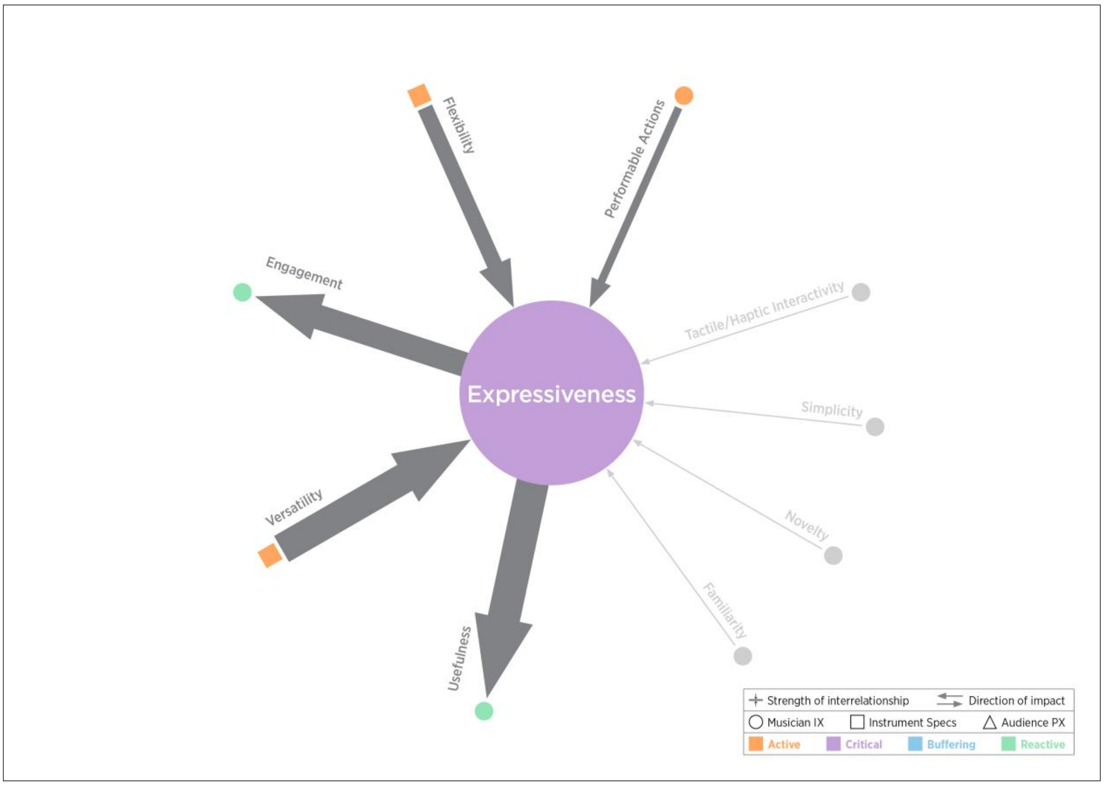

Figure 5.23 Egocentric Network Graph for Expressiveness.

This quality is essentially based on a musical instrument's ability to empower the performers to express themselves musically. Expressiveness is remarkably affected by versatility flexibility and performable actions. Musicians believe that expressive musical instruments are more useful and engaging (Figure 5.23).

> The people who manufacture these ((A), (B) and (C)) put the technological perception of their worlds in front of me too much. Here are these sounds… they need to clear these a little and maybe prioritize function. I mean they could give me a more 'cultivable' space. (P 08)

Versatile interfaces, which feature multi-touch, high gesture resolution and a continuous pitch space allow the generation of a diverse range of musical nuances and articulations, (e.g. vibrato, glissando, portamento, crescendo/decrescendo) provide the performers with the building blocks of an expressive performance.

> A good system understands your intentions and responds to you. When you use different techniques, it responds to all of them. (P 02)

Evidently, as musical expressiveness is about conveying personal ideas and emotions through sounds, musicians believe a flexible use scenario which allows personalizability and customizability of an instrument's user interface, features and functions directly impact its expressiveness. Expandability of the pitch space, reconfigurability of the user interface components, connectivity/compatibility to other devices and instruments (in order to make use of their expressive abilities as well) appear to be the main dimensions of flexibility that improve expressiveness.

> If I was able to connect this (C) to a violoncello and could assign some sounds here, and process them on the violoncello… I think that would be beautiful… (P 26)

> A good instrument is open; it has an open system. It 'understands' whatever you do, it doesn't make things difficult for you. You can customize it. It understands the nuances and the things you want to do. When you use different techniques it responds to all of them. Close system: no understanding and you need to play it in a certain way. (P 02)

Musicians believe that bodily interactivity can offer them new ways to express themselves musically. Contact and non-contact gestures empower musicians to explore new input methods from the human body, which can be used to generate and modify new sounds and timbres.

> Having sensors in (A) is an advantage. It liberates the performer from the surface. It becomes possible to achieve new musical expressions through gestures, just like a Theremin. (P 11)

5.3.3 Interpretation of Qualities in the Buffering Sector

The qualities in the buffering sector only slightly influence the other qualities in the system and they are also weakly affected by them. They are important to achieve the system's main goals nevertheless. The qualities in this sector are collaborative interactivity, direct input-output relation, reliability, repeatability, materials, virtual instrument, anthropometry and accessibility.

5.3.3.1 Collaborative Interactivity

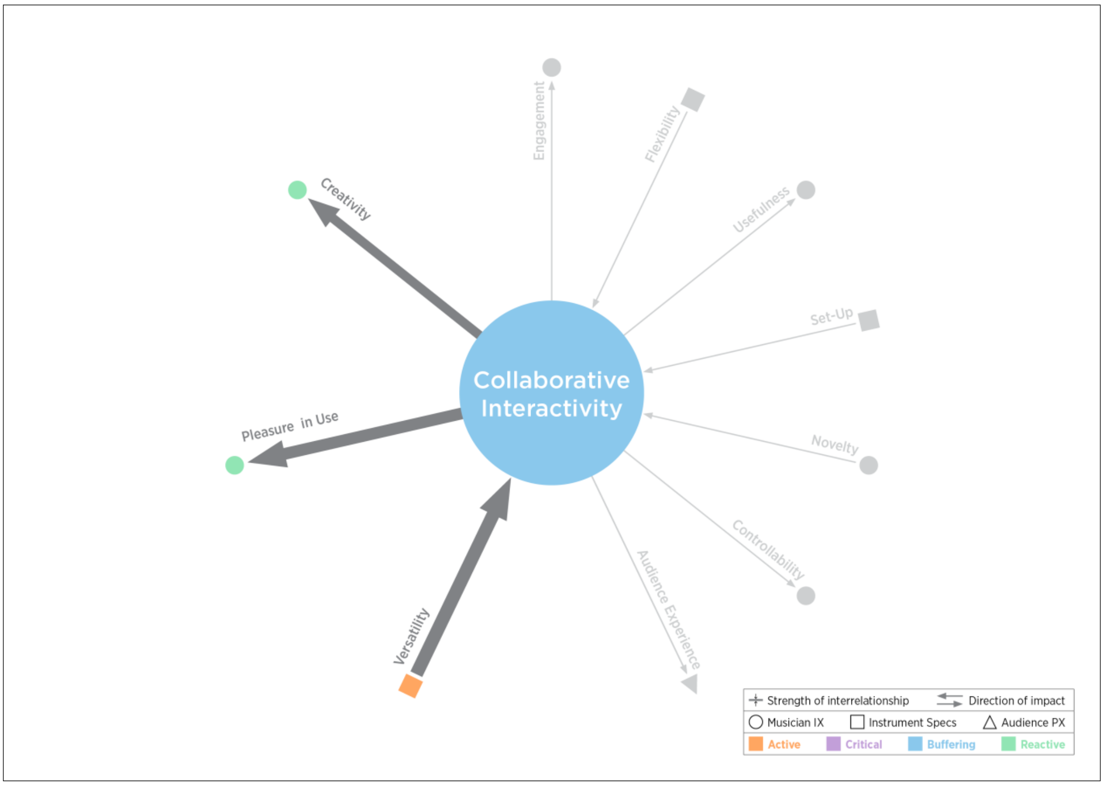

Figure 5.24 Egocentric Network Graph for Collaborative Interactivity.

Collaborative interactivity is a quality defined by instruments which can be simultaneously played by multiple performers and/or the interactivity between multiple identical instruments. This quality is mainly associated with versatility and it has direct impacts on perceived pleasure in use and creativity (Figure 5.24).

Musicians believe that one dimension of versatile interfaces is to facilitate an essential quality of a music: a collective performance experience. However, they also state that the instrument should feature collaborative interactivity as an option rather than mandatory. In other words, musicians expect to be able to perform solo with these instruments to their full capacity.

> (B) is a multi-user instrument. Being playable by multiple performers is a favourable feature. Either single performer or multiple performers… Same logic as two performers sitting at a piano. (P 24)

In return, musicians associate the impact of a collaborative interaction experience positively with creativity, pleasure in use and engagement.

> On (B) while one of them rotate the green square, the other does not push the red but the green instead. This means that there is a seeking for ‘harmony’… They are dependent to each others’ possibilities… Maybe this becomes a pleasurable activity, more than just generating sound… I find it ‘witty’ in that sense. You can make ensemble music with this instrument. (P 13)
>
> One instrument, multiple performers and interaction… and infinite possibilities… (P 14)

5.3.3.2 Direct Input-Output Relation

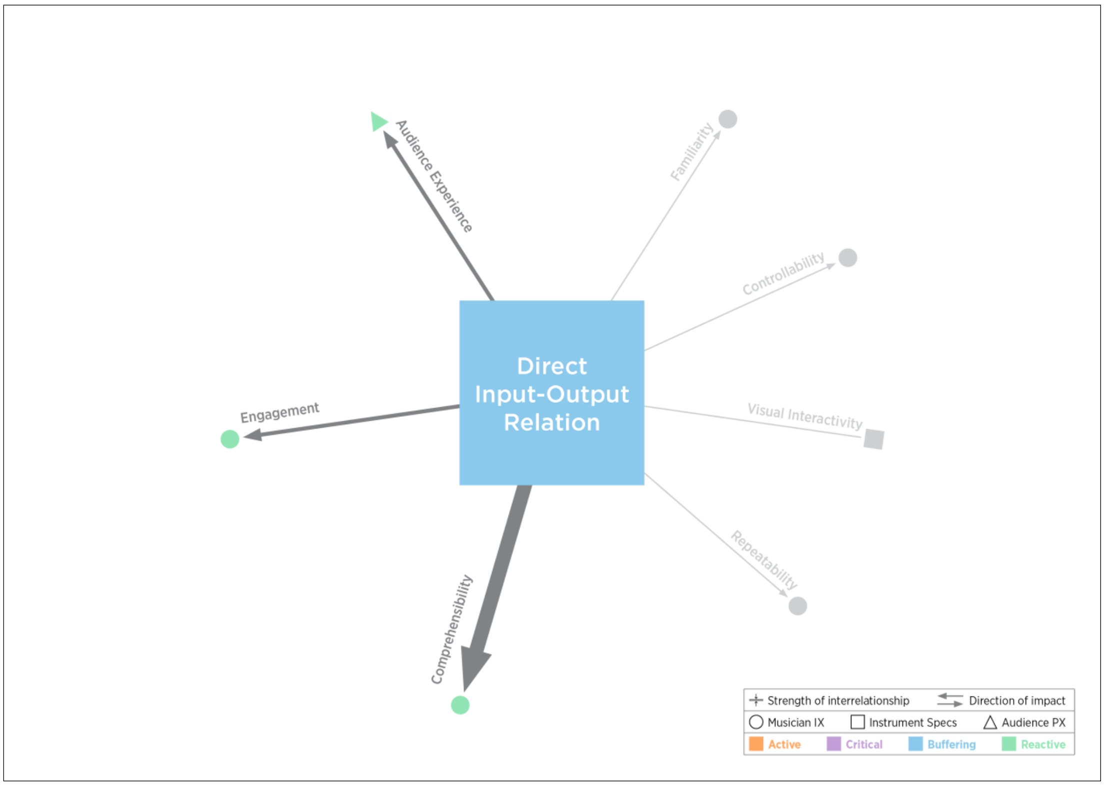

Figure 5.25 Egocentric Network Graph for Direct Input-Output Relation.

Direct input-output relation is a quality that predominantly affects the comprehensibility of a musical instrument (Figure 5.25).

> Instruments, where I can either see or guess the connection between the actions and the emerging sounds. For example, when I watch (D), I can directly see (understand) that the sound gets more treble when the finger moves in one direction, sound frequency changes on the X-axis and the timbre changes on the Y-axis. On (E) however, people hit it, I hear a

> percussive sound. They hit again and I hear a percussive sound in a different tone. There is a constant rhythm in the background. I cannot exactly understand what is generating that rhythm. (P 21)

Being able to understand how the instrument works makes the performance more engaging for the performer.

> I mean; it runs your input through its system and generates an output. It should be possible for you to understand the relationship between the input and the output with your perception. (P 17)

> Logical... In five to ten seconds, I understand how it works and what happens when I do something. (P 24)

Furthermore, musicians associate this impact in relation to both the performer and the Audience.

> I cannot hear 'what changes and how' when two instruments are brought together like this. This is very important to me. When I watch it, I can see this: there is a 'dialogue' between them but it is not clear. It is a bit confusing. I can give my attention because I am someone interested in musical instrument design. If I was an ordinary audience, I think that I would briefly look at it, and if I don't understand it, I would lose my interest completely. (P 21)

> I am going back to a classical instrument again. You can watch and follow whatever emerges completely. It is not complicated from the audience's perspective either. The performer may be performing a very complex piece but the result is in a completely simple, minimal and perfect form. (P 10)

> You can play a symphony in a tiny tablet. A CD player can play a symphony but the important thing is for the audience to reach that feeling when we give this to them with those parameters. When I make this gesture (shows) it should fit the generated sound. Imagine I have an X-Y sensor, when I keep my hand straight, the sound is in a constant structure and when I wave my hand the sound also fluctuates, this situation facilitates the perception (of the audience). (P 10)

5.3.3.3 Materials

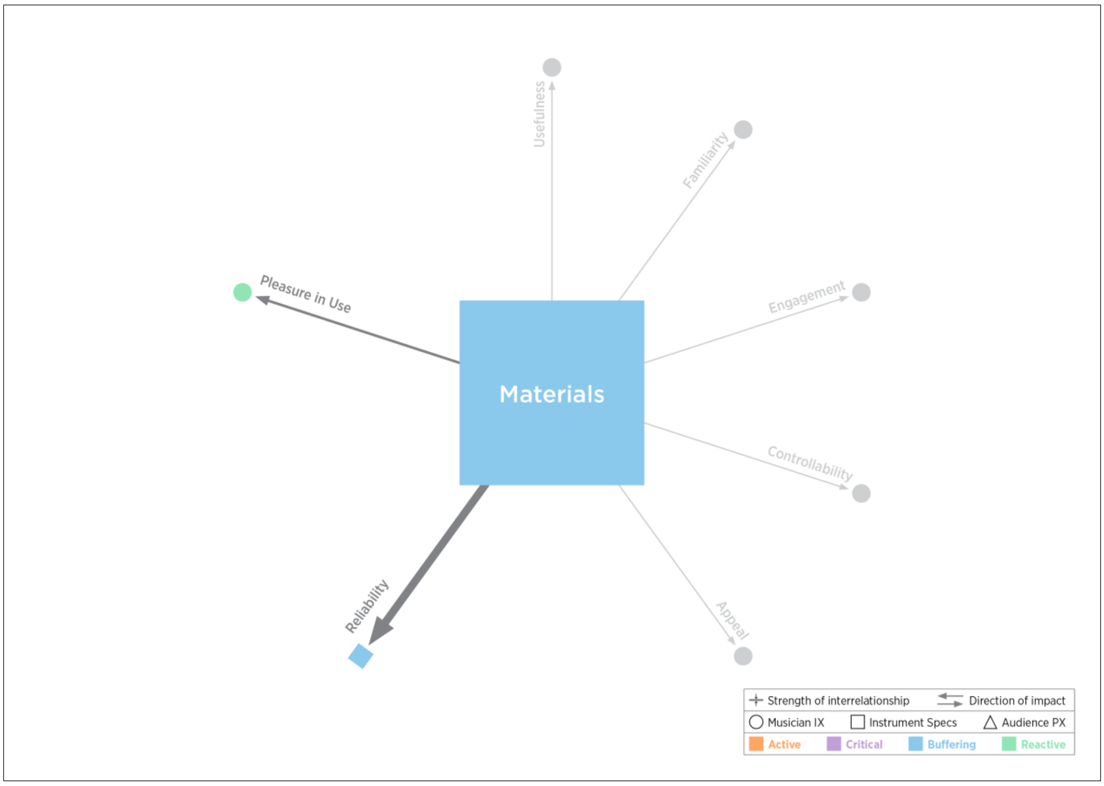

Figure 5.26 Egocentric Network Graph for Materials.

Materials is mainly associated with the reliability of a musical instrument (Figure 5.26). According to the musicians, high quality materials, good engineering and craftsmanship are important factors affecting perceived reliability for logistics, practise, rehearsals and live performances. Natural materials such as wood and metal are perceived to make more durable and sturdy musical instruments with longer life-spans.

> You know the saying: If it's heavy, it's good… Even just the weight of it gives you a sense of it. After all, 'material' can become something that could let you down. Most of the time you don't choose a plastic over a metal thing because if it breaks, you are in deep shit! (P 22)

> Naturally, having a plastic instrument and having a wooden or metal instrument are different sensations. I definitely prefer wood or metal! Definitely! Firstly, definitely organic… Secondly, we have adopted/embraced these materials as 'musical instrument materials' since many many years. They obviously bring forth a feeling of durability. Opposite: Plastic and derivatives. (P 23)

Additionally, natural materials also impact Pleasure in Use.

(E) didn't evoke any feeling in me I guess… Having a plastic look is not nice. It looks like plastic. Material-wise. For example, it looks like a soap box… I guess when I look at it, if there was genuine wood instead of this, its feeling and warmth would transfer to me rather differently. (P 26)

5.3.3.4 Virtual Instrument

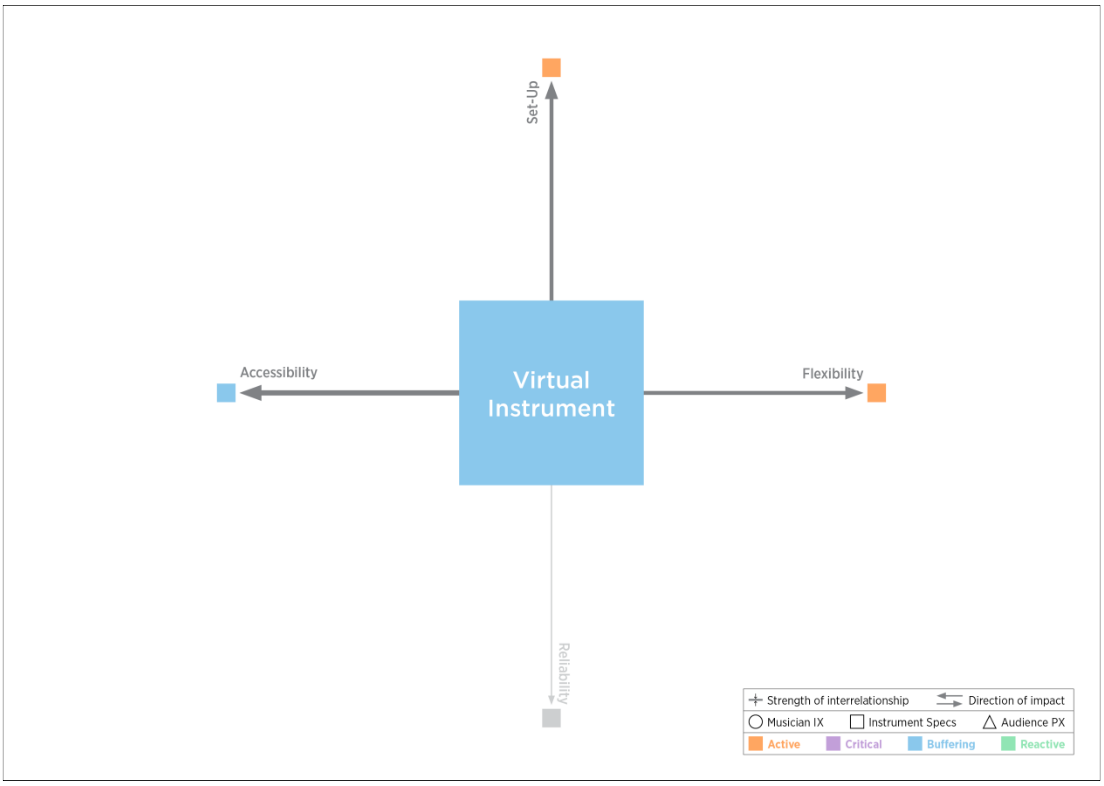

Figure 5.27 Egocentric Network Graph for Virtual Instrument.

As mentioned in the Accessibility sub section of this Chapter, virtual instruments are defined by software instruments and music making apps developed for smart phones and digital tablets. Musicians associate virtual instruments with accessibility, set-up, and flexibility (Figure 5.27).

> Being software makes an instrument more accessible, affordable and gives it a better chance of becoming widespread. (P 23)

> Very easy to carry, very easy to access. There is no maintenance but only 'updates'. Let's say you have a ribbon controller; 5 octaves, it's a huge thing and you also have (D). You have an iPad and you go to a gig, there are three easy partitions, which you will play with the ribbon, surely you take (D). You don't carry the ribbon controller. This is also an important thing because when I go to a gig I leave with at least three or four bags. (P 17)

Software is suitable for cross-platform. Cross-platform compatibility is very important. Let's say your computer broke down, take your software with a USB stick, connect it to another computer and run it… (P 22)

5.3.3.5 Anthropometry

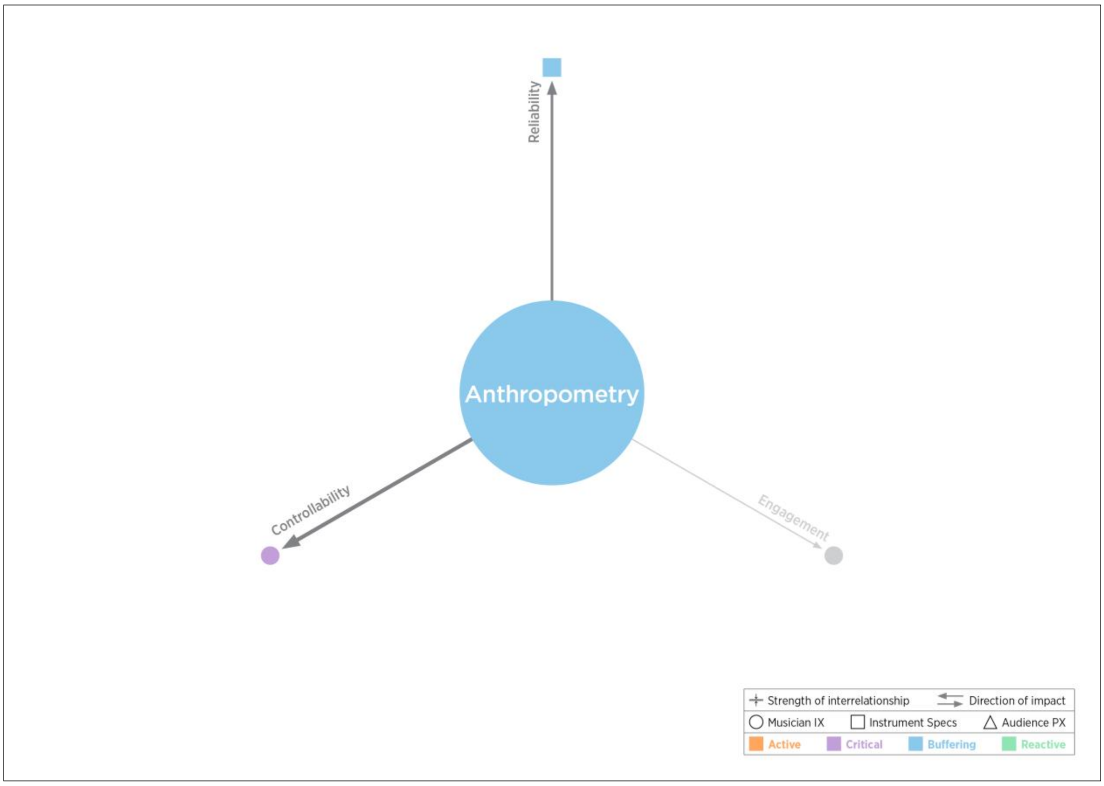

Figure 5.28 Egocentric Network Graph for Anthropometry.

Anthropometry is a quality, which is defined by design appropriateness to human anatomy and the dimensions of ergonomics. Musicians believe that anthropometric and ergonomic features of a musical instrument mainly influence its reliability and controllability (Figure 5.28).

When approaching a new musical instrument, musicians are concerned about injury risks in relation to practise rehearsals and performance. Thus, they expect the user interface to direct the performer to safe and reasonable postures and gestures. Similarly, an ergonomic and anthropometrically appropriate design is associated with better perceived control over the instrument.

Concerning (C) and (D) there may be a risk of injury. On the working surface, especially if your fingers are extending somewhere further away, as in here with your thumb, if you think about violin or piano playing positions, you need to do the extension moves as little as possible. If you spend long hours on these instruments, you may have a risk of injury. (P 05)

But this (D) is again difficult for me... I don't get on well with touchscreen things... This is a personal thing but my hands sweat a lot. But these may actually be considered very practical for many people… Opposite: Shall we say something that fits inside my palm? Easier to control? Physically easier to control. Naturally, physical space is very important. (P 12)

One advantage of (C) is to be able to use thumbs. Actually we have a better control with our thumbs but in many soft synths we use index fingers, which I believe is a very awkward gesture. (C) is more like 'Game & Watch™ mode'. 2 thumbs. It is a more natural grip. You know piano forces you to a gesture with its flatness, if you compare a guitar to piano such a thing exists. You know the computer keyboard is flat and forces our hands, that's why they designed split keyboards. (P 11)

5.3.3.6 Reliability

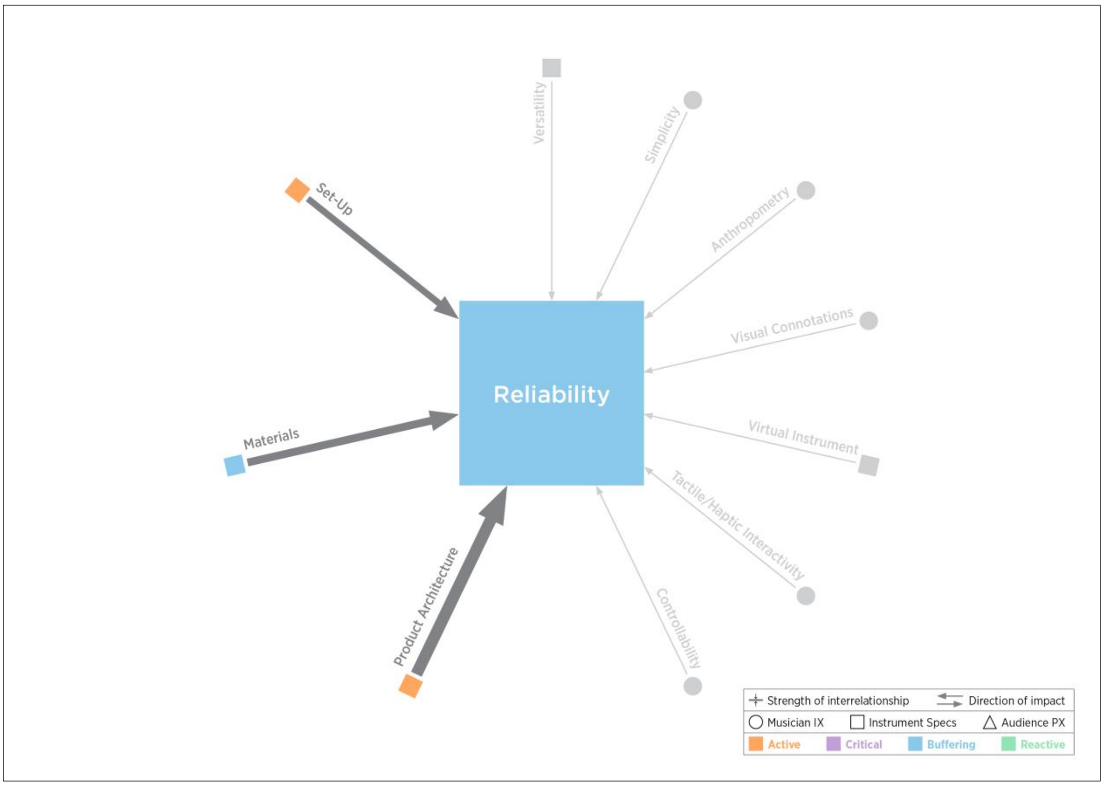

Figure 5.29 Egocentric Network Graph for Reliability.

A musical instrument's reliability is mainly associated with product architecture, materials and set-up (Figure 5.29). The nature of live performances inevitably carries risks in relation to a variety of potential hardware and software failures. Thus, musicians expect their musical instruments to be dependable for a problem-free live performance. In this sense, stand-alone, compact and unibody instruments are perceived to be more trustable because connectivity to computers increase potential failure. Additionally, modular instruments pose higher risks regarding lost forgotten or malfunctioned components that are vital for live performance. Similarly, especially for multi-instrumentalist performers, complex set-ups (e.g. effect pedals, live samplers, filters) increase the number of required cables and thus, risks of failure. Musicians prefer wireless protocols but only when an uninterrupted and reliable data flow is guaranteed.

> To me, this (A) is a nightmare! Every time, you mistakenly connect something wrongly. During a rehearsal, you unplug a cable, which was perfectly functional for the last 25 times, for something and then totally forget to re-plug it during the actual performance that's why cables are always a problem. I love systems where everything runs through wireless networks. I set even my MIDI connections that way. (P 06)

> Going on the stage with a drum machine rather than with a computer is a safer and more comfortable feeling. Even though it has fewer possibilities. Even though stand-alone instruments offer fewer possibilities, they are safer than the concept a controller that runs through a laptop. (P 14)

According to the musicians, organic materials such as metal and wood have a higher perceived durability and reliability where as plastic materials are associated with cheapness or shorter life-spans. Easy set-up is also associated with the reliability of a live performance. Musicians expect to run into more problems if the set-up process involves too many steps.

> You know the saying: if it's heavy, it's good? Even that alone gives you the feeling… At the end of the day, materials may turn out to become something that can let you down. Most often, you don't prefer a plastic instrument over a metal instrument because if it breaks, you are in deep shit. Where will you find another? The opposite: A material I can rely on. I always prefer materials, which are not easy to break and not affected from electronic environments; materials that can protect themselves… (P 22)

> Because there is a higher possibility of running into problems and as a musician what you want to be occupied in is not solving problems. The more steps there are, the more steps that can cause problems. I compare this (B) with acoustic instruments; when you are to play the guitar, there is not much that could go wrong except for a string to break. When you pick up

your guitar, it is ready for playing. I believe that electronic instruments may try to come close to this ideal somehow… (P 21)

5.3.3.7 Repeatability

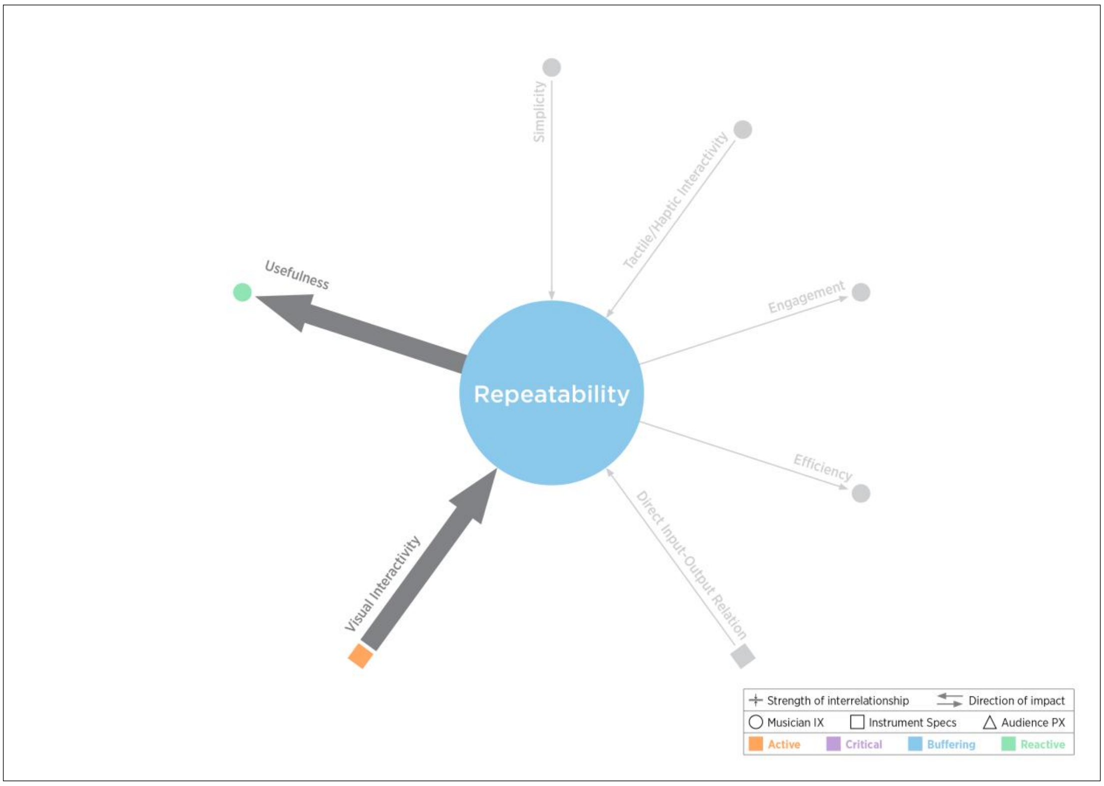

Figure 5.30 Egocentric Network Graph for Repeatability.

This quality is defined by the repeatability of the performer's musical actions and the memorability of a musical instrument's user interface, features, functions and interactions. Repeatability becomes essential especially concerning the performance of traditional music genres where the musician needs to play melodies intervals and chords. Therefore, being able to repeat musical actions directly affect perceived usefulness. Musicians believe that the repeatability of musical actions on new generation electronic musical instruments is primarily associated with visual interactivity (Figure 5.30).

> The locations of the musical notes are visually identified. I may not prefer to play them, but regardless of my preference, the instrument should give me the option. When designing an instrument like this, the attitude is always to go against the traditional structure; they are designed as if denying the past. Maybe that's not the intention but that's how it looks like.

It’s as if erasing all the past. You cannot play these ((C) and (E)) like a traditional instrument but you can play (D). You can play this like a Theremin; a perennial instrument. You may not want to play like that, but you can, if you want to. This is very important. (P 10)

(B) and (C) have a graphical aspect I mean you can see visuals regarding what they do. It’s important to see what you press and where. Because while using these instruments you do something and then modify it but then you may forget; ‘Where did I press to do that?’ kind of situations. (P 25)

5.3.3.8 Accessibility

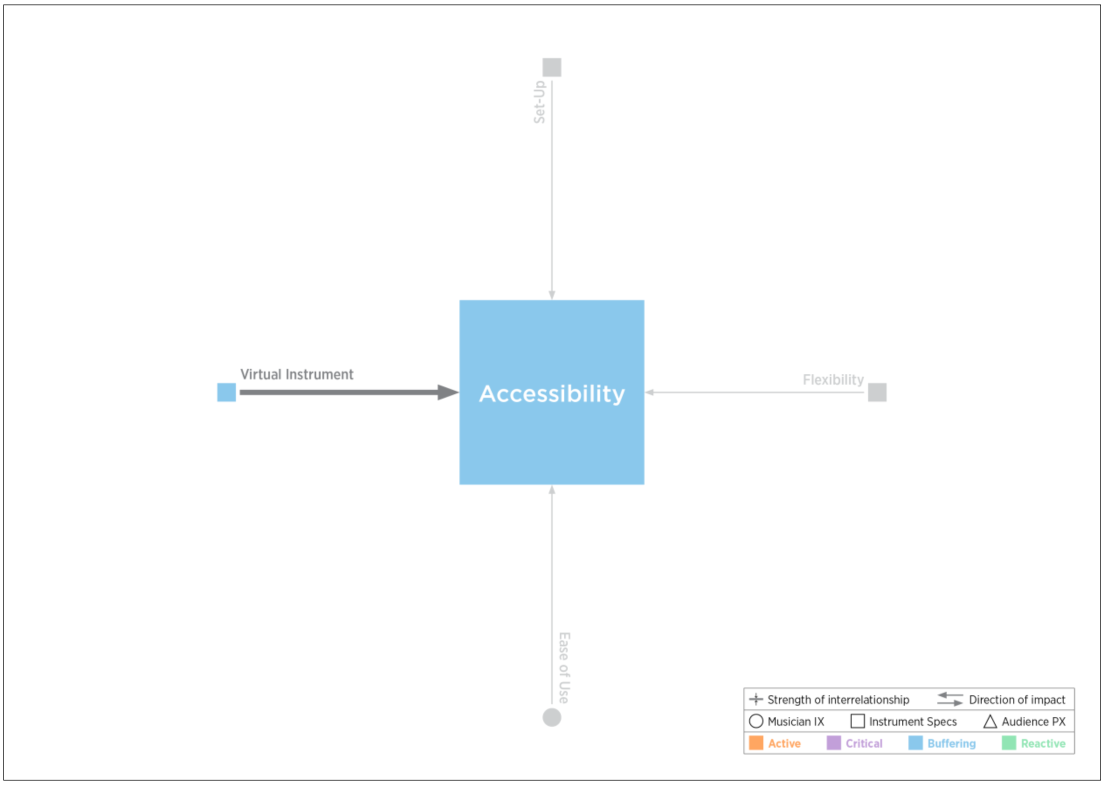

Figure 5.31 Egocentric Network Graph for Accessibility.

Accessibility is mainly associated with virtual instruments (Figure 5.31). As previously stated, while software musical instruments and financial aspects of instrument manufacture have been intentionally left out of the scope of this research, musicians believe that virtual instruments and emerging music-making ‘apps’ are easier to access due to their global online availability as well as their affordable price tags.

> It's accessible and widely available. […] […] (D) is in AppStore. I like it very much and I will go and buy it. (P 01)

5.3.4 Interpretation of Qualities in the Passive (Reactive) Sector

The qualities in the passive sector are strongly affected by the other qualities in the system and they have only a weak influence on them. They are considered as the end goals of the system. These qualities are: usefulness, engagement, efficiency, comprehensibility, creativity, pleasure in use, easy of use, audience experience and appeal.

5.3.4.1 Usefulness

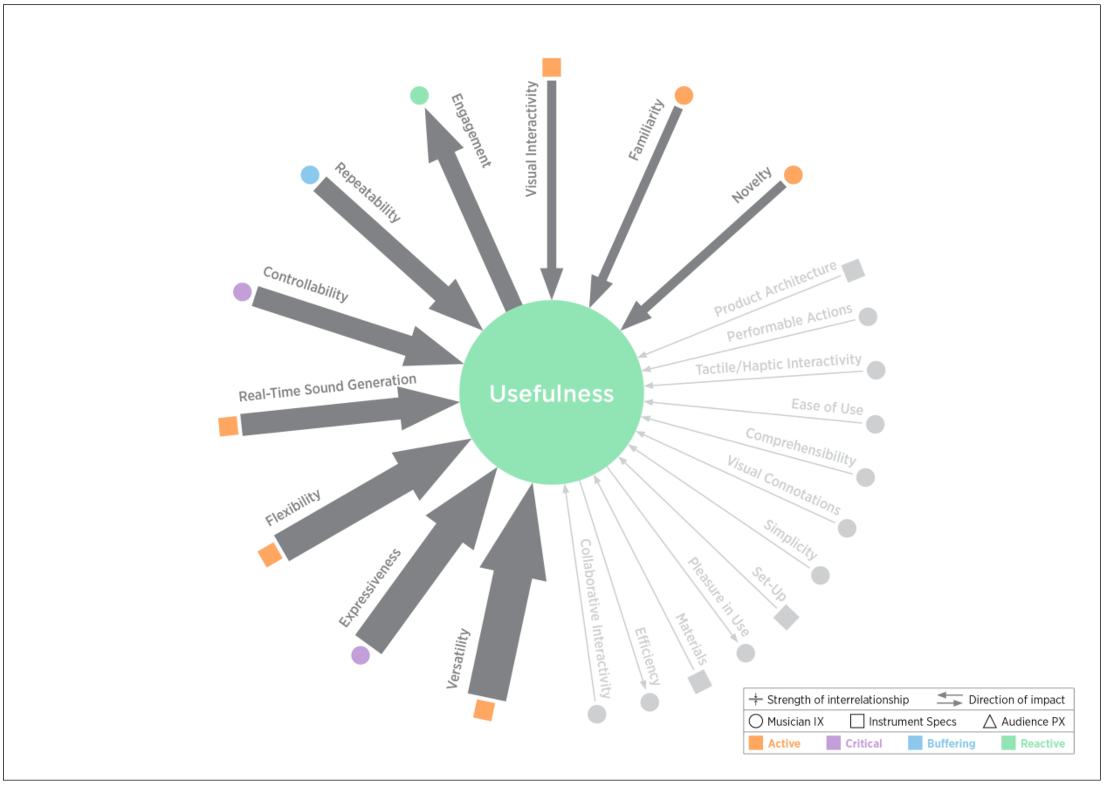

Figure 5.32 Egocentric Network Graph for Usefulness.

Musicians consider usefulness to be the foremost quality concerning a musical instrument and thus, associate it with a wide range of diverse qualities. Usefulness of a musical instrument is strongly affected by its versatility, expressiveness, flexibility, real-time sound generation, controllability and repeatability (Figure 5.32). In return, usefulness has a high impact on musicians' engagement to a musical instrument. Additionally, visual feedback, familiarity, performable actions and novelty are also associated with perceived usefulness.

Musicians expect musical instruments to provide them with as many 'possibilities' as possible through the versatility of their features and functions. Multifunctionality, a high ceiling of virtuosity and diversity of the generated sounds are among the major dimensions within the versatility umbrella, which are associated with usefulness.

> I believe that a person who performs on (B) has a lot of possibilities for modifying sound. I mean 'time' in the rhythmic sense… the timbre… I think one has too many options to create all these respective layers in music. (P 05)

Similarly, musical instruments are perceived useful only when their design and technical capabilities provide the performers enough 'space' for individual expressive exploration.

> To begin with, the instrument with a wide expression, a wide range of expressiveness... you do 'vibrato', you can 'bend', it has a wide range of expressions. The opposite? Think of a Zurna; the sound outcome is obvious… the range is obvious... the emotions it will evoke in you is obvious … The more expressions there are, the better for me... I'd never say 'why does this one exist' to any of them… (P 23)

> Any instrument with which, I cannot make (musical) 'nuances' is not useful to me. (P 10)

Since musicians have very diverse needs and playing habits in regards to musical performance, flexibility of a musical instrument directly improves its perceived usefulness. Customizability, personalizability, expandability and compatibility are the leading dimensions, which the musicians consider favourable. Conversely, rigid or restricted interface designs decrease the perceived usefulness of a musical instrument.

> Because (C) delivers me a 'ready-made building' and tells me to live in it. But the electric cables will be here and the lights there, it tells me 'when you press here this happens, when you press there that happens'. It arrives as a finished package. But here (A) and (B) I can build my own house, I can choose the brick and the glass and the frame which I will use for these two ((A) & (B)) and I can specifically and personally design this based on the requirements of my habitat. (P 03)

The study clearly reflects that being able to generate and modify sound instantaneously is extremely important to perceived usefulness of a musical instrument. Musicians strongly argue that regardless of their musical intentions, a useful musical instrument should always feature real-time sound generation (and modification) as an ‘option’. Musicians consider triggering pre-recorded loops a severe obstacle if it is the instrument’s only function. Similarly, musicians believe that the level of ‘user control’ of a musical interface’s functions features and sonic output directly affects its usefulness.

> The pitch control is pretty good in (D). I can play a solo with high precision and this is very very favourable for me and it is a ‘must have’ for many instruments. Because, acoustic instruments, with the exception of percussion, are founded completely on this feature. (P 03)

> I should be able to control the pitch when I want to. It becomes important ‘if’ I want to control it. Naturally it depends on the music, I might want to control it extensively, or not, or just a little, but ‘when’ I want to, I should be able to control it. (P 05)

On the other hand, musicians tend to consider a musical instrument to be more engaging when they are satisfied by its perceived usefulness.

5.3.4.2 Engagement

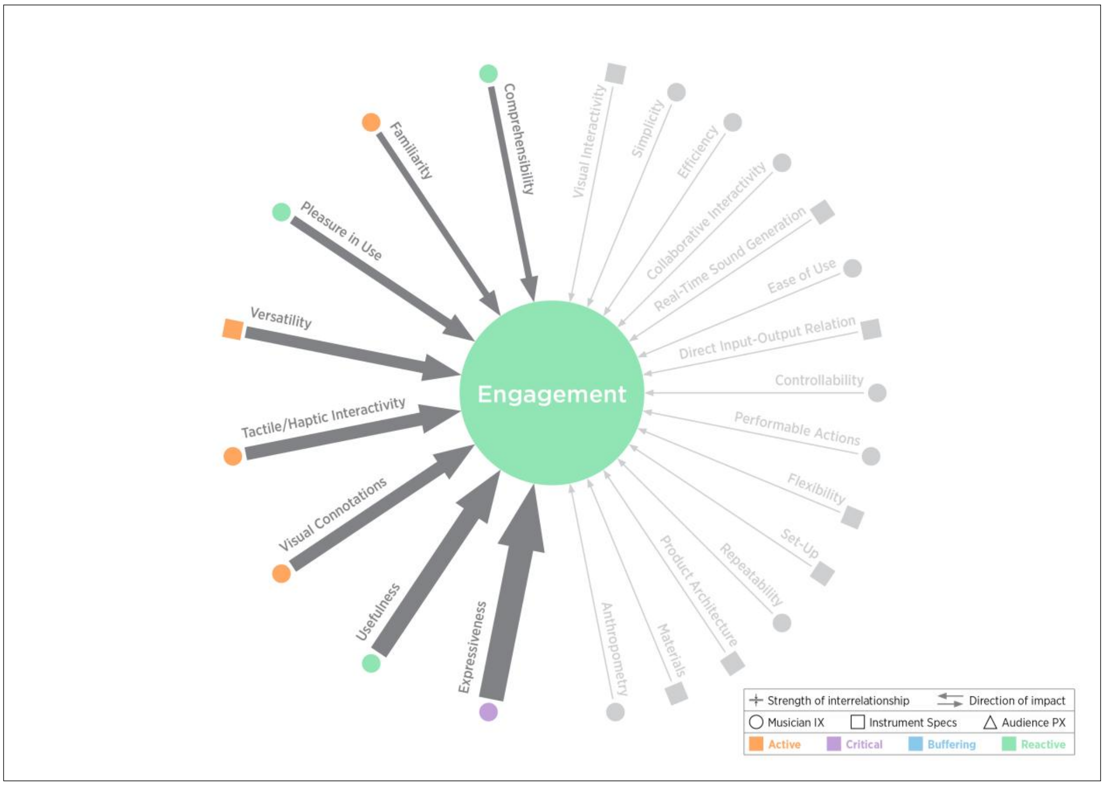

Figure 5.33 Egocentric Network Graph for Engagement.

Engagement with a musical instrument is strongly affected by an instrument's expressiveness and usefulness. Visual connotations, tactile/haptic interactivity and versatility also have considerable influence on this quality (Figure 5.33).

Musicians are willing to engage deeper with a musical instrument if the product allows and facilitates an expressive performance. Musical interfaces, which support the generation of musical nuances (e.g. vibrato, portamento, glissando), a continuous pitch space and high resolution gesture capture are among the most commonly mentioned characteristics of expressive instruments. Musicians believe that the absence of these qualities make the instrument unworthy of the 'time investment'; in other words; they are seen as trivial products for entertainment purposes:

> (E) is something trivial, but I don't think I could sit at it and create something much with which I can express myself… (P 04)

Similarly, musicians believe Usefulness and Versatility to be critical factors in deciding to engage long term with an instrument.

> …Because at the end of the day, if we are to form an emotional relationship (with the instrument), I don't want to constantly change the instrument. I mean, if possible, it should serve me as long as possible… If you are making music, it is important (forming an emotional relationship). What facilitates it is design, I mean design is also in the loop. Other than that, obviously, how much the instrument can satisfy my needs… its abilities… (P 24)

The musicians believe that 'visual connotations' is not enough on its own to make a musical instrument engaging. However, irrespective of the many design directions that can be taken, musicians expect an instrument to always communicate a 'respectful' character, and thus, support and improve the performer's 'image' and self-confidence on stage. The lack of this character affects engagement negatively.

> This (E) instrument looks funny to me, it looks like a mouse. For instance, I wouldn't use it; I wouldn't use it on stage. (P 07)

> This is a showerhead (E)... It is psychological. I am doing this (shower gesture) because I feel very much troubled. If I was 5 years old, it would have been favourable. Right now it is a very negative thing. People shouldn't say this is a mouse or a showerhead. Looks like it is out of a fairy tale, cheap… Objects, which can be mocked… The concepts, which are attached to them, are used for childish, fairy-tale contexts. The 'positive opposite'? Looks serious, helps the electronic music world to be respected. (P 29)

While new musical instruments feature many novel contact and non-contact (i.e. spatial) gestural interaction models for generating sound, musicians believe that interacting with tactile and haptic interfaces leads to a more engaging experience.

> The moment you lose that bond… the physical bond… How much can you get 'inside the music' with that instrument? (P 04)

The musicians also state that they decide to engage deeper with the musical instrument when the versatility of its functions features and the diversity and quality of the sounds it offers, convince them of the 'worth' of the instrument.

5.3.4.3 Efficiency

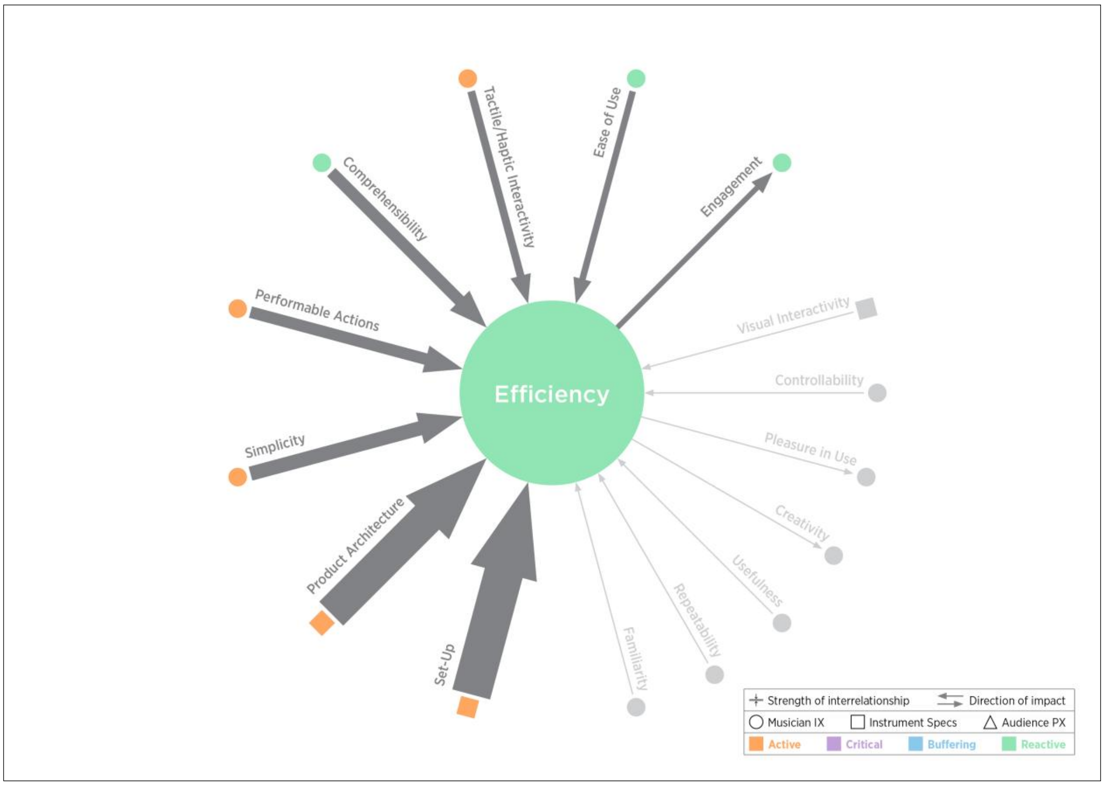

Figure 5.34 Egocentric Network Graph for Efficiency.

The efficiency of a musical instrument is dependent on a variety of dimensions that are related as much to the actual performance as they are to pre and post performance activities (e.g. logistics, rehearsals, set-up and disassembly). Thus, based on this perspective efficiency of a musical instrument is defined by practicality of set-up, maintenance and disassembly, immediacy of sound generation (and interaction) and the actual (during) performance efficiency. This quality is remarkably affected by set-up and product architecture, followed by simplicity, performable actions, comprehensibility and tactile/haptic interactivity (Figure 5.34).

According to the musicians, practicality (and thus; duration) of the performance set-up (and disassembly), portability of the instruments and wireless interactivity are among the major dimensions that influence set-up efficiency and immediacy.

> When you go to a performance with (C) you just want one cable but for (A) and (B) you need to have at least 20 minutes or half an hour preparation and set-up sequence. As far as I can see there are computers, power cables, etc. Usually, we start to play an instrument the moment we tune it. If the ‘evolution’ forced us to ask such questions, I mean if the

> traditional, acoustic instruments can deliver our needs immediately, sooner or later the same thing will be expected from them (electronic instruments). Activation time! The time needed to generate sound once the instrument is turned on. To be more precise, the duration for system set-up and sound generation. (P 13)

Similarly, compact, uni-body and wireless instruments are the most commonly mentioned dimensions of product architecture, which are positively associated with improved efficiency. Musicians also favour stand-alone musical instruments (internal sound generation and inbuilt speakers) because these products facilitate immediate interactivity anywhere, including rehearsals, actual performances and even during transportation.

> (C) is both practical to carry and everything is within the reach of my hand here… Small, portable… I can throw it in my bag and play everywhere… But you cannot take (A) or (B) everywhere… Not portable... You will need a roadie (P 19)

Concerning the actual (during) performance efficiency; musicians favour musical instruments, which embody a simple product design and interaction model. Similarly, simplicity in visual feedback and user interface parameters are considered facilitators of a more efficient performance.

> For example, (B) has too many parameters and I will have to think so many things at once while playing, I won't feel comfortable. In my opinion, rather than 250 parameters, five strong parameters are much better. Simplicity of an instrument is really important. (P 10)

> […] because during the gig, it's very important to be used to something tidier rather than something that will distract your concentration […] Visuality shouldn't manipulate you during the performance. You shouldn't arrive at a state where you cannot take your eyes off the instrument. You should be able to see and play it as a musical instrument. (P 22)

Being able to play an instrument with multiple hand positions, bodily interaction and single or two handed playability, are the major dimensions of performable actions that are favoured by musicians.

> You need to use both of your hands while playing (D) and (E) however you can play (A) with a single hand, which I believe is a beautiful thing... to be able to play an instrument both with single or both hands. If you can do something with one hand, you can use your other hand to do something else on that instrument… Actually, holding something is a very dysfunctional state… (P 15)

Musicians believe that the immediacy of interaction is also dependent on how fast the performer can understand and learn the user interface.

> When you look at an instrument you want to play it immediately. If it is something that can be easily comprehensible you already play it in a snap! An instrument's initial stage shouldn't wear me out. (P 11)

Finally, performance efficiency is also associated with tactile/haptic interactivity. Musicians favour this interrelation based on a feature, which some of the participants termed as 'Blind Interaction'.

> I am almost about to invent a category such as this: These are 'visual musical instruments'. They are musical instruments but visual. They are not aural. I mean you cannot play them without seeing. They are designed in that direction. You cannot play without looking. You have to see. You can't if you are blind. This is negative. They have to be played without seeing. (P 24)

> I need to be able to play also without looking at the instrument. […] This is an important thing. Not all electronic instruments may feature this […] All professional musicians sometimes look and sometimes don't. (P 17)

> […] That's why for these instruments your eyes need to be constantly on the screen. This is something I consider negative. (P 21)

> You shouldn't be forced to look in order to play. Everything needs to be at your fingertips… head or feet will do too… When I say 'within your grasp' I mean it both metaphorically and physically. (P 22)

5.3.4.4 Creativity

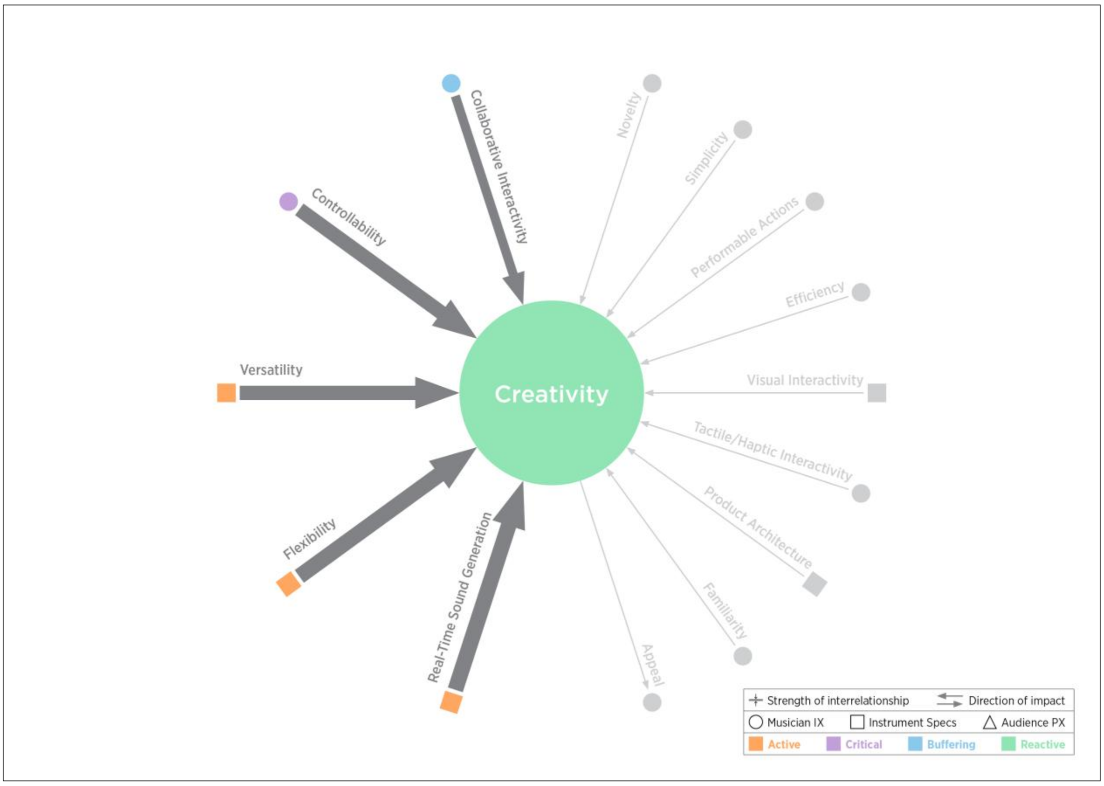

Figure 5.35 Egocentric Network Graph for Creativity.

This quality refers to a musical instrument's ability to support and facilitate musical creativity in a <u>performance</u> context. Creativity is remarkably affected by real-time sound generation, flexibility, versatility, controllability and collaborative interactivity (Figure 5.35).

Musicians believe that versatile musical interfaces offer more possibilities to the performer for musical creativity. Multifunctionality is the predominantly associated with a creative performance. Musicians also favour being able to use an instrument as a 'controller' only, through connecting it to computers and other hardware; a feature, which offers infinite possibilities for musical creativity.

> It is very important to be able to reflect your imagination to the instrument. You are limited in (C). Eventually, there is only one control gesture. After all you just press the buttons here. You can press them all simultaneously but they all have only a single expectation, there is a timeline there and you trigger certain events, etc. (P 22)

> You can make sophisticated music with this… I use the word 'sophisticated' in a positive way. I'm talking about the houses you can build here, which have more complex structures. I'm talking about sophisticated music… (P 04)

> In (B), every component has its own possibilities. It gives me the impression that with these, there are more possibilities. Musical possibilities. It gives a more 'creative' feeling… (P 28)

Musicians consider real-time sound generation to be a prerequisite of musical creativity because it enables the performers to create their own sounds and melodies.

> But regarding creativity, when you compose something on these instruments you can't feel much satisfied because you won't believe that you created it. Many things are ready-made, already loaded; loops or sounds. Because everything seems to be conceived in advance, designed in advance. You cannot design all the 'possibilities' when you touch a piano's keyboard. (P 19)

Similarly, flexible musical interfaces empower musicians to customize and personalize the instrument's sound generation, functions and features to realize their creative intentions. Reconfigurable expandable and compatible interface components and parameters are among the frequently mentioned dimensions of creative musical instruments.

> When the instrument enables the user to intervene with the sound processor and 'shape' the sounds that are triggered through the interface, I call this an instrument which is 'open to creativity'. (P 03)

Musicians who prefer to work and perform solo, expect the instrument to provide 'complete controllability' of sound generation in order to reflect their creative intentions to the performance.

> If your main objective is to perform a composition live or be it an improvisation, (C) and (D) provide better control where as (E) may lead to more random situations. (P 03)

However, some musicians believe that collaborative interactivity (on the same instrument) may indeed open new doors to creative possibilities.

> Actually, one of the primary functions of music is to be able to generate sound 'together'; to feel the 'harmony'. In other words; to create something together, which is stronger than what it would normally be… To be able to interact together… (P 13)

5.3.4.5 Comprehensibility

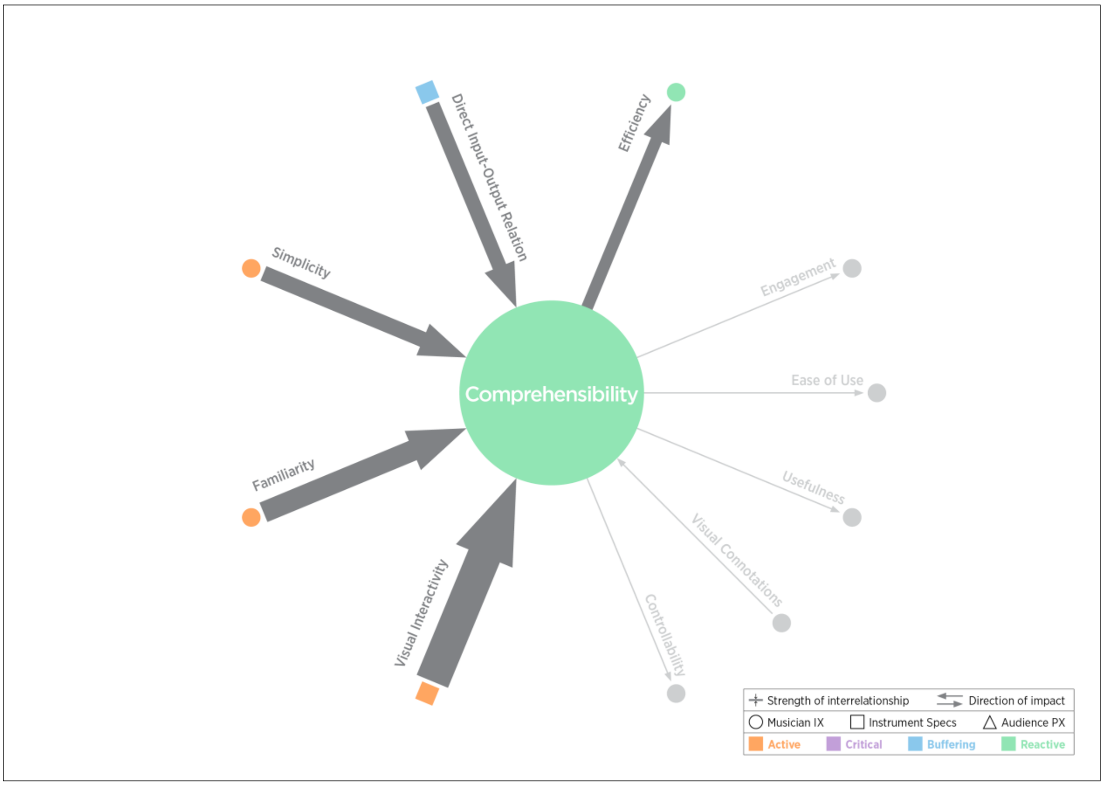

Figure 5.36 Egocentric Network Graph for Comprehensibility.

In the context of electronic musical instruments, this quality embodies dimensions such as understanding the interaction, predicting and discovering functions and features as well as learning how to perform on them. Comprehensibility of a musical instrument is associated mainly with visual interactivity. Familiarity, simplicity and direct input-output relation also make an instrument more comprehensible. An easily comprehensible, predictable and learnable instrument facilitates a more efficient performance (Figure 5.36).

Musicians expect new musical instruments to be easy to understand, predict and learn. Light feedback, colour coding and guiding visual references (e.g. icons, text, signifiers, graphical representations) are all associated with a comprehensible instrument. However, excessive or random visuality should not compromise comprehensibility.

> […] As opposed to (A) how the components affect each other is defined on the light surface on (B) and it can be seen visually. The same graphic support exists here. Even the links

visualizing various interactions are different. Visually, this has been made very beautifully. In (A), how the components affect each other can only be understood from the generated sound. (P 03)

Musicians strongly associate familiarity with predictable and discoverable musical interfaces. Frequently mentioned dimensions include: design references to traditional musical instruments, universal notation, familiar or traditional interaction models and familiar visual cues.

> Also it is very easy for a classically trained person to understand how to play this (D) when he or she looks at it because it has that structure. Even for someone who lacks that training but who has that reasoning, who can play a classical instrument. For example, when you look at (E) you may not even understand it is a musical instrument (P 10)

> It uses very traditional languages… (C) is a step sequencer. However, it’s not obvious what (A) really is. (C) interpreted an existing language… in a ‘usable’ way… it took its ‘essence’. Sound is generated from where you touch, like a kanun (zither), like a guitar… (P 14)

Furthermore, simplicity of product design, interaction model and visual interactivity increase clarity and thus help musicians avoid confusion especially during the initial stages of their interaction with the instrument.

> An instrument… Truly, the underlying idea should be refined to such an extent that a person facing the instrument should be able to grasp how it works immediately. (P 21)

> […] What those ‘thousand’ buttons do is not apparent. Where to start?? […] (P 07)

Especially concerning musical instruments, which feature completely novel interaction models or user interfaces, a direct input-output relation (i.e. transparent mapping) helps compensate for the lack of familiarity.

> I mean... It runs your input through its system and returns it to you as an output. And you need to understand the relationship between the input and output with your perception. I mean, then, it turns into a relationship, which you can follow and solve with your brain, and you try to control it, then, you are in fact completely ‘tuned in’. (P 17)

> The user can immediately hear the increase in frequency as soon as his hand wanders from left to right. I mean, to ‘hear’ the impact of your action... You pull your hand back and now it’s treble... You move up and down and it turned the volume up and down. (P 13)

Musicians propose that once achieved, comprehensibility affects the immediacy of their interaction with the instrument, as well as their engagement, efficiency and ease of use.

> I think – in the context of electronic musical instruments – it's like this: when you understand the working principles you can start playing music immediately but if understanding how it works 'part' is prolonged, you may give up the instrument... At least this is how it is with me. (P 07)

> Engagement is connected to even just understanding roughly how it generates sound… Opposite: Not intriguing in any way… When you see no apparent reason to try it because how it works isn't comprehensible. (P 21)

> How easy is it to use the functions of the instrument? How much prior knowledge do you need? How easy is it when it is in your hands? Can you understand it? You immediately get the result; 'when I do this, this happens' you immediately realise it... For the other one you need to read 'manuals' and stuff. What does this button do? What about that other button? (P 23)

5.3.4.6 Pleasure in Use

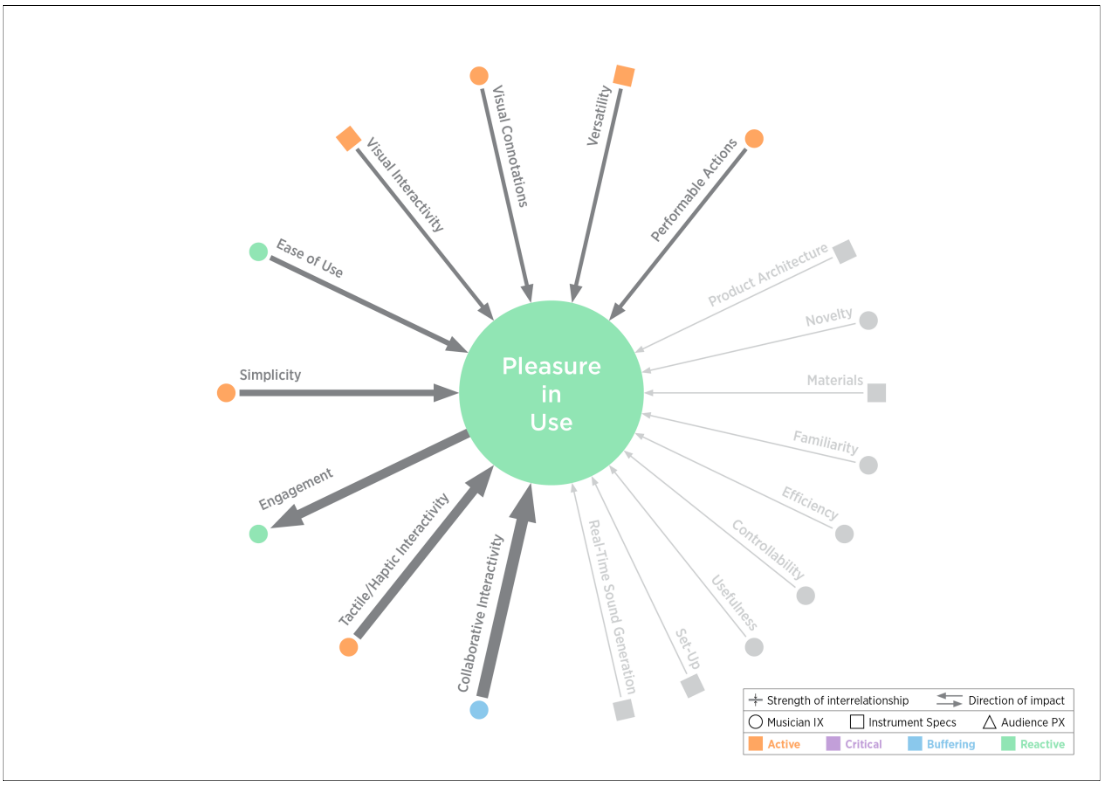

Figure 5.37 Egocentric Network Graph for Pleasure in Use.

Pleasure in use is a hedonic quality, which is affected by collaborative interactivity, tactile/haptic interactivity, simplicity and ease of use. A pleasurable interaction makes a musical instrument more engaging for the musician (Figure 5.37).

Musicians believe that performing as an ensemble is an essential part of making music and they associate musical instruments which provide multi-user compatibility with a pleasurable interaction. Collaborative interactivity can be achieved through a single musical interface with multiple performers as well as multiple identical instruments played by multiple performers.

> It would be very pleasurable to play with this all together, it can be played by a group. (P 10)
>
> In (B) while one of them is rotating the green square, the other person doesn't push red but green too. So there is a pursuit of harmony. They are depending on each other's possibilities there. Maybe this becomes a pleasurable activity for them more than generating sound. It seems witty to me from that aspect. You could perform ensemble music on that instrument. (P 10)

Musicians consider physical contact with a musical instrument to form an essential part of the emotional dimensions of music-making. Whether it is the actual performance or rehearsals, the pure sense of 'touching', tangible interactivity and feeling the resonance of the instrument are dimensions of tactile and haptic interaction that are associated with a pleasurable performance.

> When I look at this from a performer's perspective it is more pleasant. Changing the parameters on the instrument through physical contact… I find it more appealing from a performer's perspective. Rather than sitting at a table and 'clicking'. You make physical contact with the instrument and form an organic 'bond'. (P 12)

Musicians also tend to find simpler interactions and easier to use interfaces to be more pleasurable.

> (A) and (B) are more enjoyable… The opposite is complicated… For instance, when you walk up to (B) and directly generate sound… (P 07)

5.3.4.7 Ease of Use

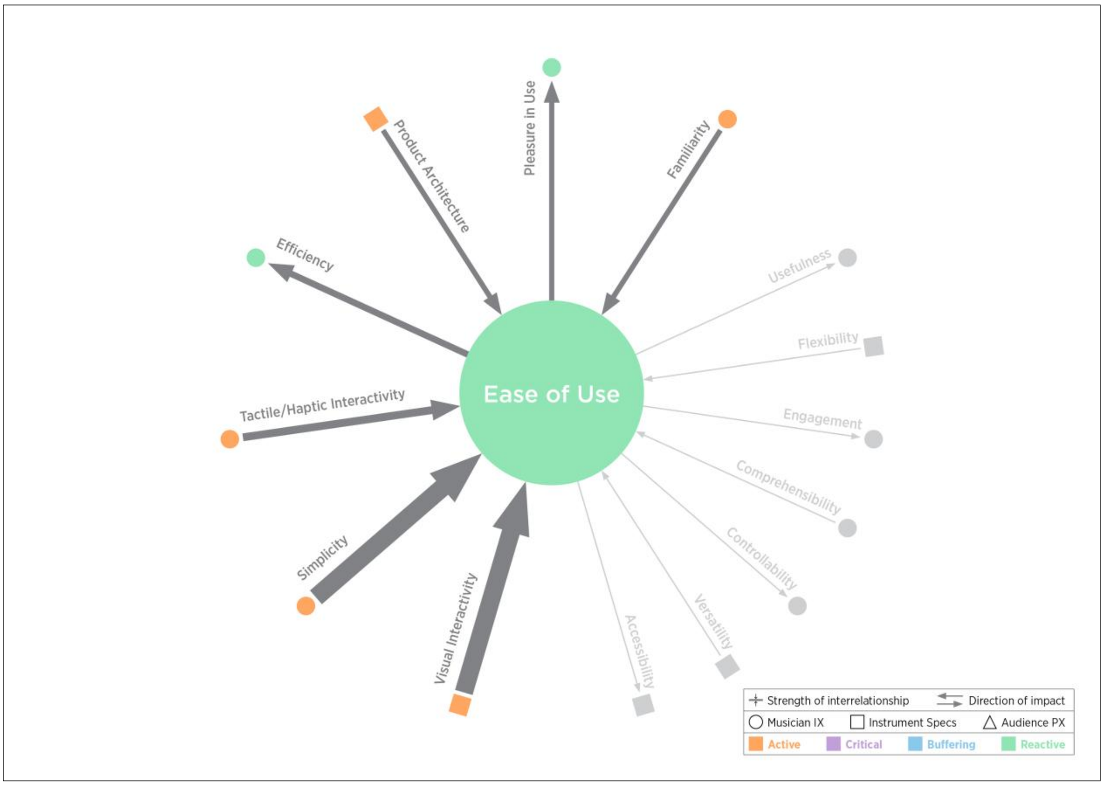

Figure 5.38 Egocentric Network Graph for Ease of Use.

This quality is concerned with the actual performance rather than practicalities of pre and post performance activities and it is strongly influenced by visual feedback and simplicity (Figure 5.38).

Musicians believe that simplicity of product design, interaction model and user interface components allow for an easier performance.

> The fewer the controls, the easier the instrument is to use… (P 05)

> The 'narrative' should be easy. A person needs to reach what he/she wants to do immediately. The section, where the sounds are stored, the section, where you arrange the sound effects… These are the things in technological gadgets where I experience the most difficulty… (P 26)

While musicians associate simplicity with an easy to use musical instrument, they also believe that the instrument should still be able to offer advanced users possibilities and depth for further progress.

> Simplicity is obviously important… It could be complex, a beginner guitarist plays a 3-chord 'Stand by me' when they handle the guitar at first… but they cannot play the solo the 'so and so' guitarists can… but they 'too' can play. In other words, instrument should allow such a thing… In my perspective, a novice user should be able to play that instrument, but expert users should be able to go far enough to satisfy themselves as well… (P 17)

Colour coding and visual guidance are among the most frequently mentioned dimensions of visual interactivity, which the musicians associate with an easy performance.

> Just like there are black and white keys on a piano, colour; as an element to distinguish between different sound zones or different features. In '(D) different strings are painted in different colours. Same colour is used from one Sol to another Sol in different octaves. I think it is a good thing to use colour. Even drummers put a black circle on snare drums on the exact spot where they are supposed to hit. On the guitar, there are dots on the neck on the fifth, seventh and twelfth frets. Colour is also a reference in using the interface easily. (P 03)

Musicians believe that the type physical interaction is very much related with the genre/style of music that they perform. Tangible musical instruments are easier to interact with physically, where as touchscreens and similar planar user interfaces are associated with easy parameter manipulation.

> It is easier to manipulate parameters on touch surfaces […] […] and look on one hand you have a touch surface. Very positive. Look… Why positive? There is something called a ribbon controller, or a d-beam controller, and here is an XY pad on the synth I use here. Which parameter? Because you don't deal with turning a knob but you just move your hand over it… (P 27)

> […] but if you are dealing with a constantly developing real/true composed electronic music circuit, then to be able to control that system much easier… at that point, touch based systems can make those things much easier. (P 20)

5.3.4.8 Audience Experience

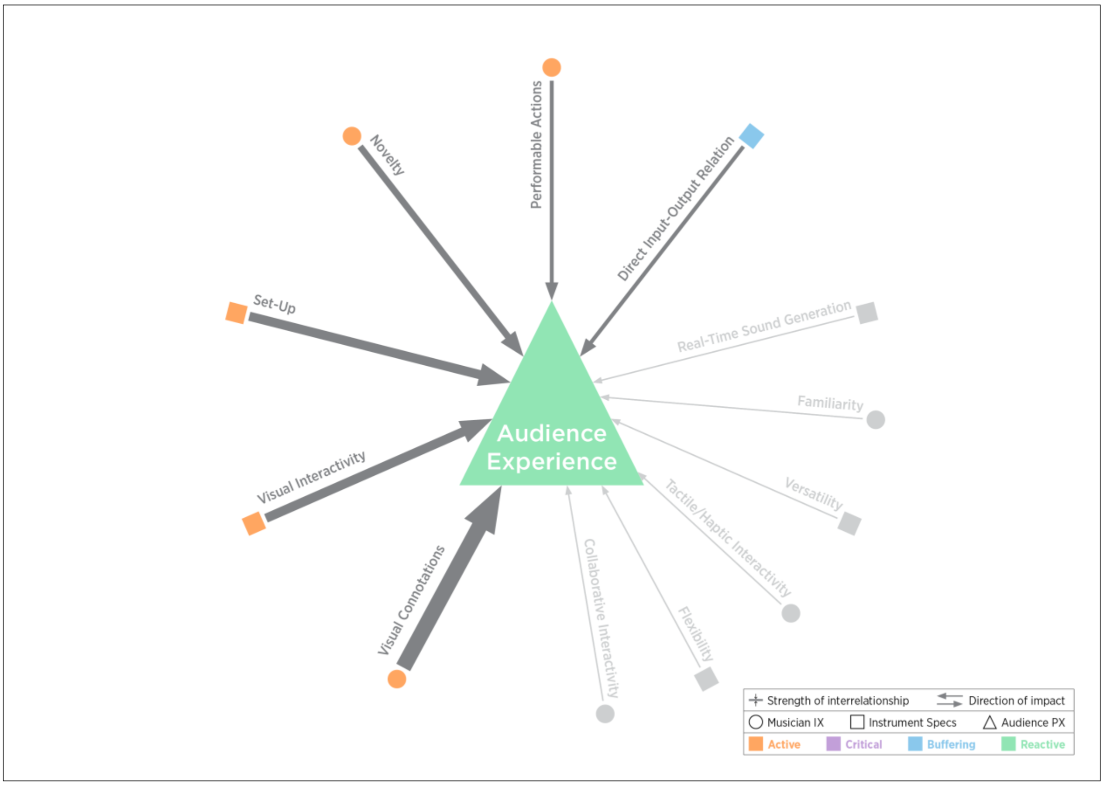

Figure 5.39 Egocentric Network Graph for Audience Experience.

This quality embodies a variety of dimensions, which form the overall live performance experience of the audience. Audience experience is defined by the visibility and comprehensibility of the musical performance, musician-audience interactivity and how engaging the overall performance is for the audience. Audience experience is mainly influenced by four qualities: visual connotations, visual feedback, set-up and novelty (Figure 5.39).

Musicians believe that there is a strong connection between the visual connotations of a musical instrument and the audience's perception of the overall performance as well as their 'image' on the stage. Musicians talk about diverse directions in regards to the visual design of the musical instruments. Playful colourful illuminated or organic designs, a simple utilitarian styling to reflect musical instrument semantics are among the popular mentions which favour this connection. Designs, which do not convey a respectable impression (e.g. 'funny looking' products, forms that resemble consumer products) negatively affect the audience's perception of the performers.

> If you are playing a live performance naturally you are in touch with an audience… Obviously there is a 'show' aspect to this in order to impress the audience. (P 12)

> When I set out thinking of the concert, I think that the changing colours in (A) are impressive for live performance. (P 05)

> The design of the instrument should support the musician's image on the stage. (P 11)

Concerning audience's comprehensibility of the live performance; visibility of the musical instruments and musician-instrument interaction (i.e. the stage set-up) as well as sound visualization and visual feedback (visible by the audience) play equally important roles.

> It is important for the audience to be able to see what the performer does in order to generate sounds… It's important to be able to see how the sounds are generated, through which method… (P 21)

> Audience should be able to follow the musical gestures… For (C) we need an overhead camera to see what's happening. Regarding the (visibility of) gestures, (A) is the most powerful. (P 11)

> Something which the audience can be immersed in or understand during the performance. (P 15)

Musicians believe that visual feedback should be considered as a dimension that affects not only the musician but everyone else who is experiencing the live performance. Thus, colours, lights and supporting visuals (e.g. visualization/visual representation of the music) are frequently associated with a more engaging and immersive performance experience for the audience.

> In (B) the existence of colours (and lights) facilitates the 'aural' audience beyond just hearing; to better concentrate on the music because visual feedback supports the music. (P 28)

> If the frequencies that are generated here would be projected visually, it would be very attractive. Frequency is a very powerful thing, a visual, which could evoke its power, I mean evoke the music… with a visual with which the music can be understood and felt. (P 26)

Finally, musicians also favour both novelty of design and novelty of interaction as facilitators of a more appealing and engaging audience experience. When audience is exposed to a completely unique design or a never-before-seen interaction, the surprising and mysterious effect they create stimulate and intrigue the audience; making the whole performance more immersive for them.

> At first glance the interaction between (A)'s components are not apparent. This creates a 'mystery'. If you are a wizard, mystery is important. I know this sounds superstitious but jazz concerts are in fact wizardry. (P 11)

5.3.4.9 Appeal

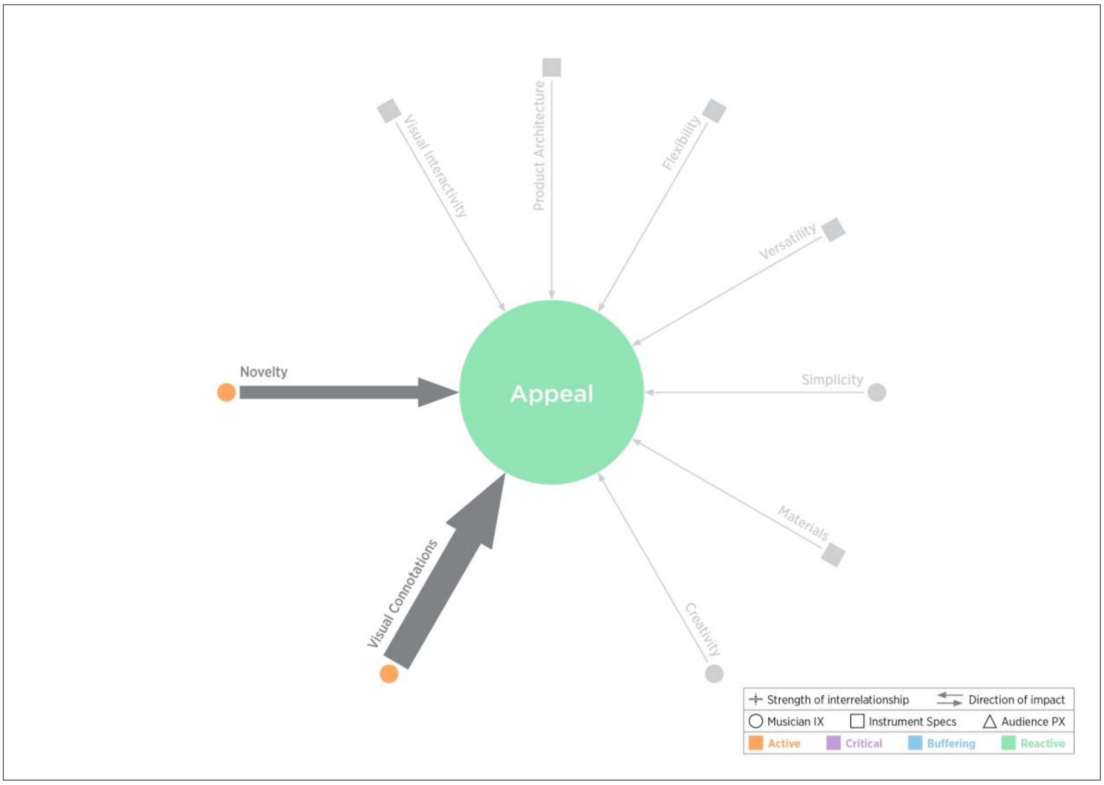

Figure 5.40 Egocentric Network Graph for Appeal.

This quality is predominantly affected by the visual characteristics of the design of a musical instrument, however, sonic qualities and novelty also inspire musicians' perception of appeal (Figure 5.40). Concerning visual connotations, musicians consider richness in colour, illumination and high saturation to be attractive and interesting. Conversely, a simple and neat design that clearly conveys 'musical instrument' semantics is also favoured. It is also important to note that musicians expect electronic musical instruments to embody their own unique visual character. Thus, design characteristics that mimic or imitate traditional musical instruments will have a negative effect on perceived appeal.

> Colours are important… Very appealing… Like playing… In (C) it is actually like playing… Colours, shapes... Not only cubes but also round shapes... There are different shapes… That vividness and brightness is very beautiful... (P 19)

> It creates more of an 'instrument' impression, I feel desire to play it. […] If you remember, we used to practice on electric pianos and whenever we saw a grand piano, we would crave to play it. When you see (B) you get the same feeling… You desire to play it. (P 04)

Novelty is also an important factor that influences perceived appeal. Uniqueness of design, a futuristic visual character, never-seen-before interaction models i.e. novel sound generation techniques as well as the novelty of the generated sounds themselves are among the most frequently mentioned dimensions associated with appealing instruments.

> (A) and (B) are new sound generation proposals… We didn't make sounds like this before, by putting some things on a table… This is positive. We never had such a musical instrument before. Imitating existing instruments doesn't really bring novelty. Wouldn't you feel excited when you see something (B) like this? You would want to touch it and play with it right? I mean you would want to interact with it… (P 13)

> The most futuristic instrument is (A). (D) is now contemporary and it is about to get old (B) is in between. I mean (A) is neither fish nor fowl… Positively… Firstly, its appearance cannot be solved immediately… (P 11)

> Doesn't look like anything else, a completely novel instrument. it doesn't have an 'ancestor'. This is very appealing. (P 19)

> The instrument, which I'd like to try the most is (B). Both the stuff that it can do and the way it does them is interesting. It is possible to do certain concepts in ways which were not possible before… (P 23)

5.4 Reflections on the Analysis Procedures

The combination of content analysis and CIA has revealed the answers to the three research questions. Considering that music is an extremely subjective art form, CIA proved to be very useful in further understanding the interrelationships between different participants' unique individual construct systems. Furthermore, it was also possible to interpret not only the relationships between major dimensions but also see the intricate connections between major and minor dimensions. After all, egocentric networks of the minor qualities were instrumental in understanding their connection to the whole system. As the relationships in the egocentric networks were formed through counting the numbers of participants' constructs, the statistical blindness (Fallman & Waterworth, 2010) of qualitative RGT analysis has also been overcome to a certain extent.

As with most qualitative analysis methods, both the initial content analysis and CIA took a lot of extra effort and time to complete compared to alternative quantitative analysis methods. However, as this thesis is a generative research, the actionability of the research depends on the richness and depth of detail of the findings. Thus, it is believed that the extra effort was justified by the usefulness of the results.

CHAPTER 6

DESIGN STRATEGIES AND GUIDELINES

This chapter presents the design strategies and guidelines to improve interaction, user experience and live performance in the context of new generation electronic musical instrument design.

Chapter's first section discusses the 'actionability' of the findings of this research. In other words, how designers can make use of the strategies and guidelines. The second section explains the 'sorting' attitude, which is employed to structure and organize the strategies and guidelines based on the cross impact analysis and framework for musical interaction. The third section presents the actual strategies and guidelines in eleven separate subsections, based on the aforementioned organization.

6.1 Actionability of the Research Findings

This thesis aims to provide designers and musical instrument makers (of various disciplines) strategies and guidelines for the design and development of new generation electronic musical instruments and interaction experiences in the context of live musical performance. The identities of the stakeholders, which this research aims at, need further elaboration. The strategies are born from a design perspective, hence, the primary stakeholders are considered to be the in-house designers at instrument manufacturers and independent designers, within a professional new product development context. However, the author argues that the way the research findings are presented and communicated, makes the strategies and guidelines comprehensible and actionable also for musical instrument makers without formal design training. Thus, it is believed that in addition to professional designers, independent instrument makers, NIME designers and designer-makers, and ‘inventor-type’ makers can also benefit from the contributions of this thesis. Additionally, the glossary of terms (see Appendix E), which was developed for this research can be used as a complementary guide for instrument makers, when they need clarification of meaning in regards to the dimensions of new musical interactions and the design/product qualities discussed in the research. While the findings of this research are not directly aimed at the remaining stakeholders of new musical interactions – namely; musicians (of various roles) and the audience – they passively benefit from the musical instruments and musical interactions, which may emerge in light of the findings of this thesis.

This research explores musicians’ perceived evaluations of musical instruments through their personal construings. Hence, the findings are qualitative in nature. The strategies and guidelines aim to provide detailed information on many aspects of new musical instruments and live musical performances while always supporting the arguments with evidence gained through the interrelationships between different dimensions of musical interaction. Also presented are the trade-offs i.e. ‘delicate balances’ for designers to consider when they need to make fundamental decisions or choices.

Designers and instrument-makers can approach the findings conveyed in this chapter from various perspectives. Each individual strategy is related to a different user goal and interprets the subject matter from the respective points of view. Hence, the strategies should be considered as individual entities rather than ‘alternatives’.

For example, top priority dimensions such as ‘design for usefulness’ or ‘design for expressiveness’ may come from upper management as strategic decisions. Where as, certain directions such as ‘design for efficiency’ or ‘design for controllability’ may be found lacking in existing musical instruments and in need of a boost. Similarly, dimensions such as ‘design for pleasure in use’ may be fit with current or future trends for new musical instruments.

Apart from these influencing factors, designers and instrument makers are also obliged to take a personal position on a lot of what is communicated in this chapter. In other words, they need to decide for themselves which directions to take, which factors to prioritise, as part of defining their own ‘designerly touch’. As these strategies are individual paths leading to different goals, there are no right and wrong decisions; only choices between equally rewarding directions.

Irrespective of which direction is taken, designers are recommended to make use of all 11 strategies specifically in the conceptual front-end of new product development; in other words, research, ideation and concept generation. The qualitative nature of the findings makes them most useful and actionable for early inspiration; when they are implemented as ‘starting points’. In relation to the ‘standard’ procedure for new product development, these ‘starting points’ can refer to initial design briefs or specific problem definitions. Hence, depending on nature of the design brief or problem, designers and instrument makers can either single out a specific strategy, or more possibly ‘pick and mix’; as design problems are often multidimensional.

6.2 Presentation Strategy for the Findings

Even though new generation musical instruments have been chosen as the subject matter, this study is primarily concerned with the ‘user’. In other words, the main objective is to propose strategies to improve musicians’ (and the audience’s) interaction, user experience and live performance. Thus, a ‘user centred’ approach is employed also for the organization and presentation of the findings.

As presented in Chapter 5, this study proposes a framework for musical interaction (Figure 5.4) in order to cluster and organize the musicians’ personal constructs. The framework classifies the constructs in three main categories: Musician IX (Musician’s interaction experiences with the musical instrument), Instrument Specs (The facts and technical specifications of the musical instrument) and Audience PX (Audience’s overall experience of the live performance; including their interactions both with the musicians and the musical instruments).

Furthermore, the interrelationships between the musicians’ constructs have been elaborated through cross impact analysis. The CIA system grid (Figure 5.8) reveals a clear hierarchy between the musicians’ constructs (design qualities), where each sector has a different significance within the greater system of constructs. Qualities in the active sector are the means to achieve the end goals of the system where as the qualities in the reactive (passive) sector are the end goals themselves. Ambivalent sector is bidirectional; in other words, the qualities in this sector act as both means and ends. Consequently, the combined qualities in the ambivalent and reactive sectors form the end goals – the main objectives – of this research; i.e. what the musicians need want and expect from new musical interactions. On the other hand, qualities in the active sector informs the study in regards to how to achieve these goals. Hence, it is no coincidence that all qualities in the ambivalent and reactive sectors are related to the 'users' of the system and they fall under the Musician IX and Audience PX sections of the framework for musical interaction. These qualities are: usefulness, engagement, efficiency, comprehensibility, controllability, expressiveness, creativity, ease of use, pleasure in use, appeal and audience experience. As a result, in order to ensure that the findings are discussed from a user-centred perspective (i.e. the musicians' end goals), the strategies are presented based on these 11 end goals of the system. A simplified version of the system grid presents the strategy headlines in Figure 6.1. Additionally, these 11 qualities are re-visited in connection to the framework for musical interaction as illustrated in Figure 6.2.

This presentation approach also ensures that all the relevant active and buffering qualities are discussed in detail within the respective strategies. After all, they are the 'tools', which designers will utilize in order to improve the musicians' interaction, user experience and live performance. In this research each quality has interactions with multiple other qualities, hence, minor repetitions inevitably occur throughout the discussions within the respective sections of the 11 individual strategies.

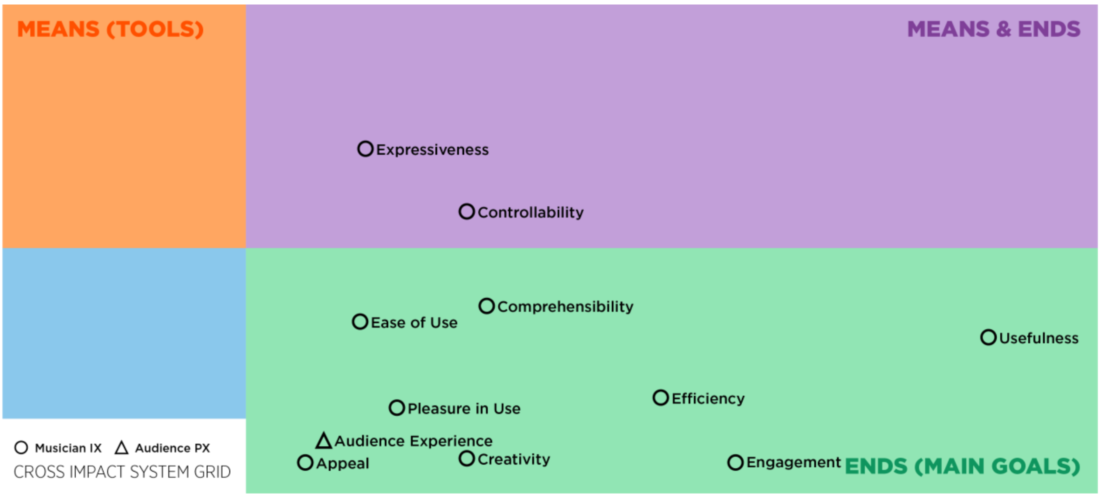

Figure 6.1 Simplified version of the Cross Impact System Grid

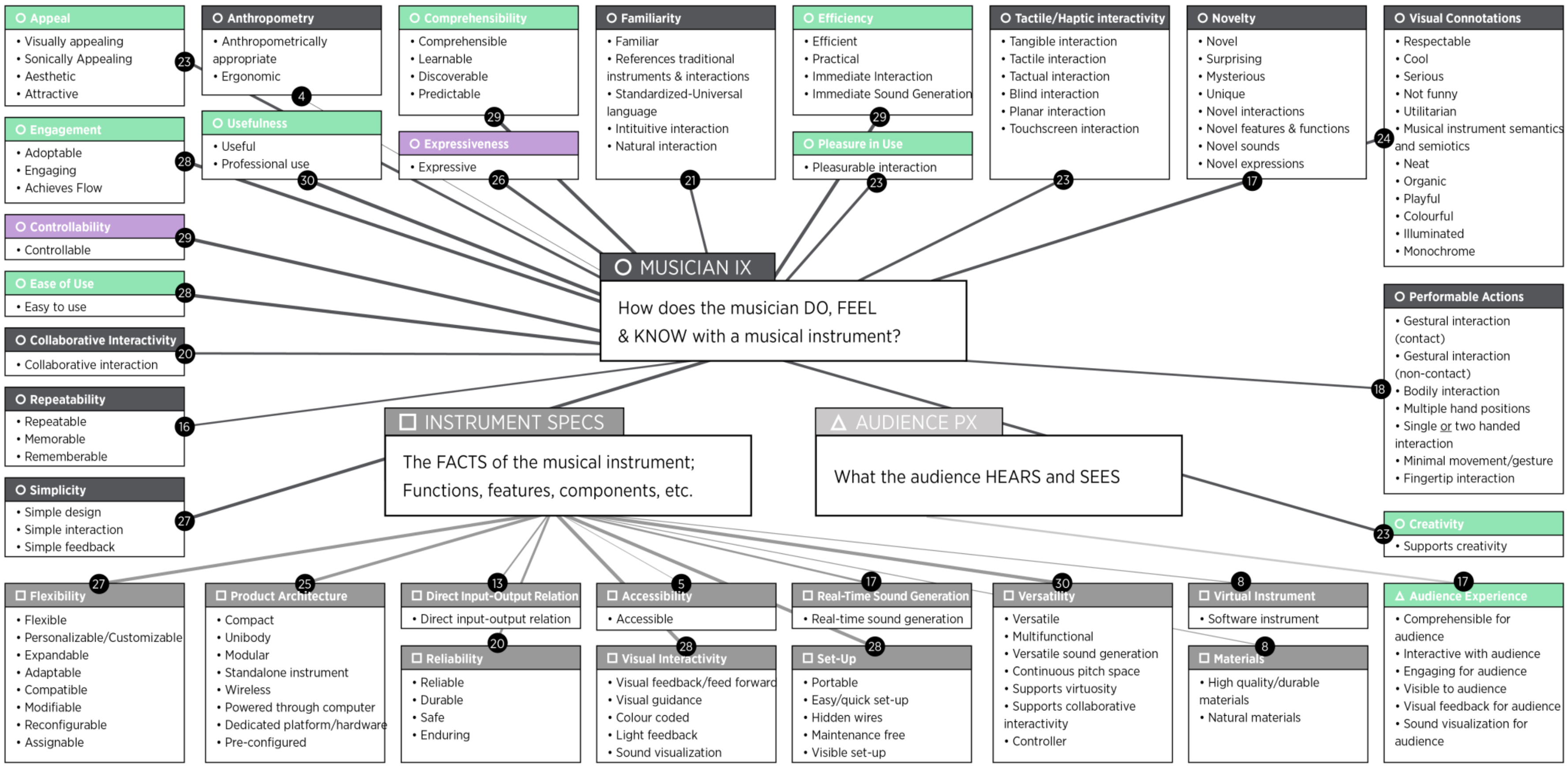

Figure 6.2 Design qualities in relation to the framework for musical interaction

6.3 Strategies to Improve Interaction, User Experience and Performance

As previously mentioned, the strategies presented in this section are all individual and they aim to deliver different end goals within the larger system concerning new musical interactions. Each quality (end goal) is narrated through a set of detailed strategies, which are accompanied by guidelines in the form of diagrams that visually summarize the design solutions, challenges, trade-offs and balances within those strategies. The anatomy and flow of the diagrams are as follows:

The large shapes (circles, squares, triangles) in the diagrams belong to the main quality (end goal) that the strategies are created for. The smaller shapes represent the interrelated qualities, – the most impactful factors/tools – which deliver the individual objectives that constitute the end goal. The headings next to these qualities are termed as 'Design Strategy'. They introduce the main strategies; which designers can use in order to deliver the respective objectives.

Finally, 'Design Decisions and Possible Actions' elevate the design strategies to an actionable level, where, designers are given practical recommendations in relation to what kind of decisions and actions can deliver the respective objectives, as well as, what decisions must be made to avoid the interrelated problems. This detailed diverse and practical information is generated entirely from the verbatim transcriptions of the musicians' RGT sessions and thus, it is not based on the author's personal interpretations. Furthermore, design decisions and actions also bring to the designer's attention various trade-offs and delicate balances which may have substantial impacts on the other strategies in this section. Designers appreciate and understand the multidimensional nature of design problems. Hence, the inclusion of these trade-offs are considered to be as useful as the dos and don'ts.

6.3.1 Strategies for Designing for Usefulness

Usefulness is arguably the most critical and essential dimension of musical interaction and it is also the topmost quality, which has received the highest number of appraisals in this study. While the absence or lack of certain qualities might become de-motivators or obstacles for a musician, usefulness draws the 'red line' between professional and amateur use contexts. This thesis study is carried out with professional musicians and the findings are also intended to be actionable and useful in a professional context. The research findings reveal that when professional musicians do not consider a musical instrument to be useful, they neither use it nor engage with it.

Usefulness is affected by and interconnected to the highest number of qualities in the study. Versatility, expressiveness, flexibility, real-time sound generation, controllability and repeatability are the main qualities that define a useful musical instrument. Additionally, visual interactivity, familiarity, novelty, product architecture, performable actions and tactile/haptic interactivity also have substantial influences on usefulness. Therefore, it is not possible to offer a ‘comprehensive’ single set of strategies for designing a useful musical instrument. The qualities, which influence a musical instrument’s usefulness are discussed and interpreted individually in their respective strategies inside the remaining sections of this Chapter. However, the predominant qualities that affect the usefulness of an instrument are briefly discussed, accompanied by a set of guidelines presented in Figure 6.3.

Musicians believe that there is a very strong link between the **versatility** and **usefulness** of a musical instrument. The dimensions, which make up versatility, are often heavily technology driven. However, while technical features such as sound sample resolution, gesture recognition resolution or multi-touch seem not to fall under the scope of industrial design, designers must take them into consideration regardless because, the implementation of the technology directly affects the design of the product, the user interface and the respective interactions.

- In terms of sound generation possibilities, musicians demand more from electronic instruments compared to acoustic instruments. Thus, a **‘rich’ content** and **diverse spectrum of functions and features** is the most commonly referred aspect of versatility.
- In the most basic sense, a musical instrument, which is versatile in relation to **multifunctionality,** can work as a synthesiser, sequencer, sampler and real-time/signal processor at the same time. Musicians consider it essential to have access to different parameters of sound such as: pitch (e.g. music notes,

melodies, intervals, chords), beat (rhythm) and timbre (sound colour, character). They associate this feature directly with the instrument's **usefulness.**

- As diverse functions and features translate to richer sound generation options, having 'more possibilities' give musicians space for more sophisticated creations.
- It is common practice in many contemporary music genres for musicians to use a musical instrument as a **'controller only'** (i.e. decoupling) through connecting it to other musical instruments and devices. The controller gives the performer immediate access to the controlled device's skillset. This approach gives the user freedom to explore many different uses for the instrument to enhance their performances.
- Additionally, versatility of the generated sounds themselves is of utmost importance. Musicians don't want technology to completely define their sound universe. Thus, diversity and quality of the sounds directly impact a musical instrument's usefulness. While the following technical specifications are matters of technology, they will have direct impact on the design of both the user interfaces and the overall products. For sampling; high sampling rate, maximum number of sample layers and maximum velocity samples enable the creation of diverse high quality samples. Similarly, analogue synthesis, digital synthesis and virtual analogue synthesis all improve the versatility of sound generation. A powerful digital sound processor (DSP) and a high quality sound card are 'must-haves' in order to achieve the aforementioned features.
- **Polyphony** (being able to generate more than one sound simultaneously (e.g. intervals (2 sound), chords (3 or more sounds, clusters (unlimited sounds)) is another important dimension of Versatility. The higher the polyphony, the more complex musical creations a performer can achieve. Polyphony is mainly a matter of technology; however, its absence takes away one of the most fundamental dimensions of music, which could easily be seen when one compares the versatility of a piano against a flute.

Expressiveness is one of the primary qualities, which musicians use in order to set themselves apart from other musicians. As expressions are individual and unique by nature, expressiveness of each musician's performance is also unique. Hence, expressiveness of a musical instrument directly affects its usefulness.

- **'Articulated instruments'** (interfaces, which allow articulations) are perceived as more expressive. If the musicians are able to manipulate the two most basic components of sound (frequency and amplitude (volume)) seamlessly, they are able to create 'nuances' such as portamento, glissando, vibrato, crescendo, decrescendo, etc. Nuances can be considered as the building blocks of musical expressions. This dimension is as much of a design matter as it is a technological feature. Designers needs to consider implementing appropriate sensor technologies to sense and capture gesture and then turn them into high resolution outputs while also decide on the form factor, material properties and dimensions of the user-interface in order to allow the musicians to create these nuances.
- Regardless of musical genre or background musicians want to make use of the complete sound palette (all possible frequencies) while performing. In this context, musicians consider user interfaces with a **continuous pitch (frequency) space** more expressive (e.g. A violin's neck offers the complete frequency range where as a piano has a fixed frequency range, where it is not possible to play any musical note between a C and a C Sharp).
- **High resolution gesture recognition** is in direct connection with the previous strategies because it allows the user interface to recognize, capture and translate any/all of musicians' gestures into input. This feature can be considered for both contact and non-contact (e.g. Theremin) musical interfaces and it is a technological matter. However, sensitivity and resolution of the working surface/space may have direct implications on design decisions related with the form factor and materials of the actual product.
- Musicians consider **further control options** to be another important dimension of expressiveness. In addition to frequency and amplitude (volume), when performers are given access to the remaining basic components of sound, namely **timbre, duration** and **envelope,** musicians

will have more **space for further expressive explorations** and thus a more **expressive performance**. Further control options could be achieved either through adding more controls to the user interface (e.g. buttons, knobs, sliders, dials) or adding more functions to existing control elements. If the designer prefers to take the second route, it is important to take precautions not to assign excessive functionality on a single control (e.g. one-two-three finger input on touchscreen interaction is possible but anything further overcomplicates the interaction).

Flexibility provides musicians a diverse set of tools, which directly influence the usefulness of a musical instrument.

- The implemented technology should not <u>dictate a fixed point of view</u> on the musician. In other words, the 'machine' should not define the musical style that could be performed on it (e.g. Loop-based, rhythmical, mono-phonic).
- **Modularity** – in the context of flexibility – offers freedom for musicians through the concept of **'expandability'**. The musicians can add new uses to their instruments by expanding the user-interface with different modules depending on their intentions. Different combinations of different modules lead to **infinite possibilities**.
- **Expandability** can also be achieved in means other than modularity. Designers are recommended to ideate/conceptualize expandability in the contexts of **form** (physical product and user-interface), **function** or **features.** Musicians expect more expandability from electronic and digital domains compared to the acoustic/traditional domain.
- **Customizability** and **personalizability** is arguably the most critical dimension of flexibility because it empowers musicians to **'shape'** the musical instruments based on their individual needs. In other words, musicians can design their own interfaces – at least to a certain extent – 'from scratch'. This <u>'open system'</u> approach enhances **usefulness** in many different directions.
- **Re-assignable** and **re-configurable user-interface elements** with an <u>'open system'</u> approach are reasonable starting points for designers in this context

(e.g. 'I need four more faders for the next piece', 'I will save the effects settings for all songs in the setlist in the quick access menu)

- As part of this strategy, musicians also expect to be able to use their own **'sounds'** with the instrument. **Rigid** structures with **inbuilt sound generators** that only offer a limited range of sounds has negative impacts on both creativity and usefulness.
- User-interfaces with <u>fixed timelines</u> often lead to 'loop-based' music generation, where as, **limitless/open-ended time spans** lead to more flexible musical interactions.
- Similarly, an **expandable and contractible frequency range** on the user-interface enables the musicians to perform in wider octaves as well as explore micro-tones on the available sound-space.
- In today's music scene, many musicians perform with complex set-ups that involve multiple instruments and devices. Thus, **compatibility** is another important quality that directly leads to more useful musical interactions. Designers are strongly recommended to consider musicians' needs in relation to the **integrity** of their set-ups. In other words, the new musical instrument should be compatible with computers (Laptops and tablets are ever more frequently used as part of musical instrument set-ups), other hardware (e.g. real-time samplers, sequencers, pedals, filters) as well as other electronic/digital and even acoustic musical instruments. In addition to physical adapters connectors and ports to achieve hardware compatibility, **cross-platform** i.e. **software compatibility** often becomes mandatory and thus, are also recommended to complement hardware compatibility for higher flexibility.

Musical notes (i.e. frequency/pitch) are one of the most fundamental building blocks of music. Especially for musicians who perform traditional music genres (e.g. classical, pop, jazz, rock) being able to generate frequencies instantaneously, in other words, **play melodies** (and intervals, chords) in **real-time** defines the usefulness of the musical instrument. Furthermore, the existence of this feature is taken for granted hence, its absence immediately becomes a demotivator.

- Musicians clearly state that a musical instrument should give them the ability – in their own words – to ***'start from silence'***, so that the musical instrument can directly respond to the musician's intentions and imagination.
- While performing with pre-recorded sonic materials can be equally useful or necessary depending on the music genre and style (e.g. loop based music), **triggering musical patterns** (of sound or rhythm) should always be given to the musicians as an **option** rather than the only possible function. In other words, the 'machine' should not dictate a certain style/ genre to the musician.
- Real-time sound generation can also be further enhanced to enable the musicians to generate and synthesise; in other words, to modify and shape the sounds they create. Therefore, **real-time sound/signal processing** is considered as a useful feature for achieving **sonically creative results**.

Repeatability is perceived as a must-have feature of a useful musical instrument. Concerning new electronic musical instruments, being able to **memorize** and **repeat** the functions features and interactions of the interface lies heavily on **visual information**.

- Especially when designing novel user-interfaces with no familiar references to traditional musical interaction, visual references and guides help the musicians **remember** and **repeat** musical actions (e.g. 'blue button changes the LFO', 'when I touch here, I get a G Flat')
- When playing **melodies intervals** or **chords,** musicians need to know the **exact placement of each frequency** to be able to play the same musical piece identically or similarly (i.e. improvisation) in different performances. While this knowledge becomes internalized in acoustic instruments after a certain amount of practise (e.g. violin, fretless guitar) unorthodox interfaces or interactions can highly benefit from visual support concerning the **repeatability** of the aforementioned musical elements.
- It is also helpful to visually represent and guide **parameter modification**. In other words, when the musician is adjusting parameters pre or during (real-time) the performance, the designers are strongly recommended to incorporate visual feedback and feed forward (e.g. blinking lights, change of

colour, changing numbers or text, opening sub-menus on screens) so that the musicians would not only hear but also see the precise changes based on their actions as well as the new options presented to them based on their selections.

One aspect of new musical instruments, which sets them apart from their acoustic counterparts is controllability. All acoustic instruments are user driven. In other words, the performer has complete control over the instrument as well as the final outcome. In the case of new electronic instruments, randomness (in sound or effects generation) can be considered as either a decrease in control or a feature that can be used for creative purposes. Concerning the former scenario, musicians consider a musical instrument more useful if they have full command of the instrument's all available features and functions. Versatility flexibility and real-time sound generation are interlinked to controllability for enhancing the usefulness of a musical instrument.

- Regarding sound generation; precise pitch controllability should always be offered as an option. Musicians may or may not want to use this feature depending on their musical intentions, however, it should be available in case it is needed.
- Complete control over the generated sound (i.e. sampling, synthesis, live processing) complements the previous strategy.
- Repeatability of musical actions also confirm perceived control and thus, usefulness.
- Single user interactivity empowers solo performers with the technical and creative control of both the instrument and the musical outcome. Collaborative musical interfaces that can be used only through multi-user interactivity are considered less useful because the musician is in need of other performers' participation.

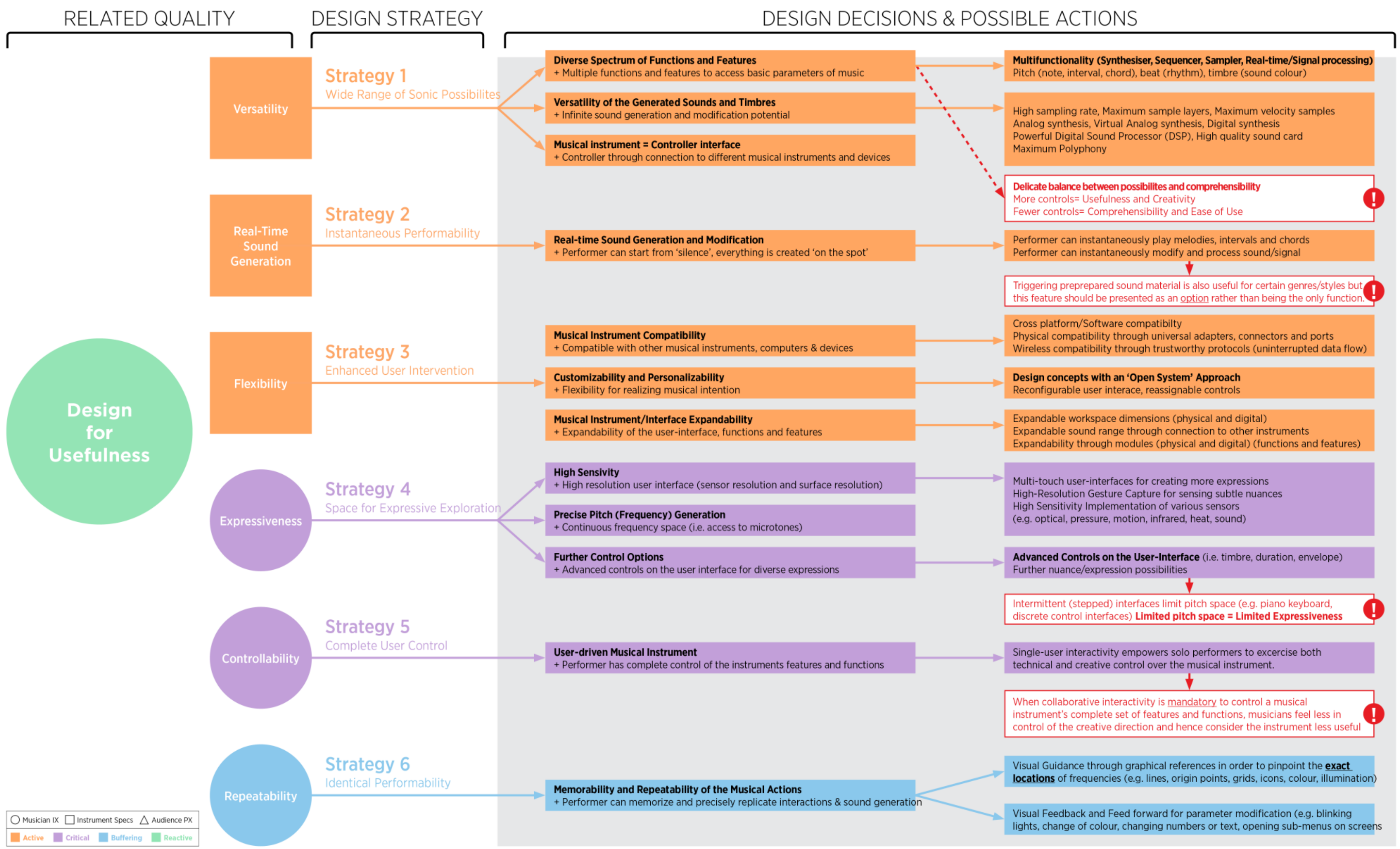

Figure 6.3 Guidelines for designing for Usefulness

6.3.2 Strategies for Designing for Comprehensibility

Comprehensibility is a critical dimension for interacting with a new musical instrument. This dimensions of comprehensibility are understanding the interaction, predicting and discovering functions and features of the user interface and learning how to perform with the instrument. When the musician has difficulty in carrying out these tasks, the whole interaction experience becomes problematic. The fundamental qualities, which have strong impacts on comprehensibility are: visual interactivity, familiarity, simplicity and direct input-output relation. In return, designing a comprehensible musical instrument/interface positively impacts the immediacy of the interaction, musicians' engagement, and ease of use. Guidelines for designing a comprehensible musical instrument and interaction are summarized in Figure 6.4.

In the context of electronic musical instruments (and as opposed to traditional musical instruments), **visual interactivity** becomes the primary facilitator for understanding how to play the instrument.

- The first and foremost strategy in regards to visual feedback and feed forward lies in its connection to sound. What musicians refer to as '**useful visual feedback**' or '**functional visuality**' translates to the strong and immediately recognizable connection between the musician's actions and their visual counterparts.
- Lack of 'meaning' and 'intention' in visual feedback can become a <u>distraction rather than a helper</u>. Random movements or changes in light and colour on the interface with the purpose of 'enhancing visual aesthetics' can be considered examples of such distractions and they should be avoided. This is especially important in the sense that musicians will potentially try to decipher a meaning or function behind the randomness and thus, misunderstand or misinterpret the interface.
- Especially for musical interfaces with complex interactions, musicians consider **colour coding** a big helper for discovering the musical instrument. Colour coding can be used to sort and identify functions, features, control parameters or different regions of the user-interface.

- **Light feedback** is another important tool to help the musicians on stage, especially in dark or low-light performance settings. Designers need to consider the overall complexity of the user-interface before deciding the type of light feedback (e.g. Static lights, blinking lights, colour-changing lights) in order to avoid further complexity if the user-interface is over crowded with many components.
- Similarly, especially for modular musical interfaces, **graphical representation of the interactions between modules or interface elements** helps the musicians identify this complex network of relationships and connections.
- The 'temporality' of visual information is also important. Designers are recommended to consider structuring the visual feedback and feed forward for musical actions in **'real-time'** (e.g. The light feedback of a 'jog-dial' moving in clockwise or anti-clockwise <u>while</u> the jog dial is being rotated).
- For musical instruments, which are played through traditional musical notation, designing elements for **visual guidance,** such as **graphical signifiers and references** (e.g. lines, origin points, grids, icons) in order to pinpoint musical notes, intervals, octaves help the musicians greatly.
- Similarly, designing **semiotics** for a parameter, which are 'in tune' with the function of that parameter (e.g. a 'filter' icon to represent an LFO filter button) improves the musicians' understanding of the user-interface components. Alternatively, **text** can also be used in cases where semiotics falls short of communicating the function of certain interface elements.
- The use of **text** is a trade-off. While text is easily readable and recognizable, even English is not guaranteed to be universally comprehensible. Thus, designers need to thread carefully when to use text and when to replace it with universally recognizable semiotics.

Familiarity is another essential factor in understanding a musical instrument. Positive transfer, intuitive and natural interactions, and standardization (e.g. performability with universal music notation) are the main dimensions of familiarity. Designing for familiarity can be interpreted in three main approaches: familiarity of product design, familiarity of the actual interaction (gesture-sound relationship) and familiarity of user-interface elements/feedback/guidance. Firstly, the form and visual design of the instrument can carry references to traditional/existing musical instruments. Secondly, the actual ‘musical interaction’ (gesture-sound relationship) can derive from traditional musical instruments. Thirdly, the user-interface may feature visual information, which mimic or reference elements of existing musical instruments.

- If the physical design of the musical instrument is based on/ has **references to the form factor and visual design elements of a traditional musical instrument,** musicians can use this familiarity in order to understand how to ‘handle’ this instrument (e.g. necks, sound holes, blow holes, keys, strings).
- If the actual **interaction model** (sound-gesture relationship) of the musical instrument **derives from traditional musical interaction models** (e.g. hitting (percussive instruments), blowing (wind instruments) or plucking (string instruments), wearing and carrying like an electric guitar or saxophone, etc.), musicians can positively transfer their experience to facilitate an immediate understanding on the workings of the instrument.
- Designers may also consider **simulating** – fully or partly – virtual or physical versions of **traditional user-interface elements** in order to create familiarity (e.g. keys, lines to reference frets or strings, direction (left to right: bass to treble)).
- Additionally, **familiar colours** (e.g. black and white keys) grids or lines to pinpoint notes (frequency) intervals or octaves can be integrated into the design to enable and improve musicians’ comprehension of the user-interface.
- Being playable through a **universal language** (traditional musical notation) is another important dimension, which enhances the instrument’s familiarity for musicians. The **familiarity of musical semiotics** (e.g. clef icons, musical terminology (text), measure/bar, time signature, etc.) may be used to enhance the graphical user interface (GUI) of the musical instrument.
- Additionally, familiarity should not be considered as being limited to traditional acoustic musical instruments. Integrating **advanced visual references** mimicking parameters found in existing electronic musical

instruments (e.g. synthesisers, samplers, sequencers) such as: signal flow, basic components of sound (frequency, amplitude, timbre, duration, envelope) can lead to a more comprehensible musical interaction; especially for musicians who have a wider experience in music technology.

Simplicity is the third major quality, which strongly affects comprehensibility. In the context of musical instruments, simplicity refers to both the simplicity of product design and the simplicity of the interaction between the musician and the instrument. The design strategies, which can be employed while designing for Simplicity are as follows:

- Designers are recommended to consider the actual product design as **clear** and **simple** as possible. Complexity of form and excessive quantity of interface elements, both for uni-body and modular products, create confusion and negatively affect comprehensibility. It is recommended to strip down the musical instrument to its bare essentials required for functionality. Simplicity enables the musicians to reach their intentions immediately.
- The underlying idea and concept of the musical instrument should be filtered down to such an extent that the musician should 'grasp' that idea immediately and understand how to 'work on it' (e.g. a flute is a 'pipe' with holes and when someone blows through it, it makes sounds).
- In regards to musical interaction, unnecessary complexity should be avoided at all costs. A difficult 'narrative' (i.e. use scenario), excessive number of interface elements, excessive amount of visual feedback (e.g. too many lights and colours, long texts, too many icons, multiple screens) will have a negative impact on the comprehensibility of the interaction.
- However, assigning multiple functions on a single interface element – while it makes the interface physically simpler by reducing the number of elements – may also cause the interaction to become less comprehensible and harder to learn. In other words, there is a trade-off between mental load (multiple functions on single control) and physical load (multiple controls on the user interface). This is a design decision, which should be treaded carefully.

The final major quality affecting comprehensibility is **direct input-output relation.**

- This quality derives from the concept **'transparent mapping',** which refers to a <u>'transparency in understanding'</u> in relation to 'which possible actions' generate 'which possible outcomes'; especially in the context of smart interactive products. Hence, the relationship between input and output should be made very clear on the musical interface. The comprehensibility of this 'relationship' in fact becomes the comprehensibility of the whole instrument and interaction.
- The instrument's response time and response type (how soon and by which means the output is presented; e.g. both visually and sonically) are also critical in achieving transparent mapping and thus, comprehensibility. It is recommended to 'standardize' the type of response (e.g. visual, tactile/tactual feedback) and ensure that the response happens as soon as technically possible.

Achieving the aforementioned four qualities is critical for designing a comprehensible interaction. In return, the musicians' comprehensibility affects the immediacy of their interaction with the instrument. Musicians consider a comprehensible instrument to be more efficient, engaging, and easy to use.

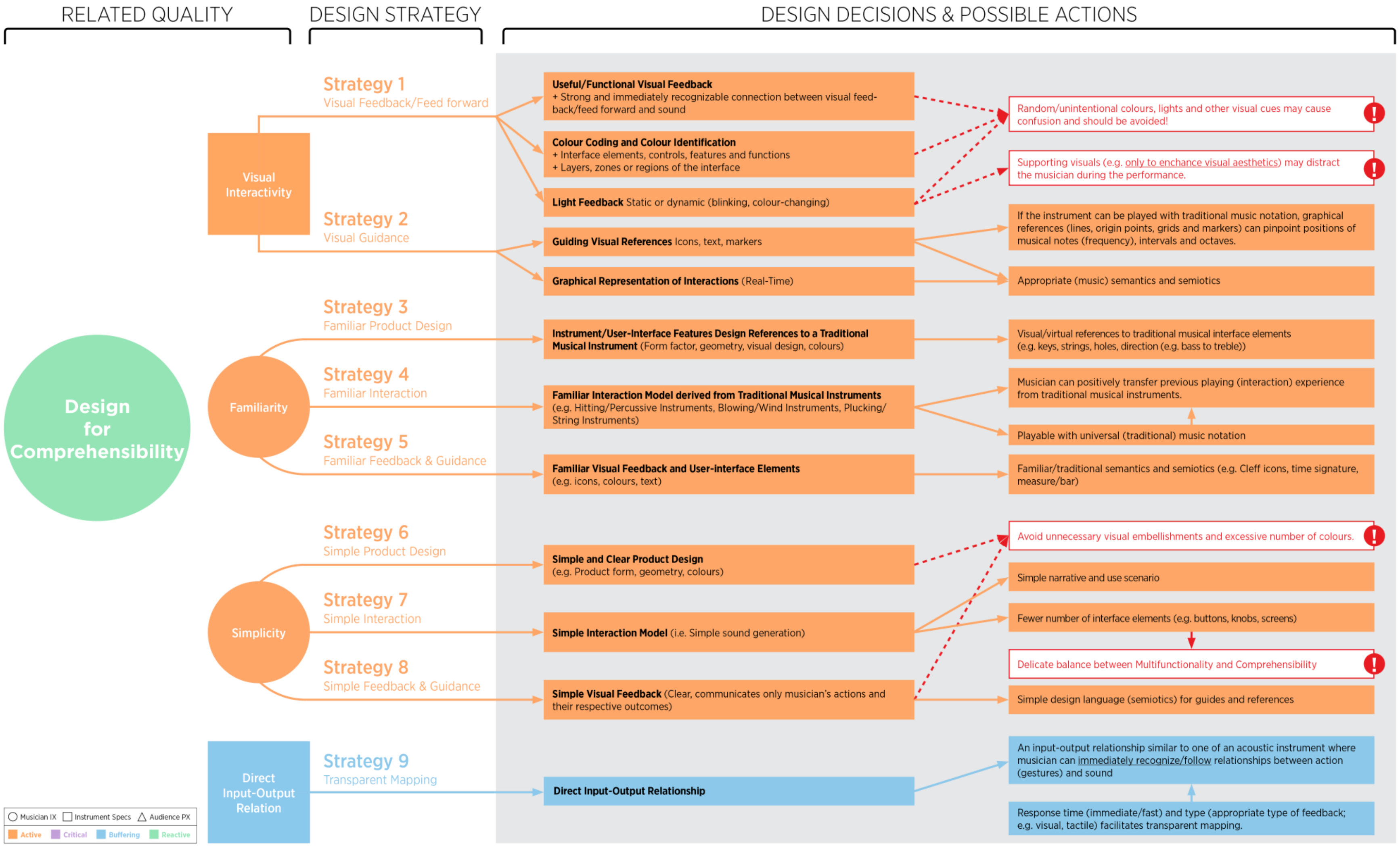

Figure 6.4 Guidelines for designing for Comprehensibility

6.3.3 Strategies for Designing for Engagement

Engagement is a decisive quality in regards to determining a musical instrument's longevity. Any musical instrument requires a profound investment in regards to time and practise. Thus, it is important that after the adoption stage, musicians consider the instrument to be engaging in order to invest and dedicate their time to it. Expressiveness and usefulness are the major qualities that make a musical interaction more engaging. Visual connotations, tactile/haptic interactivity, versatility and pleasure in use also influence engagement. Guidelines for designing an engaging musical instrument/interaction are summarized in Figure 6.5.

Musical instruments, which provide the 'space' for **expressive** exploration are considered to be more **engaging**. As the musicians continue to explore the instrument more intimately, they should discover new expressive capabilities accordingly. When the instrument reveals its expressive capabilities in time, musicians become intrinsically interested in the instrument.

- User interfaces, which can respond to different techniques and styles (of playing) are more expressive and thus, they are more engaging.
- 'Articulated' interfaces, which can generate diverse nuances (e.g. portamento, glissando, vibrato) justify the practise time a musician spends on the instrument by rewarding him or her with a more expressive playing.
- A continuous frequency space (e.g. violin) can empower the musicians to explore articulations mentioned above.
- Higher gesture/motion resolution on the user interface help musicians to engage in further explorations to capture different timbres, microtones, partials and other rich expressions that are commonly achieved in acoustic instrument performances.
- Thus, the closer an interactive interface can mimic an acoustic instrument in regards to expressiveness, the more engaging it will be.

Similarly, **usefulness** is a major factor in capturing the musicians' continued interest in the musical instruments. When the musicians don't consider the instrument to be suitable for their professional needs, they get bored and abandon the instrument during the adoption stage (The qualities that affect perceived usefulness are intrinsically related with versatility, expressiveness and flexibility and can be found in the respective sections of this Chapter).

- Musicians expect the instruments to communicate the 'sound is the purpose and not the means' message very clearly before engaging with the product.
- In this sense, 'sonic qualities' of the instrument should be perceived valuable and interesting enough without the support from the visual design (i.e. overall design, visualization of sound, colours, lights, etc.).

On the other hand, as long as the musicians are convinced of the instrument's perceived usefulness, **visual character** of a musical instrument becomes a factor in engaging with the product. However, there is no consensus among musicians in regards to 'how' an instrument is supposed to look like. Different musicians' diverse descriptions form a very wide spectrum of visual connotations. However, a musical instrument's visual connotations are never enough on their own to engage a musician. It is rather the opposite; where the 'lack' of certain visual dimensions convince the musicians to not engage with the product. The unifying aspect of the musicians' thoughts suggest that the visual character of an instrument is essential in supporting and enhancing the musician's image and self-confidence on stage. Furthermore, musicians expect the visual aspects of the instrument to facilitate their interaction with the audience. Therefore, it is possible to take make a few rules of thumb in relation to designing for an instrument's visual character:

- Musicians often use the term **'respectable'** while describing a musical instrument's visual design and expect an instrument to evoke 'respect' from the audience.
- It is important to avoid semantics and semiotics, which communicate non-music related visual references (any **non-music related consumer product or everyday object**) because musicians associate such connotations with a degrading on-stage self-image and thus, definitely do not engage with such products.
- The design of the instrument should reflect and support its essential function. In other words, visual semantics should clearly communicate a **'this device**

makes sounds' message regardless of the design direction being taken for the visual character of the musical instrument.

Especially in the post adoption stage, the physicality of the **tactile/haptic interactivity** facilitates an **'emotional bonding'** with the instrument and thus, engagement. Musicians expect the instrument to maintain and preserve a physical bond through which, they associate, accommodate and harmonize themselves. The physicality of **'touch'** is what makes them really feel that they are actually making music. Thus, the absence of physical touch leads to a distant and cold 'relationship'.

- **Non-contact gestural interfaces** – while they allow for freedom of body movement – also fall short on delivering a tactual interaction and thus, should be carefully considered in design decisions.
- Tangibility and tactility **increase interactivity**, which in turn helps the performer feel more engaged to the instrument.
- Many nuances of a rich tactual experience that come through physical interaction are missing on what the musicians call a **'digital touch',** i.e. touchscreen glass and similar flat interfaces. Avoiding such interfaces also facilitates a more engaging use.
- Similarly, secondary interfaces like computer mouse or keyboards disrupt the **'intimacy'** of the one on one relationship that the musician forms with the instrument.
- Thus, **physical mechanisms, spring-loaded actions, key depth** (not necessarily limited to 'keys' but any interface elements), **resistance** and **force feedback** can also be considered as tactile/haptic enhancers of a more engaging interaction.
- Feeling the **resonance** and **vibro-tactile feedback** helps musicians to **'become one'** with the instrument.

Versatility has a complementary role to usefulness and expressiveness in regards to engaging with a musical instrument. Musicians are not intimidated by the challenges of virtuosity; in fact, they expect the musical instruments to require talent and mastery. Thus, the more they engage with an instrument, the more sophisticated results the instrument should reward them with in time.

- Thus, a **‘high ceiling of virtuosity’** is the most critical dimension of a versatile musical instrument because the ‘promise’ of higher levels of proficiency and sophistication makes it more engaging for the musicians.
- Similarly, **versatility of the generated sounds** is equally important because musicians do not want to be restricted to a certain ‘sound-universe’ forced upon them by the technological limits of the sound generator.

Musicians also believe that a **pleasurable interaction** makes a musical instrument more engaging.

- ‘Playing the instrument like playing with a toy’ is a metaphor, which can be used to design both a pleasurable product design as well as the actual pleasurable interactions.
- Designing the product in a ‘playful’ manner enhances perceived pleasure in use and thus, facilitates the ‘urge’ to immediately engage with the instrument.
- In this sense, musicians perceive pleasurable musical instruments as neither too difficult to understand nor too sophisticated to ‘get inside’.

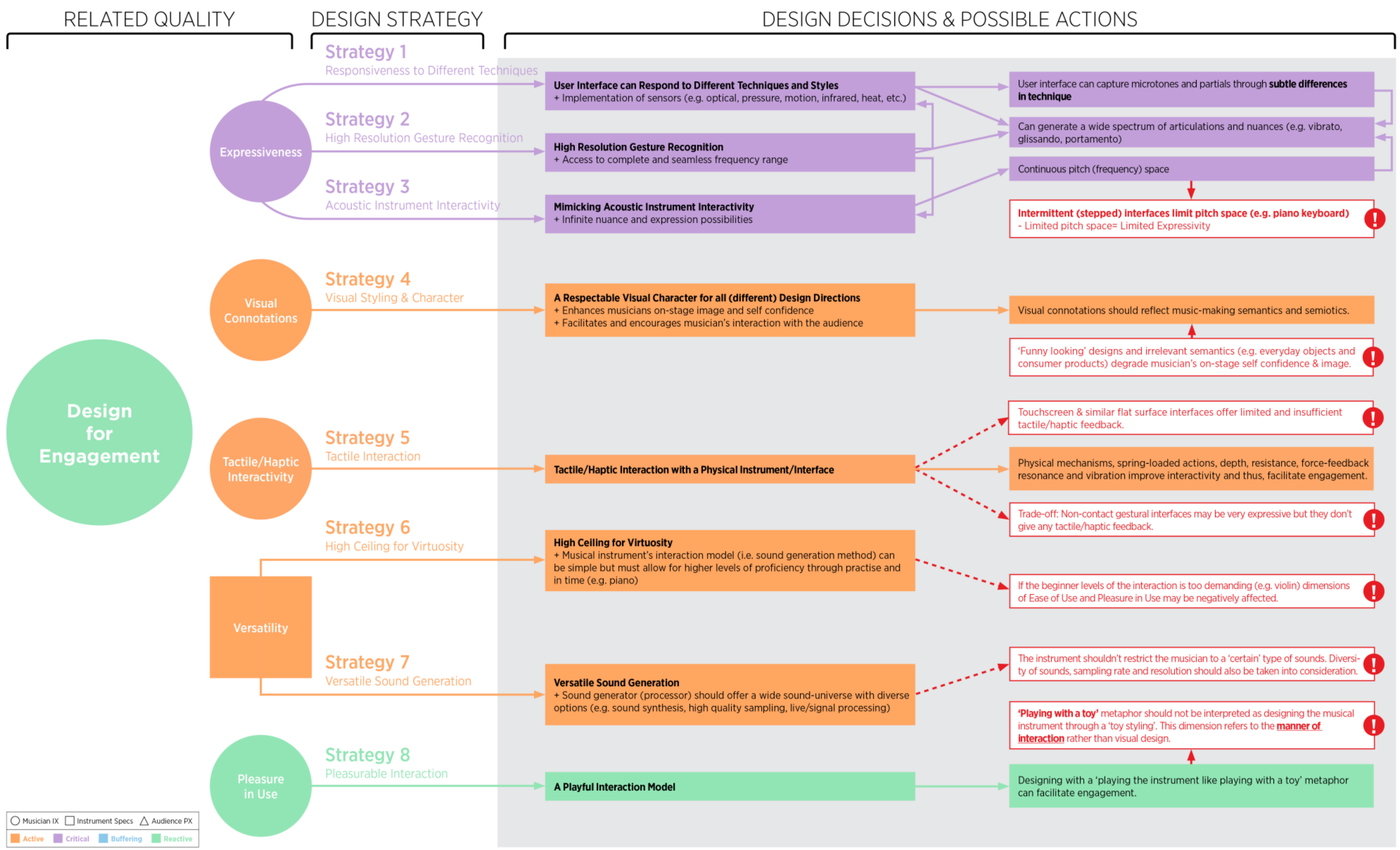

Figure 6.5 Guidelines for designing for Engagement

6.3.4 Strategies for Designing for Ease of Use

In the context of new generation musical instruments what makes the product 'easy to use' is mainly associated with simplicity, visual interactivity, tactile/haptic interactivity and product architecture. When achieved, this quality positively influences efficiency and pleasure in use. Guidelines for designing an easy to use musical instrument/interaction are summarized in Figure 6.6.

The concept of **simplicity** should be considered both in regards to the actual product design and the musician-instrument interaction (including the narrative of the interaction) during the early stages of the design process.

A **clear and simple design** for both the overall form and the user-interface contribute positively to ease of use.

- While offering more 'possibilities' is an attractive feature of any musical instrument, more possibilities means more controls and more controls means the instrument is harder to use. While this rule of thumb may have its exceptions, <u>the fewer the controls, the easier the musical instrument is to use.</u>
- **Simple mapping** (relationship between musician's gestures/actions and the respective outcomes (sound/parameter change)) is a key element of an easy interaction. Simple mapping design gives the musician a chance to modify parameters and play effortlessly.
- For parameter modification, designers need to consider a delicate balance between <u>'compiling functions and features inside menus'</u> and <u>'assigning individual control elements to functions and features'</u>.
- In other words, a menu containing too many functions and features is equally difficult to use as a scenario with no menu and many individual controls. Inside a Menu, the user needs to press the same buttons consecutively to reach a specific function/feature. Without a Menu, there will be too many control components over crowding the user-interface.
- In either case, designers should try to avoid use-scenarios where the musician has to press <u>two or more different controls to activate a single function</u> or feature.

- Additionally, while simplicity ensures ease of use especially for the initial interaction, design decisions must also allow for a **high ceiling of virtuosity**. In other words, instrument's simplicity should potentially embody enough 'space' or 'playground' for advanced levels of performance and musical exploration (e.g. a piano is simple enough for a child to play and still offers a virtuoso infinite complexity, challenges and space for life long exploration).

In regards to **visual interactivity,** musicians associate colour coding, visual guidance (e.g. lines, reference points, grids, icons and similar graphical signifiers), and visual representation (of interactions, functions and features) positively with an easy to use musical instrument.

- Using **colour** to distinguish different functions, features, controls and zones of the user-interface facilitates an easy performance.
- Similarly, guiding the musicians through visual references and graphical signifiers, which are already known to them (music/musical instrument semiotics) contribute to ease of use.
- **Geometrical references** such as origin points, centre points, lines and grids are very helpful for the musicians especially for unfamiliar user-interfaces (e.g. on a classical guitar, there are black circles on the 5^{th}, 7^{th} and 12^{th} frets to help the performer).
- Similar to their role in relation to comprehensibility, random use of colour becomes an obstruction to ease of use and should be avoided.
- Especially for more complex interfaces, **graphical representation** of interactions between the interface components and parameter changes deliver a significantly easier performance.

Musicians predominantly believe that interacting with **physical interfaces** are easier compared to soft synths (i.e. software instruments) or non-contact gestural instruments.

- Tangible interfaces are easier to handle because multiple or dimensional surfaces make the best use of hands and fingers.

- On the other hand, playing on flat surfaces such as 2-axis or planar interfaces can be easier especially for musicians with traditional backgrounds because they are used to moving on similar axes on acoustic instruments (e.g. necks of guitar, cello, violin, piano).
- However, when designing single surface interfaces, it is important to remember that material properties of touchscreens and similar homogeneous surfaces provide very poor tactility; a dimension vital for higher levels of controllability.

In regards to **product architecture,** compact and unibody designs are considered easier to use.

- A '**unibody**' design indicates that the physical input and visual information are located in the same place. Hence, the instrument will be easier to use.
- Additionally, a compact instrument with reasonable dimensions, which would 'fit inside two hands' is considered easier to play.
- Musicians also associate **'pre-configuration'** with an easy to use musical instrument. Pre-configuration – to some extent – 'hides' the technology from the user by presenting a 'ready to use' interface. This type of interface does not require advanced technical knowledge and thus considered easier to use.

From this perspective, modular instruments or 'controllers' physically divide the performer's attention on stage between different locations.

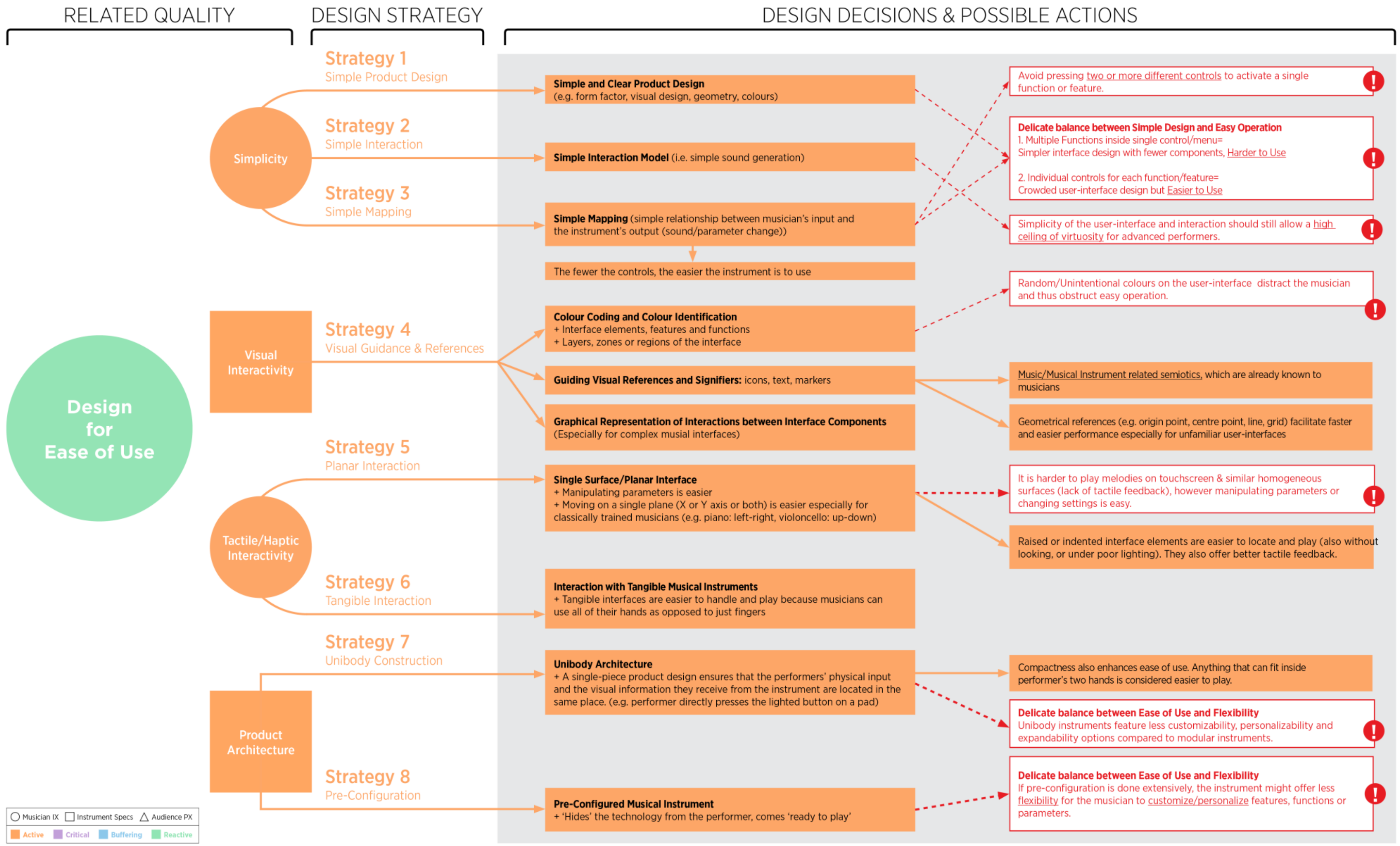

Figure 6.6 Guidelines for designing for Ease of Use

6.3.5 Strategies for Designing for Controllability

Controllability is one of the most essential concepts in new musical instrument design and it embodies a variety of dimensions, which have critical impacts on usefulness and creativity. Strategies for designing for controllability are discussed under four categories: tactile/haptic feedback, performable actions, versatility and real-time sound generation. Guidelines for designing a controllable musical interface/instrument are summarized in Figure 6.7.

Musicians consider **tactile/haptic interactivity** a central quality, which directly impacts their control over a musical instrument. The design strategies, which can be employed while designing for tactile/tangible interaction are as follows:

- **Multi-surface/three-dimensional** musical interfaces increase the performer's concentration and control during a performance. Being able to hold and grip a musical instrument creates a 'multi-dimensional' use experience while offering a richer physical interaction and tangible feedback for the musician.
- **Single-surface** or **planar** musical interfaces may offer better precise parameter control. Additionally, musicians with traditional backgrounds can exert better control especially when performing on high speeds (e.g. melodies) along a single axis (e.g. piano, violin, cello)
- However, the nature of the surface is of great importance. **Touchscreen** interaction (i.e. the material/surface properties of glass) cause poor or limited controllability due to **insufficient tactile feedback**. If the design decisions concerning the musical interface lead towards a 'planar interaction' <u>avoiding touchscreen interfaces</u> and similar <u>homogeneous surfaces</u> where possible is an important precaution to ensure better controllability.
- Additionally, the digital or 'virtual' interface elements on touchscreens/touch-surfaces (e.g. digital keys buttons knobs faders) offer zero/minimum physical response to the performer. Thus, adding **dimensionality to interface elements** (e.g. raised, protruded, indented) enhances controllability.

- The previous strategy is especially important in relation to performers with **sweaty hands,** which is actually more frequently experienced among musicians than presumed.
- Designing the user interface in a **physically responsive/reactive** manner enhances the 'nature' of tactile feedback and thus, also controllability. **Physical resistance** and **vibration** generate additional dimensions for tactile feedback, which is in turn very useful for achieving precise control over the instrument. Physical resistance can be achieved through material properties, key depth, weight, flex sensors and spring loaded mechanisms (e.g. keys, buttons, benders, faders, dials). Similarly, resonance and vibration (i.e. vibro-tactile feedback or force feedback) can be incorporated to the interface design on macro or micro levels (e.g. vibrating whole body of the instrument, vibrating the user interface, vibrating a single interface element).
- All the aforementioned strategies concerning the design of tactual/haptic musical interfaces positively contribute to achieving a **'blind interaction'** model. Especially in professional use context, musicians utilize the information coming from tactile/haptic feedback to 'know' where they are without having to look at the user interface constantly during the performance. In other words, the feedback enables them to <u>'see' with their hands and fingers</u> (also other limbs concerning bodily interactions).

In regards to **performable actions,** there are many unexplored opportunities for creating new input methods from the human body in order to translate bodily movements into data (sound).

- **Utilizing whole of the body** – as opposed to only hands – helps musicians exercise new ways of control over their musical instruments. Bodily interactivity can be achieved by both <u>contact</u> and <u>non-contact gestural interfaces</u> through the help of video tracking and various sensors (e.g. motion, pressure, light, heat). Through bodily interactivity, musicians can bypass conventional user interfaces and explore control possibilities with a more 'direct' interaction (i.e. body replaces the user interface).

- **Wearable instruments** (e.g. gloves, head-pieces, full body suits) can be considered as some of the best applications of bodily interactivity.
- Bodily interactivity also enables controllability through **larger gestures** as well as **wider movement space.**
- **Flexibility in hand positions** (alternative hand positions for the same instrument) on a musical interface create freedom of control for musicians with diverse anthropometric features or different performance habits.
- **'Single handed interaction'** (being able to play the instrument with a single hand <u>or</u> both hands) enables the musician to simultaneously control more than one musical instrument. This kind of control is especially beneficial for 'multi instrumentalist' performers who use 'crowded' instrument set-ups on stage.

Versatile musical interfaces, which feature **continuum in pitch** (seamless frequency control similar to a violin's fingerboard) enable musicians to have a complete and precise control over sound generation in regards to both technical, creative and expressive qualities of the musical performance.

In this context, **avoiding fixed** or **stepped musical interfaces** (e.g. a piano keyboard where frequencies between half tones are not available) is recommended.

- However, continuous interfaces can still be played as fixed/stepped interfaces with the help of visual guidance (e.g. pinpointing tampered frequencies with dots or circles on a fretless guitar's neck)
- Similarly, **randomness** in sound generation (unpredictable or unintentional sounds or effects) must be avoided.

Real-time (instantaneous) sound generation lies at the 'heart' of technical and creative control over a musical instrument. Being able to generate sounds in real-time directly impacts the usefulness of a musical instrument. Additionally, musicians interpret the lack of real-time sound generation as the complete lack of control over the creative aspects of the musical performance.

- Musicians need to 'form' all sound generation concretely, and 'from scratch'. While this strategy seems to be related to a technological specification, it is important to design the instrument and the user interface in such a way to allow integration of this technological feature.

- It is essential to avoid designing musical interactions, where the user interface can only trigger pre-designed or pre-recorded sounds (e.g. loops, patterns, textures, melodies).
- Triggering/playback of pre-recorded sounds can be included as an 'option'. However, it is important to keep in mind that for cases where the musician is not experienced or knowledgeable on audio technologies, a third-party intervention by a professional is necessary for the creation storage and transfer of the sonic data (e.g. samples, loops, sequences). Musicians interpret this intervention also as a loss of control over the creative aspects of the musical performance.

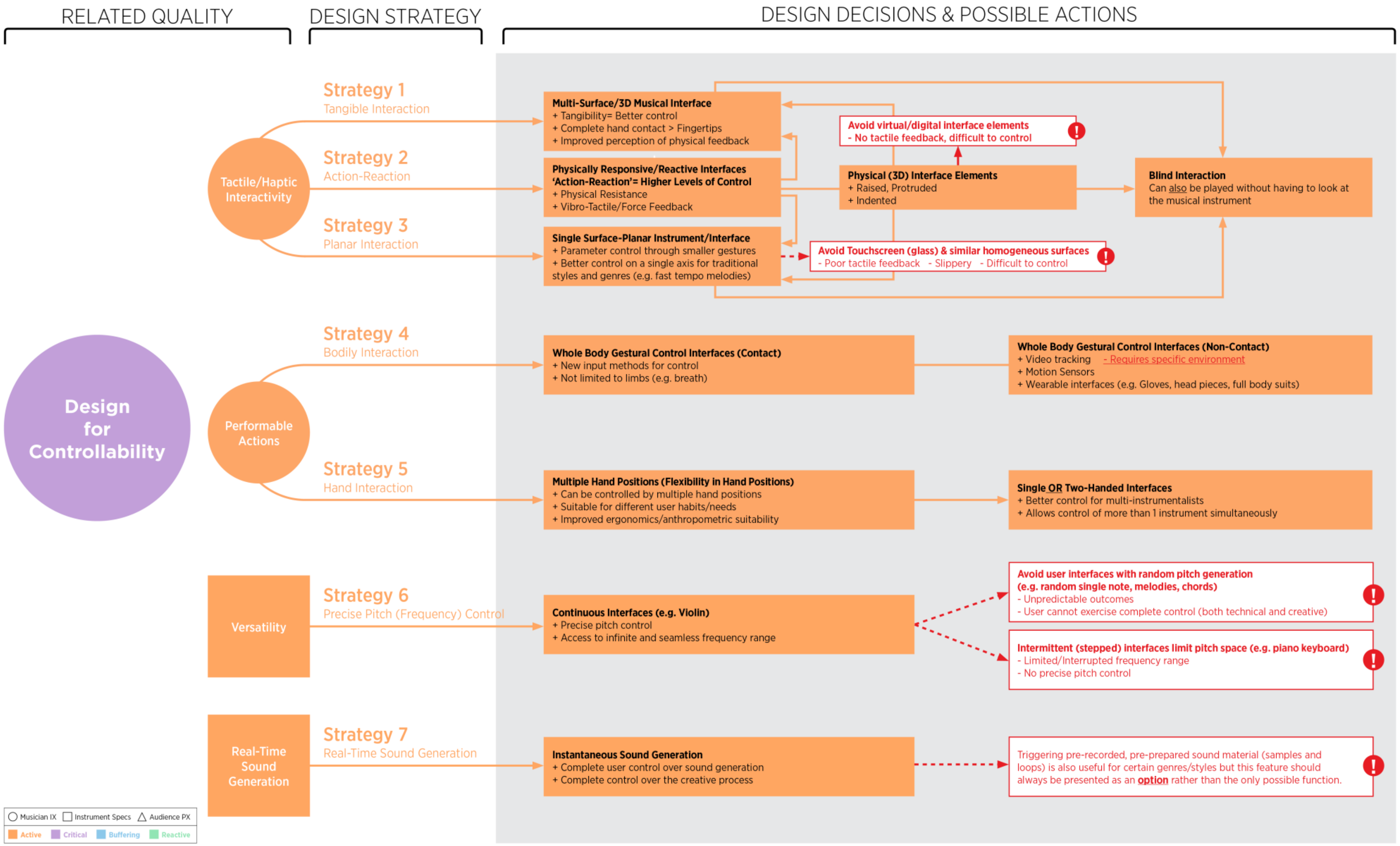

Figure 6.7 Guidelines for designing for Controllability

6.3.6 Strategies for Designing for Efficiency

The role of efficiency in new musical instrument design deserves extra attention because it refers to dimensions, which are related to pre- and post- performance activities as well as the actual live performance itself. For this reason, this section discusses efficiency in two parts: The first part will focus on the practicalities of **performance set-up, disassembly, rehearsals** and **logistics** where as, the second part will elaborate on the actual **live performance efficiency**. Guidelines for designing an efficient musical instrument/interaction for both of the aforementioned contexts are summarized in Figures 6.8 and 6.9 respectively.

What makes an instrument **'efficient'** pre- and post- performance is mainly associated with **set-up** and **product architecture**.

Portability, practicality and immediacy are the main dimensions of **set-up**, which influence efficiency. A practical set-up experience does not only affect musicians' actual performance but the entirety of the time they spend with their musical instruments, which include daily practise, rehearsal, transportation, stage set-up and disassembly.

- **Portability** is the 'must have' feature of any musical instrument for being considered 'practical'. As mentioned earlier, the importance of 'mobility' is elevated for live performance settings (as opposed to studio recording and compositional contexts) because most musicians carry their own instruments as a common practise. Thus, portability of an instrument is not only related with convenience of movement but also health of the musician (risks of injury and long term orthopaedic/neurological problems) and finance (additional expenses for storage, transportation and extra personnel).
- In addition to portability, if the musical instrument is designed with a **'works everywhere'** approach – meaning that it does not require a 'sterile' environment such as indoors or specific light conditions – musicians can carry their everyday musical activities in a more practical manner.
- While electronic musical instruments already bring the need for **maintenance** activities to a minimum, design decisions could further avoid them (e.g.

charging, battery replacement, configuration) similar to the ones carried out for acoustic traditional instruments (e.g. tuning, string replacement).

‘Activation time’ of a musical instrument is considered extremely important for an efficiency in both rehearsals and performances. Performers ideally want to be able to grab and start playing their instruments immediately. In this perspective, musicians believe that new musical instruments should aim to come as close as possible to the ideal scenario concerning acoustic instruments (with the exception of drums).

- A **‘Plug & Play’** approach to the instrument set-up (e.g. a guitar as opposed to a drum set) benefits the musicians pre, during and after the performances, not to mention the practicality of home practise or rehearsals.
- Similarly, musicians state that especially for festival performances (where the bands/ensembles perform for shorter durations), they are not given much (or any) rehearsal times before the performance. Thus, design decisions concerning set-up activities should try to decrease the **duration** of the set-up as much as possible.

Strategies concerning **product architecture** act complementary to the aforementioned set-up strategies.

- Musicians consider **lightness** and **minimal dimensions** as the primary facilitators to enable them to carry their musical instruments directly ‘from rehearsal room to concert venue’.
- Thus, **‘hand-held’** devices have an obvious advantage in terms of practicality.
- In this context, while ‘smaller’ translates to ‘more practical’, designers need to find balance between ‘practical’ and <u>‘controllable’</u> because miniaturizing the user-interface might cause problems related with the musician’s control over the instrument. Designers should consider their decisions on the dimensions of the musical instrument with this balance in mind.
- Designs, which efficiently use the **interactable space of the user interface** are also considered a good solution to avoid unnecessary dimensions.

- As long as designed in appropriate dimensions and weight, modular instruments can also be carried easily. However, the risk of forgetting, losing or breaking individual modules make them less practical than compact instruments.
- **Self-sufficiency** in design and construction of a musical instrument is a big facilitator of efficiency. In the context of electronic musical instruments, this concept can be interpreted as having an **'inbuilt'** user-interface, sound generator (sound source) and sound output (e.g. loudspeakers).
- A musician can play a self-sufficient or **'standalone'** musical instrument anywhere without the need to connect it to a system. While the need might still arise to plug a standalone musical instrument to a larger Set-Up (e.g. to amplify volume or connect it with other instruments/hardware for the actual performance), musicians' daily routine will become much more efficient through being able to <u>practise or rehearse anywhere</u> (e.g. at home, rehearsal hall, while commuting or travelling, etc.).
- **Wireless interactivity** is yet once more recommended in connection to efficiency. Especially during crowded ensemble set-ups on stage, laying cables increase set-up duration, cables can be forgotten, plugged to the wrong instrument/hardware, or create tangles all over the stage floor.
- In case of modular instruments, if the design of the modules requires them to be connected to each other through cables as well, the risks and problems increase much higher. Thus, cables should be avoided as long as possible.

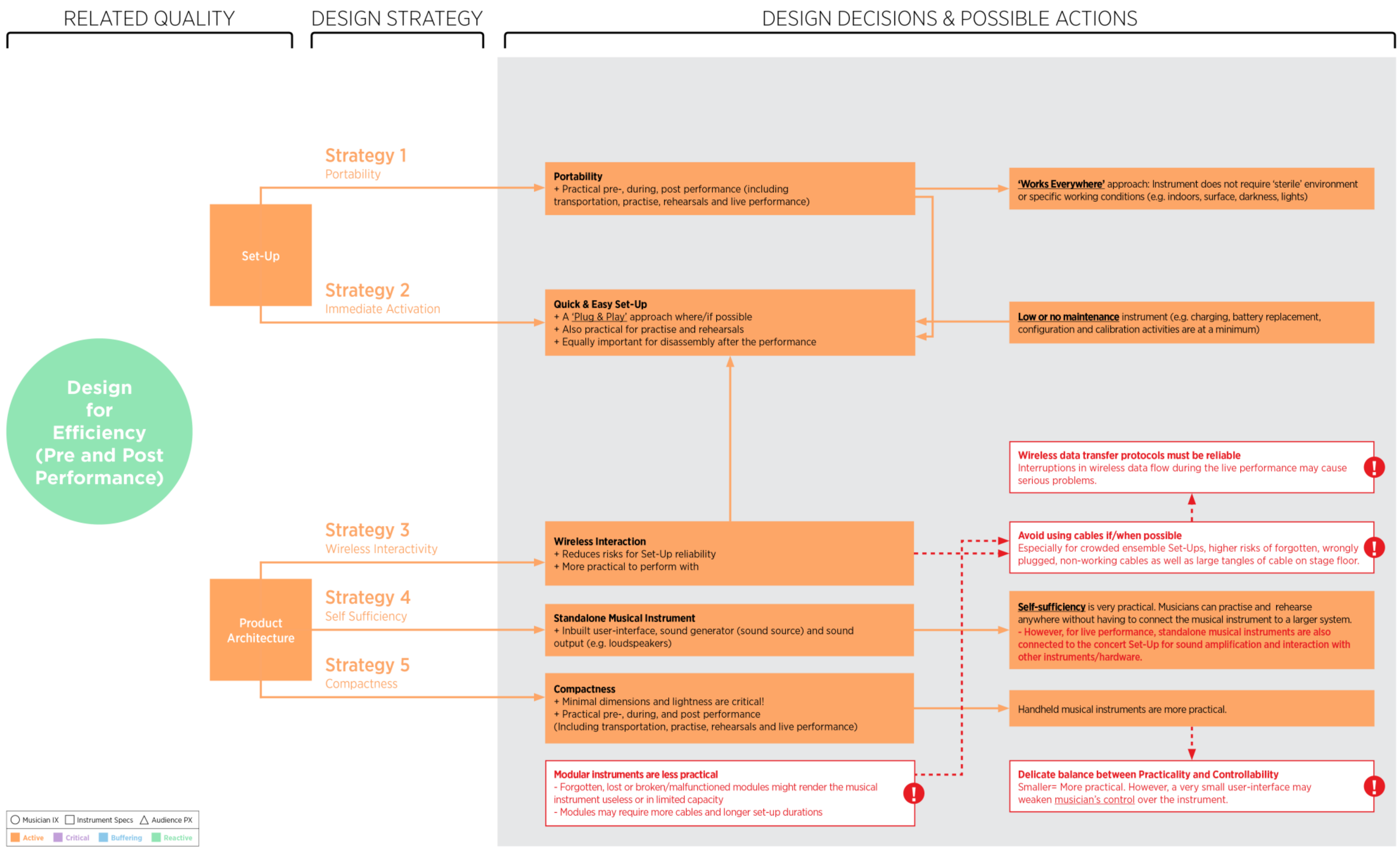

Figure 6.8 Guidelines for designing for Pre and Post Performance Efficiency

In regards to the actual performance, **simplicity, performable actions, comprehensibility** and **tactile/haptic interactivity** are the main qualities associated with efficiency. The interrelationship between comprehensibility and simplicity facilitate the performer to immediately interact with the instrument.

- Immediacy during the actual performance is also as important as the immediacy of set-up. A **simple product design** and **interaction model** enables the musicians to start playing the instruments quickly.
- Too many parameters and controls on the user interface takes longer times to master and may still confuse the musician during the performance.
- Thus, '**over-engineered'** products with high **technical barriers** decrease the efficiency of the performance because 'too many', after a certain threshold, may lead to not being able to use 'any' at all.
- Similarly, the visual aspects of the instrument (i.e. visual feedback and feed forward, visualization of the generated sound) should be kept simple in order not to distract the musician during the performance.
- Musicians consider 'not being able to take their eyes off the instrument' an issue that negatively affects their efficiency.

Tactile/haptic interactivity plays a very critical role in the aforementioned issue concerning the potential visual distractions. A very important dimension of tactile interactivity is concerned with a phenomenon, which some musicians in this study name as **'blind interactivity'**. In regards to acoustic instruments, this skill is achieved through engaging with the musical instrument for a long time; reaching a level of proficiency where the musician is able to 'flow' with the instrument. This skill has a very strong influence on musicians' performance efficiency. Proposing that performers 'sometimes look and sometimes don't' is a reasonable assumption for any proficient musician who plays a traditional musical instrument.

- Being able to play a musical without looking, is a skill, which can be achieved through **physical contact** with the instrument. Thus, regardless of the visual information it offers, a musical interface should always allow blind interactivity as an **option**.

A variety of **performable actions** also have strong impacts on live performance efficiency.

- Designing the instrument to allow playability through different/multiple hand positions help musicians with different styles or performance habits to perform more efficiently.
- Similarly, single or two handed playability gives multi-instrumentalist performers with complex instrument set-ups freedom to perform on multiple devices simultaneously.
- This feature may also help musicians to concentrate on multiple aspects of the same musical instrument.
- More input methods from the human body directly translates to higher efficiency, especially for multi instrumentalists. Making use of not only the hands but all of the body (e.g. feet, breath, nose) may save a lot of time and reduce risks while switching between devices. Geddy Lee, who is the bass player and vocalist of 'The Rock & Roll Hall of Fame' inductee band Rush, often uses his nose to move the microphone while he is simultaneously singing and playing. He also uses his feet to play keyboards similar to a church organ interaction.
- On the other hand, musical interfaces, which can be played by minimal movement and gestures can prove equally efficient for musicians who prefer to perform 'within the reach of their hands'.

Having to interact with secondary interfaces such as computer mouse and keyboard as opposed to directly interacting with the instrument, has a negative effect on efficiency.

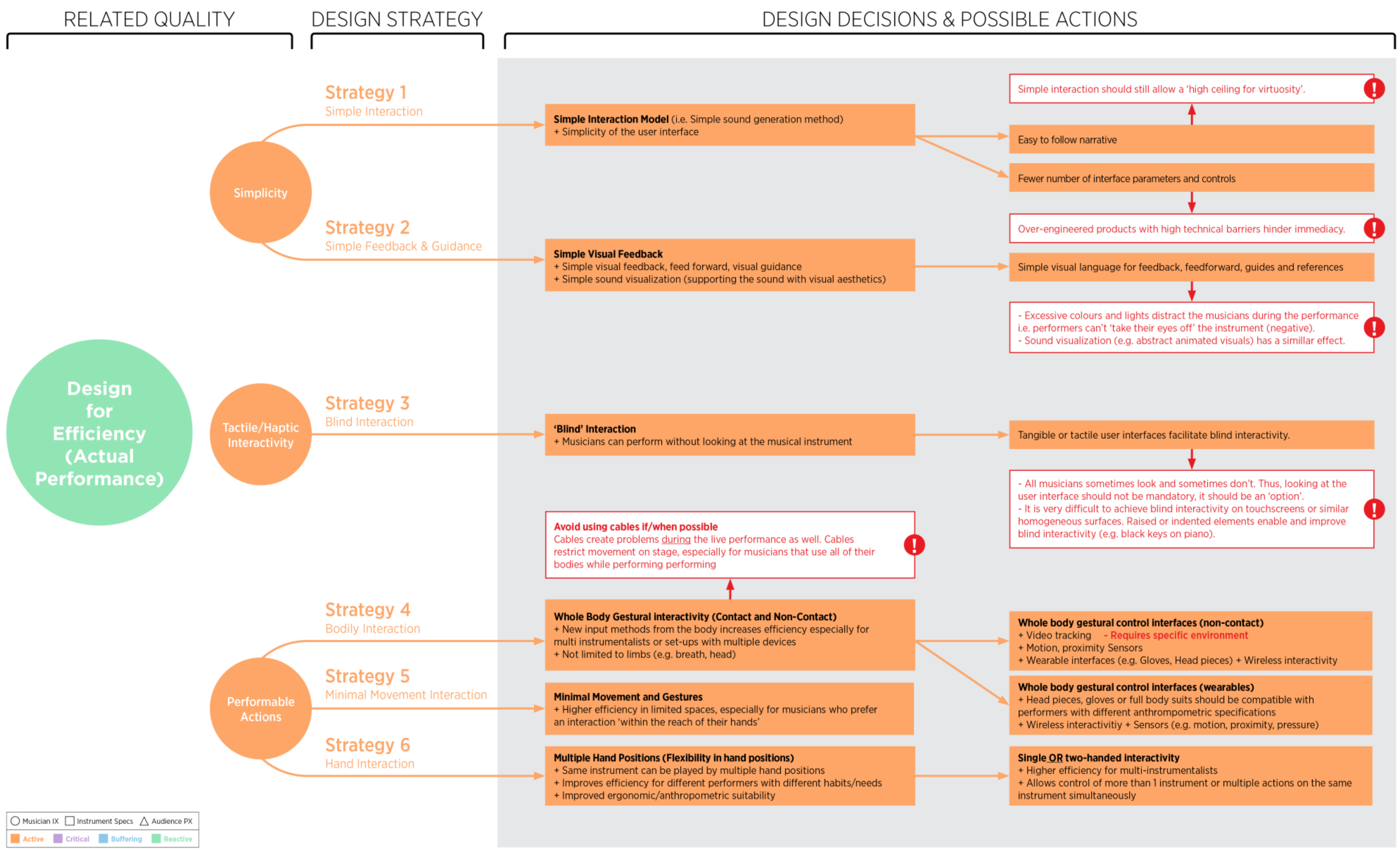

Figure 6.9 Guidelines for designing for Actual Performance Efficiency

6.3.7 Strategies for Designing for Expressiveness

As discussed in the Literature Survey Chapter of this Thesis, expressiveness is a very abstract concept with diverse definitions deriving from various perspectives. This thesis takes Fels et al.'s definition (2002) of Expressiveness; *'the act of communicating meaning or feeling'* and builds upon it to define 'musical expressiveness' as: The act of musically communicating a feeling or meaning. However, the expressiveness of a musical instrument/interface is a matter of design decisions and technology implementation. In other words, this section discusses 'expressiveness' as an <u>intrinsic quality</u> of a musical instrument/interface, which enables and facilitates the musician to communicate a feeling, emotion, message or meaning through his/her performance. It is reasonable to argue that expressiveness of a musical instrument/interface can be measured by the difference in the sonic outcome (expressiveness of the sound) when two musicians of either different levels of talent (and/or mastery) or with different intentions for communication perform on the same instrument. What makes a musical instrument 'expressive' is primarily associated with versatility flexibility and performable actions. Guidelines for designing an expressive musical instrument/interaction are summarized in Figure 6.10.

Musicians use a combination of complex decisions involving timing (duration of sounds), pressure (volume of sounds) and articulation (e.g. vibrato, glissando, portamento, crescendo, decrescendo, etc.) to create what is called 'nuances' in their playing. It can be argued that nuances form the building blocks of an expressive performance because it is a chain of nuances throughout the performance that enables musicians to express their musical identity; the very same quality that distinguishes one musician from another.

- The primary feature of a **versatile** and thus, expressive user-interface lies in its **'sensitivity'**. In other words, the technology implemented in the interface must be advanced enough to sense and capture musician's **'subtle' nuances**. A **high-sensitivity user-interface** can be achieved through an array of sensors (e.g. optical, pressure, heat, sound, etc.) and the resolution of the interface (e.g. pressure resolution of digital tablets and touchscreen interfaces)

- **High resolution gesture capture** is an extension of the previous strategy and it is critical for expressiveness because nuances have very subtle differences between them. The holistic perception of micro-changes in these gestures create the overall expressions. Gesture capture resolution is equally important for both contact and non-contact (e.g. Theremin or wearable musical instruments) musical interfaces.
- The user-interface should not force the musician into a fixed/pre-determined sound-space. Musicians can perform certain articulations such as vibrato or portamento (a continuous glissando) only on a **continuous pitch (frequency) space**. This feature also enables musicians to explore micro-tones (i.e. the infinite soundscape between 2 tones (e.g. between Do and Re)).
- **Multi-touch** is another feature; which designers are recommended to consider while making decisions for the user-interface. However, while multi-touch offers new opportunities for an expressive performance, designers may consider alternative materials to touchscreen glass because of its obvious disadvantages on controllability. Additionally, touchscreen glass lacks the third dimension (depth) where as musicians often use the 'depth' of a key (e.g. piano) to create articulation, especially expressive nuances related with volume-change.

By nature of definition, expressions are individual and personal. Thus, **flexible** instruments, which enable musicians to **personalize** and **customize** the user interface in order to realize their individual expressive performances open many possibilities. In this context, an **'open system'** approach becomes the most critical dimension of flexibility.

- Creating nuances is a matter that is also related with the form and overall dimensions of the user-interface. If the musicians are given freedom to **digitally modify** the dimensions of usable space (through resolution change) or **physically expand** the user-interface they will have more opportunities to create more nuances.

- Thus, an **expandable pitch (frequency) range** can generate micro-tones or multiple octaves, depending on the musicians' preference.
- Musicians also manipulate additional components of sound such as timbre (i.e. characteristic sound or tone colour of the instrument; e.g. A flute has a different timbre than a saxophone), duration and envelope (i.e. shape or contour of the sound as it evolves over time; it has three stages: attack, sustain, decay). Providing performers with further control options through **reconfigurability of controls and parameters** creates new possibilities for new expressions. However, designers should tread carefully while considering the balance between increasing the number of controls on the user-interface (<u>physically over-crowding the interface</u>) and increasing the functionality of existing controls (<u>mentally over-crowding musician's memorized tasks</u>).
- **Compatibility** with other electronic devices (e.g. effects, filters, plug-ins, real-time samplers) and **connectivity to acoustic instruments** through sensors and adapters may create a completely new space for expressive exploration because musicians are also empowered with the sounds and expressive capabilities of those devices and acoustic instruments (e.g. the expressive potential of a cello) to which they connect their musical instruments.
- Finally, the instrument's sound processor should be flexible enough to allow musicians to generate different sounds for different musical styles/genres. In other words, the instrument should not dictate the performer a style or genre concerning both individual sounds and the overall music.

Concerning acoustic instruments, even the slightest differences in the performer's each gesture movement or motion directly affect the nature of generated sounds. Hence, how the new instruments handle musicians' **physical actions** become an essential subject for expressive performances.

- User-interfaces, which allow musicians to utilize whole of their bodies (as opposed to only hands) create possibilities for new expressions. Thus, **'bodily interaction'** is an important opportunity for designers to consider in the ideation/concept development stage of the design process.
- As mentioned before, **spatial gestural interaction** (non-contact gestures) also offers new possibilities for expressive performances. However, designers are recommended to keep in mind the critical trade-off between freedom of gesture and tactual/tactile feedback.
- Musicians use tactual feedback as 'primary facilitator' to create subtle nuances (e.g. resistance of the keys/strings, physical vibration, depth perception, micro-movement, etc.). The user-interface shouldn't become a 'wall' between the musician and the expression but rather act as an enabler.
- In connection to the previous strategy, user-interfaces that allow the use of the **whole of the hands** – as opposed to fingertips (touchscreen interaction) – allow a wider range of expressions.

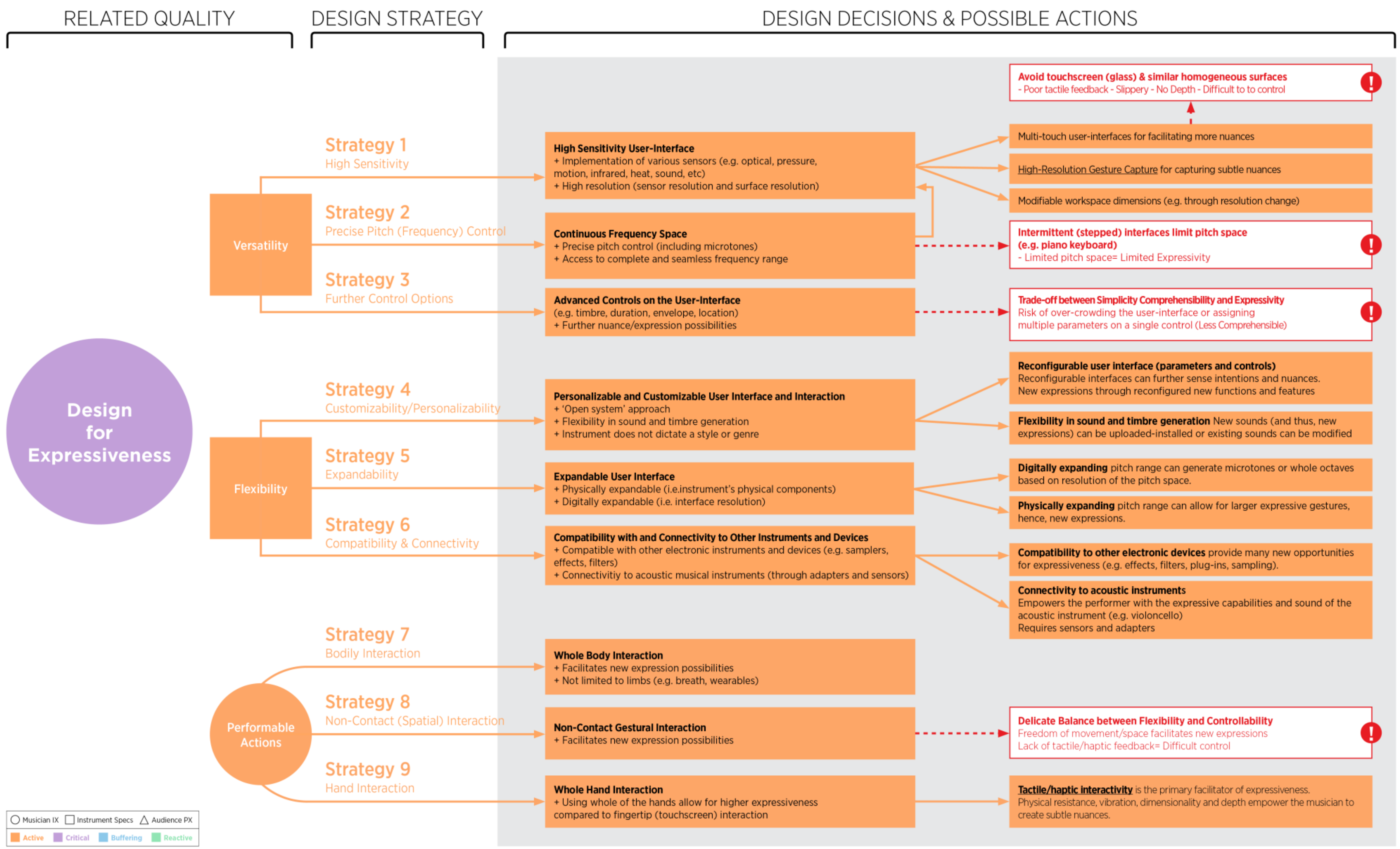

Figure 6.10 Guidelines for designing for Expressiveness

6.3.8 Strategies for Designing for Appeal

When musicians talk about what makes a musical instrument appealing, they refer to both visual and sonic dimensions. However, it's the visual aspects of a musical instrument, which dominate the perception of appeal. Furthermore, the musicians' and the audience's impression of visual appeal is closely interlinked. Visual connotations and novelty are the main qualities, which are associated with appealing musical instruments and appealing interactions. Guidelines for designing for Appeal are summarized in Figure 6.11.

Visual design of musical instruments is a quality that underwent radical changes with the emergence of new electronic musical instruments because thanks to emerging technologies a strict relationship between the form and sound generation is no longer a necessity. In other words, while the slightest alterations on a violin's form dimensions or materials directly change its timbre, electronic/digital instruments can generate identical sounds regardless of their designs. As a result, this great flexibility in product design led to the development of diverse instruments with a wide spectrum of visual characters.

In regards to the visual design of a musical instrument, there isn't a consensus among musicians in regards to how a musical instrument is supposed to look like. Therefore, there is not a single path, which leads to an appealing visual character. In fact, different musicians find very diverse design directions to be appealing and attractive. However, certain dos and don'ts are equally essential for musicians as well as the audience.

- **Simple, neat** and **monochromatic** designs can be as appealing as **colourful organic** and **illuminated** products. Hence, musical instruments can be designed to communicate a certain **seriousness** or they can also look **playful, easy to approach** and **inviting**.
- **High saturation colours** and **lights** are both **stimulating** and **aesthetically pleasing.** However, overdesigning this feature might result in garish and obtrusive products.

- A **utilitarian** design language also ensures to communicate a <u>‘this device makes music’</u> message, which is a useful feature, especially for instruments with unorthodox/unordinary interactions.
- For either scenario, musicians draw the <u>red line</u> at looking **respectable** on the stage. **Funny**-looking products are not only less appealing, they are also not engaging. Musicians clearly state that they wouldn’t engage with any instrument, which would degrade their on-stage presence in the eyes of the audience in any way. For this reason, visual references to **everyday objects** or **non-music related consumer products** should be avoided if possible.
- **Cables** have been previously mentioned in relation to efficiency in its respective section. Similarly, tangles of cables also degrade the visual appeal of a musical instrument.

Novelty also plays an important role in making the musical instrument, interaction and the user experience more appealing. Novelty has three essential dimensions, which directly influence both visual and sonic appeal:

- Firstly, a **novel musical instrument design** (product design and visual styling) is considered to be **intriguing** and **appealing**. **Futuristic, unique, mysterious, surprising, unordinary** and **unorthodox** are the terms musicians frequently use to describe novel designs.
- Their common attribute is to <u>not imitate</u> the visual designs of <u>acoustic instruments.</u>
- Secondly, musical instruments, which suggest **new ways of interacting** with the **user interface** and **generating sound** (i.e. novel interactions) are considered to be very **appealing** and interesting. While the interactions featured by these instruments are not immediately apparent or discoverable (<u>trade off</u> with comprehensibility and performance efficiency), the unique sound generation proposals persuade the musicians to immediately touch and interact with the product.
- Designs, which cannot be traced back to an **‘ancestor’** (e.g. harpsichord-clavichord-fortepiano-modern piano) have an obvious advantage in this

context. Therefore, **not simulating** acoustic instrument interactions strongly enhances the impression of **‘newness’**.

- Finally, the third dimension of novelty is concerned with the actual **sounds** themselves. Musicians consider **unique sounds** and **timbres,** which cannot be generated by acoustic instruments to be **sonically appealing**.
- From this perspective, modelling or sampling sounds of acoustic instruments is not considered to be interesting because the real **richness** of new musical instruments lies within their ability to generate **new sounds**.
- While it is possible to achieve novelty through visual design, technology or sound generation method, as long as the actual result (sound) is ordinary, musicians don’t consider the musical instrument to be **sonically appealing** in regards to novelty.

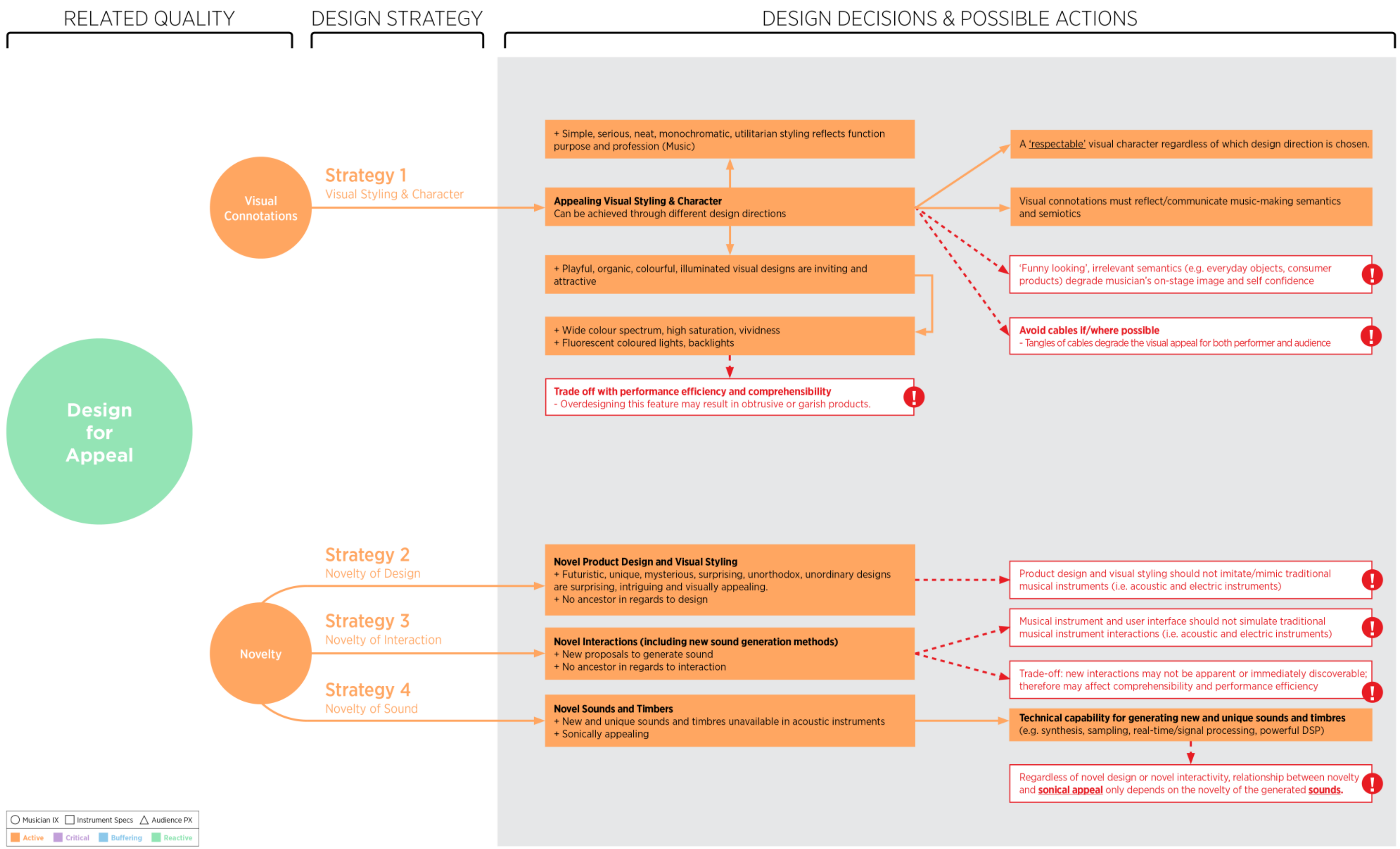

Figure 6.11 Guidelines for designing for Appeal

6.3.9 Strategies for Designing for Pleasure in Use

Concerning new generation musical instruments, designing for pleasurable interactions is mainly associated with collaborative interactivity, tactile/haptic interactivity, simplicity, ease of use, visual feedback and efficiency. When achieved, pleasurable interactions make a musical instrument more engaging. Guidelines for designing a pleasurable musical interaction are summarized in Figure 6.12.

Musicians believe that one of the primary reasons for making music is to play **'together'** with other musicians. In traditional contexts, orchestra or ensemble musicians (i.e. classical, jazz, popular, rock) constantly listen to each other while playing and simultaneously make subtle tunings and adjustments to achieve a **'unity'** of sound and expression. They consider this phenomenon as one of the most pleasurable aspects of making music. However, performing together on a single instrument is not common in the mainstream music scene (with the exception of piano). Thus, the idea of collaborating on a single musical instrument is perceived to offer new possibilities for pleasurable interactions and experiences. Some musicians define interacting with collaborative instruments as (playing a) **'game-music'** rather than making music and thus, the fun and pleasure aspects are enhanced. They also consider collaborative interactivity as 'genuine interactivity' because of the way performers interact with each other.

- What some musicians name as **'social instruments'** can be designed with two approaches: The musical instrument can feature a **single user interface**, which can be played by multiple musicians. This user interface can be either **unibody** or **modular**.
- Alternatively, **multiple identical instruments** can be connected to each other through a **network** and these instruments can be played by multiple performers. Hence, each performer's actions would have an impact on the other performers and the whole system.
- While collaborative interactivity opens up many possibilities for the musicians, if this feature is given to them as an **'option'** rather than mandatory, single performers would still be able to play the instrument. Optional collaborative interactivity affects the instrument's **usability** and

usefulness because when the instrument cannot be played by a single performer, it can only be played under certain contexts.

- However, designers can intentionally take the alternative path and make collective performance a prerequisite of the instrument; in a way this would be designing for social musical interaction; in other words, to 'bring musicians together'.

Interacting with **physical** objects is directly connected to **pleasure in use**.

- **Tangible instruments** and **interfaces** offer more pleasurable interactions because the physicality of **'touching'** makes the musicians feel good. Furthermore, musicians associate lack of tangibility negatively with pleasure in use.
- Instrument set-ups with computers, which use secondary user interfaces such as keyboard and mouse should be avoided because musicians believe that it is more enjoyable to hold and touch musical instruments as opposed to 'sitting at a table and clicking a mouse'.
- Regarding the user interface elements (e.g. buttons, keys, sliders), **less virtual** and **more physical** can be considered a rule of the thumb. When a musician touches a virtual string on a touchscreen, he or she cannot actually 'feel' the string but only the glass. Virtual interfaces become an **emotional barrier** between the musician and the actual instrument.
- Furthermore, **reactive/responsive** user interfaces are even more enjoyable to use because feeling the physical response of the instrument (i.e. **softness hardness, resonance, vibrations, physical resistance**) increases the pleasure of the interaction.
- Through tangible interaction, musicians form a **warmer** and more **intimate relationship** with their instruments.

Musicians believe that **simplicity** and **immediacy** (efficiency) also play important roles for achieving a pleasurable interaction.

- The **simplicity of the interaction** enables the musicians to start playing **immediately**. Being able to play music and generate sounds quickly increases the enjoyment one gets from the musical interaction.

- From this perspective, when musicians interact with musical instruments, which require a **complicated learning process**, they have to wait for **longer durations** in order to start getting **enjoyable** results.
- Musicians prefer to **'play <u>with</u>'** a musical instrument rather than 'playing' it. The playing metaphor points to approaching a musical instrument and start enjoying its possibilities immediately.
- Up until reaching the 'playing' stage, if the musicians have to connect cables, press a series of buttons, configure the software, adjust controls, make patch-ins, they **lose their interest** (and excitement).
- Additionally, musical instruments, which don't require **physical** (anthropometric) **competence** (e.g. shape of oral cavity and teeth for oboe, hand size for violin, piano) give **pleasurable** results quickly and easily.

Ease of use also facilitates a pleasurable interaction experience.

- When the instrument is easy to play, musicians can get enjoyable results before working on the instrument for a long time.
- Similarly, musical interfaces that don't require 'technical skills' (e.g. pressing the switches on a tactile touchpad as opposed to playing high speed chromatic scales on a piano) also facilitates a pleasurable interaction for performers.

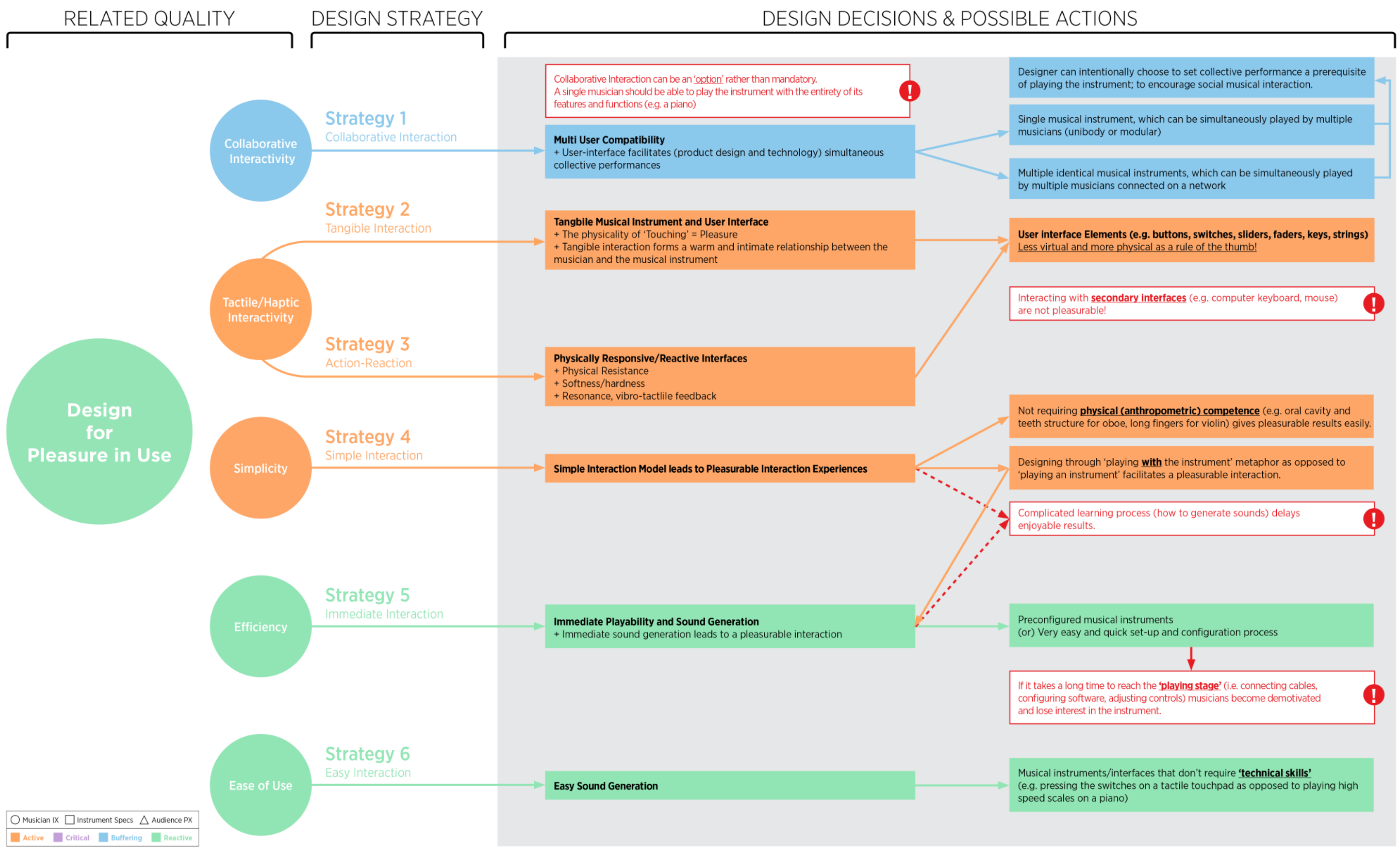

Figure 6.12 Guidelines for designing for Pleasure in Use

6.3.10 Strategies for Designing for Creativity

Concerning music, as with any other art form, creativity is an extremely abstract and borderless concept. 'Being creative' has very different meanings for different music-making paradigms such as performance, composition, conducting, arranging and so on... As this study draws the line at the context of 'live musical performances' the intricate dimensions of creativity in regards to **musical composition** are beyond the scope of this thesis. The way musicians interact with any musical instrument in order to compose music is radically different from performing with a musical instrument live on the stage. This statement naturally excludes specific music genres and concepts such as 'true composed' or 'real-time composed' music (during a live performance). Therefore, this section discusses creativity in relation to the musical instrument's ability to empower musicians for realizing their creative intentions during a live musical performance. Real-time sound generation, flexibility, versatility, controllability and collaborative interactivity are the qualities that have equally important impacts on creativity. Guidelines for designing for a creative musical instrument and interaction experience are summarized in Figure 6.13.

Real-time (instantaneous) sound generation lies at the heart of a creative performance because this feature enables the musicians to literally create music from scratch. Musical notes (i.e. frequency or pitch) are one of the most fundamental 'building blocks' of music. Thus, being able to play melodies, intervals and chords form a substantial part of a creative performance. Additionally, instantaneous sound generation means everything is happening **'there and then'**; completely created by the musician. This dimension also affects emotional contentment because musicians need to believe that the generated music is of their own creation/design.

- Musicians clearly state that a musical instrument should give them the ability – in their own words – to ***'start from silence'***, so that the musical instrument can directly respond to the musician's imagination.
- While no musical style or genre can be disregarded as not being creative (i.e. loop-based music is equally creative as any other genre) **triggering musical patterns** (of sound or rhythm) in other words, **pre-recorded, pre-prepared** sound material (including sound samples) should always be given to the

musicians as an **option** rather than the only possible function. In other words, the 'machine' should not dictate a certain type of music.

- Real-time sound generation can also be further enhanced to enable the musicians to generate and synthesise; in other words, to modify and shape the sounds they create. Therefore, **real-time sound/signal processing** is a powerful feature to achieve **sonically creative results**.

Flexibility arms the musicians with a diverse set of tools to achieve a creative performance:

- The implemented technology should not <u>dictate a fixed point of view</u> on the musician. In other words, the 'machine' should not define the musical style that could be performed on it (e.g. Loop-based, rhythmical, mono-phonic).
- Similar to its relationship with expressiveness, a musical instrument's **expandability** of features and functions gives musicians limitless possibilities for creative exploration. Expandability can be achieved both physically and digitally: Modular interfaces can be expanded by adding new modules; an 'infinite' number of tools for creativity. Similarly, this feature can be achieved by digitally expanding the interface through virtual modules and elements.
- Flexible interfaces allow the musicians to **'design their instruments from scratch'**. In other words, through the **'open system'** approach, musicians can **customize** and **personalize** the instruments based on their creative intentions. This feature also ensures that creativity is not limited within the borders determined by the designer (of the instrument).
- Designers can consider **reassignable**, **reconfigurable** and **reprogrammable** interface elements as reasonable starting points to initiate an open system approach for facilitating creativity.
- Customizability and personalizability go beyond the freedom to add functions or features. Musicians also want to **create** their **own sounds**. Thus, instruments which are limited to **inbuilt sound banks** (sound samples) or **limited sound generation** are considered **rigid** constructions that restrict creativity.

- **Compatibility** is another useful dimension of flexibility that substantially improves a musical instrument's creative capabilities. When a musical instrument is compatible with other instruments, devices and software, musicians can form many diverse combinations; shaping a system of devices to fulfil their creative intentions (e.g. instruments, pedals, effects, filters, computers, workstations). In this context cross-platform/software compatibility is as important as hardware compatibility (e.g. universal connectors, adapters and cables).
- As an extension of the previous strategy, if the musical instrument has compatibility and connectivity to its own kind, it is possible to form new ways of interactions by connecting multiple quantities of the same musical instruments to each other, creating **'new ensemble approaches'**.
- Similarly, being able to connect the instrument to an **acoustic musical instrument** give musicians access to the **creative capabilities** of that acoustic instrument. This feature can be accomplished through the implementation of **sensors convertors** and **adapters**.

Versatility has a complementary role to flexibility for improving creativity. Wide range of possibilities, in other words having access to basic functions of music (**synthesis, sampling, sequencing, real-time processing**) directly translates to a wider creative space.

- Giving musicians access to different dimensions of music such as **time, frequency** (musical notes), **timbre, rhythm and layers,** facilitates the creation of more **sophisticated** musical performances.
- Being able to use the musical instruments as **'controllers'** (decoupling), opens up infinite creative possibilities. Basically, a controller can be **programmed** to do **anything** – from turning on the lights in a living room to operating a complex sound generator – because a controller's basic ability enables it to send electronic **signals** to other devices through universal communication protocols such as **MIDI** (Musical Instrument Digital Interface) or **OSC** (Open Sound Control). Concerning controllers, the

creative opportunities for sound generation and design are only limited by the user's imagination.

While its dedicated section discusses **controllability** predominantly focused on the musician's physical control over the instrument, here, the quality refers to how much **creative control** the musicians has over the final result; i.e. the music. Two contrasting approaches will be discussed on this and following subsections:

- Music can be performed both solo or as an ensemble. However, some musicians prefer to have complete control over their musical creations. Collective performances, by nature, does not allow such control over the musical output. Hence, musicians consider being able to play 'solo' an important aspect of **creative control** because they don't feel comfortable with other musicians' **interventions**.
- This choice becomes especially important when the musician aims to perform an existing composition in a precise manner. Therefore, musical interfaces, which can be played solo gives complete control over the whole system to a single performer.
- In this context, deterministic user interfaces provide better control for realizing pre-composed music.

Collaborative interactivity, on the other hand, proposes a completely opposite alternative for improving creativity:

- When multiple performers interact through a **single musical instrument**, they also unite their creative forces. Hence, the collective sum of their ideas and imaginations, potentially enable them to create something **more powerful** or **different** than their individual efforts.
- In other words, the creative possibilities increase further by the addition of every new performer.

Collaborative interactivity can be more suitable for **improvisational** music styles and genres (e.g. jam sessions) because collective interactions offer infinite possibilities for **completely spontaneous** and **random** creations; which is another essential dimension of musical creativity.

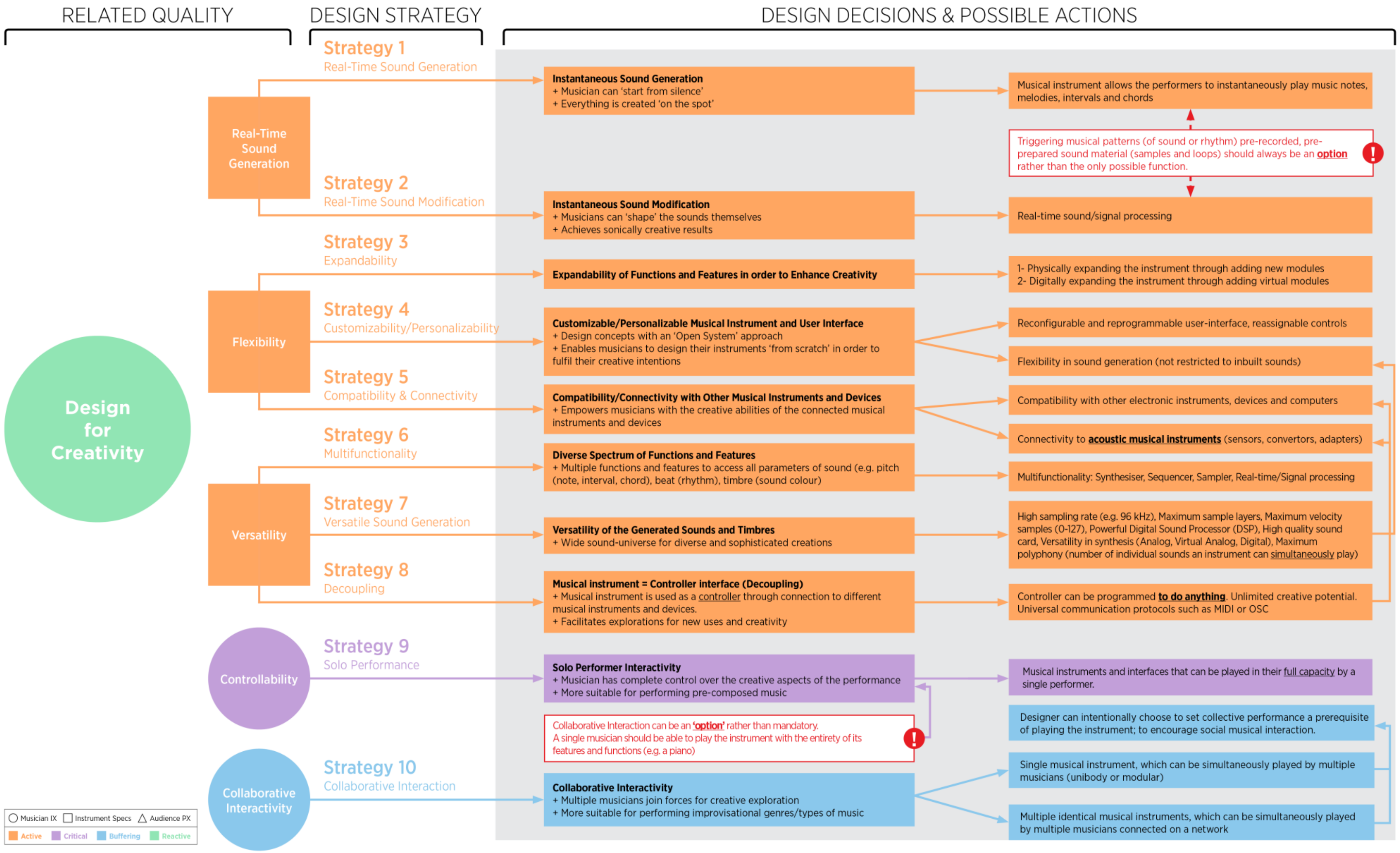

Figure 6.13 Guidelines for designing for Creativity

6.3.11 Strategies for Designing for Audience Experience

Musicians consider audience an essential dimension of any live musical performance. Thus, audience’s overall performance experience becomes a critical quality, which designers need to consider while making decisions during the ideation and concept development stages of the design process. Visual connotations, visual interactivity, set-up and novelty are the main qualities, which influence audience’s understanding and engagement with the performance. Additionally, performable actions and direct input-output relation also affect audience’s perception of the performance in lesser roles. Guidelines for designing for audience experience are summarized in Figure 6.14

- **Visibility** is the primary dynamic of a live performance set-up that ensures a positive audience experience. Compared to traditional acoustic instruments – which are easily visible in relation to their designs and placement on stage – electronic musical instruments already have a disadvantage due to their unorthodox forms and interactions. The first rule of thumb is to ensure that musical instruments and musical interaction (musician-instrument) can be placed on stage in a way the audience can see them.
- For cases where the musical instrument is too small or the musician-instrument interaction does not allow a clear viewpoint for the audience, designers can consider **projecting** either the user-interface or the whole interaction itself with a camera or through internal connections (e.g. wireless networks) to a larger media (e.g. mounted screens). Visibility is important also to ensure there is no suspicion among the audience regarding whether the performance is actually happening live or it is played back.
- **Visual connotations** play an important rule for cultivating awe and respect from the audience. A **stimulating and engaging visual character** can be achieved through many diverse design directions:
- **Colours** and **illumination** (both static and dynamic) play an important role in making the interaction more **visually appealing** and **aesthetically pleasing**.
- As long as they clearly communicate **‘musical instrument semantics’** (i.e. <u>‘this device is designed to make music’</u>) a simple, utilitarian or serious visual

character may be equally successful as playful organic or colourful designs in capturing the audience's attention and leaving a positive impression.

- However, it is important to ensure the musical instrument's design does not carry references irrelevant to making music such as **everyday consumer products**. Musicians particularly stress that regardless of design decisions a musical instrument must always evoke **dignity** and **respect** from the audience at all costs because this dimension directly impacts <u>musicians' self-confidence</u> on and off the stage.
- There is a clear difference between being **playful** and looking **toy-like**. When designed through a 'playing with toys' metaphor, the instrument can become **attractive** and **engaging** for both the musician and the audience. However, audience should always be under the visual impression that what they are experiencing is a <u>musical performance</u>.
- Additionally, **overdesigned** or **obtrusive** instruments carry the risk of **outshining** or **overshadowing** the performers themselves. Designers are recommended to always keep in mind that it is the performers and not the instruments that should always be in the limelight.
- Similarly, performers also reject playing instruments, which force them to perform bizarre or odd gestures on the stage (e.g. musical instruments which resemble everyday touchscreen devices such as digital tablets give audience the impression that the musician might in fact be sending an email or doing work while what they are hearing might be an extremely sophisticated piece of music)
- **Novelty** also plays an important role in influencing the audience's perception and it can be considered in two aspects: the **novelty of visual design** communicates an **intriguing** and **mysterious** character, which evokes discovery. Similarly, **novel interactions** (i.e. <u>never before seen methods of generating sound</u> with an instrument) immediately **surprise** the audience with their **'magic'**. Musicians consider both approaches an integral part of the 'magic' of music making on stage. Either path can lead to a more engaged and immersed audience.

- Designing a musical instrument to look unique and **mysterious**, gives the performers an immediate urge for **exploration** while creating an element of **'magic'** for the audience. As musicians often refer to musical performances as 'rituals', the element of magic indeed becomes more than a metaphor.
- **Visual feedback** and **feed forward** can – in many cases – be as useful to the **audience's comprehensibility** as it is to the performer's. Therefore, designers can consider scenarios where visual feedback is either visible to or projected for the audience, especially for musical instruments that feature new interactions.
- The visual feedback may not always facilitate the audience's comprehensibility, however, it can still enhance the performance by making it a **visually more interesting experience**. Hence, it is important to consider the resolution (i.e. quality) of the feedback as well as means of projection.
- **Visual representation of the sounds** – even in the form of abstract graphics similar to those found in digital music players or apps – could be considered an example of a visual feed, which can be intriguing for the audience. This visual support can in fact improve audience's **concentration** when the music itself is difficult to follow.
- However, it is not realistic to argue that the combination of sound and visual always enhances the performance experience for the audience. **Excessive** 'visual communication' might also **distract the audience** from the primary output of a live performance; namely the music itself. Thus, designers are recommended to consider the balance between these two dimensions while making design decisions.
- Designers may also decide to consider **simplicity** in order to avoid an **obtrusive design**, which could distract the audience attention from the actual performance.
- **Familiarity** is a quality, which enhances audience understanding of a live performance. Especially for musical instruments, which offer <u>familiar design elements or interaction models derived from traditional acoustic musical instruments,</u> audience can positively transfer previous live performance experience to follow and understand the musical interactions.
- While previously mentioned on more than one occasion in this Chapter, **wireless** interactivity also contributes to the audience experience simply

because cable-free musical instruments enable the performers to use the entirety of the stage with complete freedom, thus improving audience's visibility of the musical interactions greatly.

- **Direct input-output relation** facilitates audience's comprehensibility of the whole performance. Especially for instruments with novel designs or unorthodox sound generation models, 'transparent mapping'; delivers comprehensibility for the audience as well as the performers.
- **Performable actions** play a complementary role to the previous strategy. Musicians expect the musical interaction to create basis for a 'theatrical' performance in regards to allowing **'grand/visible gestures'**. Traditional acoustic musical instruments are played through gestures, which directly reflect the momentary changes in music. In other words, it is possible to argue that sound is directly based on gestures (e.g. moving the hands to right on the piano makes the sound treble, a stronger hand movement coming down from a higher position translates to an increase in volume, etc.). Even breathing or holding one's breath has considerable impact on the sound outcome. Thus, designers are recommended to explore new possibilities where gesture and sound connections are obvious and easily visible by the audience.
- **Non-contact gestural interaction** has a 'magical' effect on the audience; thus, its possibilities (e.g. wearable instruments) can be explored as long as gesture-sound relationships are transparent and visible to the audience.
- For the reasons mentioned in the previous strategies, touchscreen interaction especially in small instruments should be avoided because audience views all touchscreen gestures in the same way regardless of the changes in sound. In other words, whether the musician is sending an email or performing a very complex musical piece, audience's perception of the musical interaction is often identical.
- **Real-time sound generation** as opposed to triggering pre-recorded sonic material, enables the audience to witness the actual performance 'there and then'. It is important to avoid a design, which features only playback of pre-recorded sounds because audience may also question the 'authenticity' of the performance.

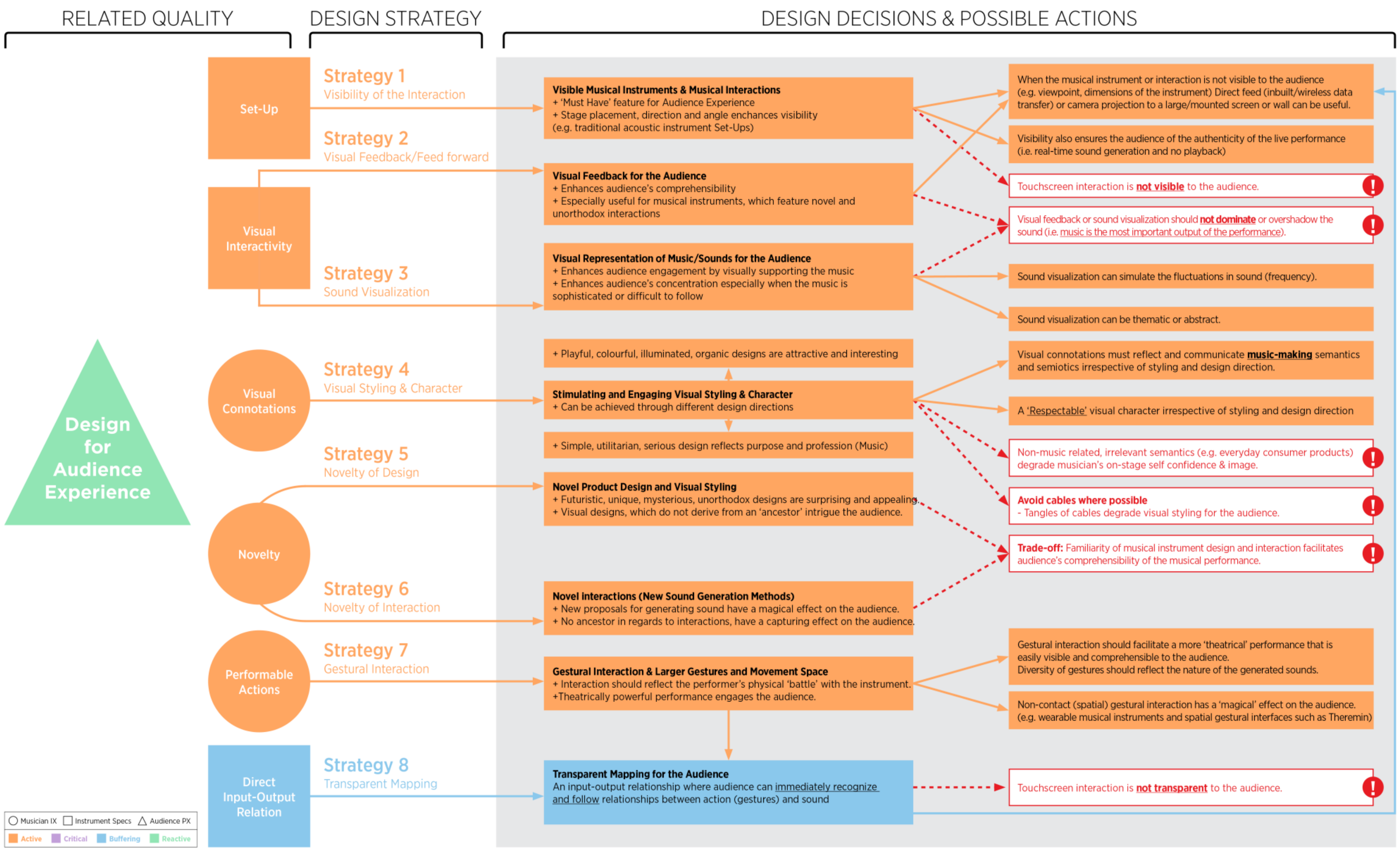

Figure 6.14 Guidelines for designing for Audience Experience

CHAPTER 7

DISCUSSION AND CONCLUSIONS

This thesis has explored the interdisciplinary field of new generation electronic musical instruments from a design perspective; seeking to establish an understanding regarding the multidimensional nature of live musical performances, which intricately connect musicians, their musical instruments and the audience. This concluding chapter summarizes the work undertaken, revisits the research questions, states the contributions to knowledge as well as the possible implications of the research. Limitations of the research and suggestions for future directions are concluded by further reflections in relation to the entire thesis process.

7.1 Summary of the Work Undertaken

This thesis has adopted a user-centred research approach in order to elicit professional musicians' unique individual construings in relation to dimensions of new generation electronic musical instruments and their surrounding musical interaction experiences. The methodological approach consults John Kelly's personal construct theory (PCT) and utilizes the repertory grid technique (RGT), laddering and pyramiding in order to acquire musicians' personal constructs through a series of in depth interviews.

An initial content analysis was carried out in order to cluster and organize the findings with the help of a conceptual framework for musical interaction; revealing 31 unique design qualities, which form the core dimensions in the greater system of new musical interactions. Within the scope of this research, the aforementioned term 'system' (i.e. system of new musical interactions) refers to the complex network of personal constructs, which collectively represent the mind-sets of the musicians (i.e. participants of the research) when they are exposed to new musical instruments; in other words, their perceptions and experiences in relation to new musical interactions. Further more, the design qualities (i.e. dimensions of new musical interactions), which constitute this system have specific roles within the system, which can be described with a ‘means and ends’ (i.e. ‘tools and goals’) model.

Following the identification of the design qualities, a cross impact analysis (CIA) was carried out in order to investigate the interrelationships and interactions between these qualities while also successfully establishing a hierarchy among them. Finally, 11 individual strategies were proposed as the main output of the research; based on 11 of the aforementioned 31 qualities, which were identified as the musicians’ main goals (i.e. ‘ends’) in relation to new musical interactions. These strategies embody in depth, diverse and actionable knowledge for designers and instrument makers to consider, in order to improve musicians’ interaction, user experience and live performance with new musical instruments.

7.2 Research Questions Revisited

This section revisits the research questions posed in the Introduction Chapter and provides answers based on the findings of the research.

<u>RQ 1: What are the dimensions of new musical interactions, which matter to musicians?</u>

This research has identified – through literature search, personal construct theory and repertory grid technique – 31 unique design qualities (i.e. dimensions of new musical interactions), which matter to musicians concerning new generation electronic musical instruments and their surrounding musical interactions. A conceptual framework for musical interaction (Figure 5.3) was developed in order to sort these design qualities into three categories: (i) the musicians’ interaction experience (<u>Musician IX</u>), which embodies dimensions in relation to *How a musician would DO, FEEL and KNOW* (Verplank, 2009) with a musical instrument; (ii) musical instrument specification (<u>Instrument Specs</u>), which reveals the facts and technical features of the products themselves; and (iii) the audience’s overall experience of the live performance (Audience PX). A breakdown of these 31 design qualities based on the conceptual framework is as follows:

Musician IX: Usefulness, comprehensibility, controllability, efficiency, engagement, ease of use, expressiveness, visual connotations, tactile/haptic interactivity, creativity, appeal, pleasure in use, simplicity, familiarity, collaborative interactivity, performable actions, novelty, repeatability and anthropometry.

Instrument Specs: Versatility, set-up, visual interactivity, flexibility, product architecture, reliability, real-time sound generation, direct input-output relation, virtual instrument, materials and accessibility.

Audience PX: Audience experience.

RQ 2: Why do these dimensions matter to musicians?

During the interviews, the reasons behind musicians' construing were identified through RGT, laddering (by asking 'why?' questions) and pyramiding (by asking 'how?' or 'what?' questions). Laddering and pyramiding were particularly instrumental in establishing the relations of causality between the 31 design qualities. The majority of causal (subordinate constructs) qualities belong to the instrument specification where as, the end goals (superordinate constructs) of the system are all related to the musicians' and the audience's interaction experiences.

RQ 3: How can these dimensions be utilized to improve the musicians' interaction, user experience and live performance with new generation electronic musical instruments?

This thesis utilizes a complex network of unique individual constructs acquired from 30 musicians to propose a set of 11 design strategies and guidelines to improve musicians' interaction, user experience and live performance with new generation electronic musical instruments. The construction of these strategies were achieved through a meticulous process, which involved: investigating the key concepts and dimensions in the research area (literature survey), picking up a suitable theory (PCT), setting a solid methodology (RGT, laddering and pyramiding), proving their effectiveness (Pilot studies), detailed research planning (timing, recruitment, selection of experiment stimuli, tools and preparations), and an elaborate analysis process (a hybrid methodology involving content analysis, a conceptual framework and CIA).

These individual strategies are based on 11 unique design qualities which the musicians identify as the most critical and essential dimensions within the system of new musical interactions. Further more, as most design problems are multidimensional in nature, answers to two further research questions were needed in order to inform the development of the aforementioned strategies.

RQ 3.1: What are the similarities and diversities between the elicited dimensions?

A three level content analysis enabled the identification of similarities and diversities between the elicited dimensions. In fact, the similarities between the musicians' individual evaluations were very high (Figure 5.5). 26 out of 31 design qualities were mentioned by more than %50 of the participants (at least 15 out of 30 musicians) where as, 14 out of 31 qualities were mentioned by more than 80% of the participants (24 out of 30 musicians).

Only 4 out of 31 qualities were mentioned by less than 30% of the participants (8 out of 30 musicians at most). These diversities – while still considered valuable – do not have a substantial influence on the system. However, they are still discussed in Chapter 5; within general reflections on the content analysis and also in their respective cross impact egocentric networks.

These numbers also prove that, irrespective of musical background, music style or experience in music technology, professional musicians think similarly and express similar concerns when they are asked to evaluate new musical instruments and new musical interactions. As a result, 27 out of 31 qualities – an overwhelmingly high ratio – made into the detailed discussions within the 11 individual strategies, which are the main output of this thesis.

RQ 3.2: How/In which ways are these dimensions interrelated?

Cross impact analysis was instrumental in revealing both the complex network of interrelations between the qualities as well as establishing a hierarchy of purpose and importance among them (Figure 5.8). It is no coincidence that all the core goals of the system are identified as qualities belonging to the musicians' and audience's interaction experiences, where as the means – or tools – to reach these goals are delivered predominantly by the qualities belonging to the musical instruments. The interrelations between the 31 design qualities form a very complex and intricately woven network, which is elaborated in great detail in chapters 5 and 6. Therefore, in order to reveal the 'big picture', a holistic view of the findings are presented in the form of a summary as follows:

For clarity of communication, (g) represents the core goals of the system where as (m) indicates the means to achieve the goals. Two qualities act as both ends and means and thus, they are indicated as (g/m).

Musicians' first and foremost expectation from new generation musical instruments is for them to be useful (g). This quality is in fact a prerequisite of professional use and it is influenced by the highest number of dimensions in the study. Musicians associate the versatility (m) and flexibility (m) of a musical interface directly with its usefulness (g). Similarly, being able to exercise full control (g/m) on the music, generating and modifying sounds in real-time (m) and repeatability (m) of the musical creations/performance are strongly linked to the perceived usefulness (g) of a musical instrument.

Learning and mastering any musical instrument is a life long dedication; a process involving 'blood, sweat and tears'. As in every other art form, personal – in this case; musical – expression (g), along with creativity (g), are the main qualities that distinguish a musician from his or her peers. When the musicians are convinced by the usefulness (g) and expressiveness (g/m) of a musical instrument, they can justify the amount of time and energy they need to dedicate to master it and thus, engage (g) with it. Versatile (m) and flexible (m) user interfaces provide musicians a wide spectrum of tools to achieve a creative (g) and expressive (g/m) performance.

New generation electronic musical instruments often feature unorthodox user interfaces and interaction models. They also offer completely new functions and features unavailable in their acoustic counterparts. Furthermore, some of these instruments cannot even be traced back to a traditional lineage in regards to neither how they look nor how they make sounds. Therefore, musicians specifically emphasise the importance of being able to discover, understand, learn and memorize the instrument's functions features and interactions as quickly as possible. In this context, musicians consider various dimensions of simplicity (m), familiarity (m) and visual interactivity (m) as the main facilitators of comprehensibility (g). A transparent mapping, in other words, an immediately discoverable direct input-output relationship (m) also enhances comprehensibility (g). Visual interactivity (m) and simplicity (m) along with tactile/haptic interactivity (m) also make an instrument easy to use (g).

As new generation electronic musical instruments are heavily technology driven, pre and post performance activities can be as demanding as the actual performance itself. Thus, musicians associate efficiency (g) not only with the actual performance but with the practicalities of logistics, rehearsals, stage set-up and disassembly too. Product architecture (m) and set-up (m) are the primary dimensions associated with pre- and post performance efficiency (g). Regarding the dynamics of the actual performance efficiency (g), simplicity (m), tactile/haptic interactivity (m) and performable actions (m) are the main tools that help musicians deliver an efficient performance. Musicians also believe that having complete and effective control (g/m) over their instruments is necessary for using it in its full capacity and realizing their creative (g) intentions. Hence, tactile/haptic interactivity (m), performable actions (m) and real-time sound generation (m) are considered as the main facilitators of controllability (g/m).

Concerning the emotional dimensions of a live performance, musicians believe that the physical bond they form with an instrument (tactile/haptic interactivity (m)) strongly affects the pleasure (g) they receive from the interaction. Collaborative interactivity (m); is a feature rarely found in acoustic musical instruments (e.g. piano). Musicians favour being able to collectively perform on the same instrument simultaneously, as a feature that makes the interaction more pleasurable (g) while also opening new doors for creativity (g). Musicians express very different preferences in regards to 'how' a musical instrument is supposed to look like, hence, many diverse paths can be taken in relation to visual connotations (m), to make the new generation musical instruments more appealing (g) for both the musicians and the audience (g). Set-up (m) and visual interactivity (m) are also critical for ensuring the audience's comprehensibility (g) of a live performance. Similarly, musicians believe that novelty (m) of design, functions and interactions can make an instrument more appealing (g), in the mean time, the 'newness' effect on the audience (g) transforms their impressions of the performance to a more immersive and engaging experience.

7.3 Contribution of the Research

This thesis makes five contributions to knowledge in the fields of design research and new generation electronic musical instrument design.

Firstly, the strategies to improve musicians' interaction, user experience and live performance with new generation electronic musical instruments contribute to theoretical knowledge in the field of new musical instrument design.

Secondly, the proposed conceptual framework for musical interaction (Musician IX, Instrument Specs, Audience PX) offers a user-centred perspective, which can be adopted for future research in the field.

Thirdly, the versatility of methodology employed in data collection (PCT, RGT, laddering & pyramiding) and analysis (Content analysis, conceptual framework and CIA) generated not only theoretical knowledge but also practicable information, which is multi-layered, diverse and rich in detail. Therefore, the practical nature of the strategies and guidelines make them 'actionable' for designers and instrument makers working in the field of musical instrument design. They are intended for the earliest phases of new product development, such as ideation and concept generation.

In fact, the complex network of interrelationships and interactions between the dimensions of musical interaction, which are elicited through professional musicians' individual construing (revealed through individual egocentric networks and discussions for each dimension) is considered to be the major output of this study, because it presents a detailed picture in relation to the *musicians' problems needs and expectations concerning new musical interactions*. In other words, they offer **valuable insight** about **how the musicians would think, feel or do** (Verplank, 2009) with these products.

Finally, the methodological approach is in itself a contribution to the field of new musical instrument design. While chapters 3 and 5 acknowledge various successful research carried through the combination of RGT and CIA in the field of industrial/product design, this study is a first in conducting a user-centred research through the RGT-CIA hybrid methodology in the field of new musical instrument design.

The applicability and usefulness of the above-mentioned contributions are discussed from the perspectives of different stakeholders (of new musical interactions) as follows:

Concerning researchers; both in the fields of design and music, the design strategies and the conceptual framework for musical interaction can be used for both generative and evaluative purposes as well as further theory building. The procedure and steps of the research methodology has been thoroughly described. Hence, researchers can follow this procedure to conduct similar experiments in areas not necessarily limited to electronic musical instrument design.

Concerning designers (of various disciplines; i.e. industrial, product, interaction, UX) and instrument makers; the practicable nature of the strategies and guidelines makes them directly actionable, specifically in the earlier phases of new product development, such as ideation and concept generation. Further more, the way the strategies are communicated (including visual guidelines), combined with the glossary of terms developed for the research, make the strategies comprehensible and actionable also for instrument makers or inventor-type makers without formal design training. Finally – and most importantly – the insight into the mind-sets of professional musicians in relation to new musical interactions is expected to give designers a better and deeper understanding of their intended (target) users.

Concerning musicians and the audience; while the findings of this research are not intended for these stakeholders to be actively utilized in their professional activities, musicians and the audience are in fact the primary target group who would benefit most from the contributions of this research. Because, future musical instruments and interactions, which may be designed in light of this thesis, are intended to improve musicians' and the audience's interactions and experiences in the first place.

The dimensions of new musical interactions that emerge from this research is very much in tune with some of the previous works carried out in the field. Cook's (2001, 2009) certain principles, the ideas and concepts proposed in Jordà's (2004a, 2004b, & 2005) various publications, O'Modhrain's (2011) framework and Morrealle et al.'s (2014) conceptual model (MINUET) in particular, seem to overlap with very similar concepts and dimensions discussed in this thesis while also carrying these discussions from user-centred perspectives that involve various stakeholders of new musical interactions. The author acknowledges these invaluable contributions and proposes that this research builds on the knowledge generated by these previous works, by making a more comprehensive, detailed, specific and actionable contribution; which is derived from substantial research studies carried out with a large (30) and diverse (different levels of technology experience) sample of professional musicians.

7.4 Limitations of the Study

Music is an abstract phenomenon with infinite dimensions. Musicians' construing of music is equally abstract and subjective. Therefore, qualitative studies conducted with musicians – as with artists from any art form – require not only a lot of delicate work but also a deep understanding of their language. Upon reflection, certain inevitable limitations were also encountered throughout the course of this work.

The primary limitation of the research was the presentation method of the elements to the musicians. This study has sought to identify the dimensions of new musical interactions through the <u>perceived</u> evaluations of professional musicians. Even though the expertise and experience of the participants enabled them to have a clear understanding of the musical instruments in the study, the media in which the musical instruments were presented was not ideal due to time and budget limitations. In order to partially compensate for this disadvantage, the visual information on the musical instrument cards were supported with demonstration and live performance videos, which clearly displayed the actual interactions. During the interview sessions the participants expressed no concerns in regards to understanding the instruments and their interactions. However, if they were presented with the actual musical instruments and given enough time to physically interact with them, the findings of a ‘hands-on’ performance experience, as opposed to a perceived product experience through visual and aural stimuli, would beyond any doubt be more dimensional and richer.

On the other hand, all 30 participants of the experiment were Turkish musicians. Even though music is a universal language and those who are trained in it share a common understanding, it would be interesting to further investigate what kind of effects cultural contexts would have on the outcome if the research was carried out with international musicians. However, the author proposes that the common understanding of music combined with interaction experiences with instruments and everyday electronic products, create a high expectancy for transferability of the results to the new musical instrument design community as a whole, beyond the participants of the research. Similarly, as the research was not designed as a gender study, the participants were not sorted equally based on sex. The question remains in regards to what kind of outcomes would have been revealed if the study was carried out with all-male or all-female musicians.

Furthermore, the selection of the elements for the study has impacts on the results as well. Personal construct theory specifically states that the diversity of elements of the study should be representative of the whole field that is under investigation. This study can confidently claim that the five musical instruments that were selected for the experiment establish necessary diversity to cover both ends of the spectrum. However, there might have been slight variations in the findings if different elements were used.

As with any qualitative data collection and analysis method, both repertory grid technique and the cross impact analysis proved to be handy and required a lot of work. Even though quantitative analysis methods could have given faster results, the semantic blindness of the findings would have rendered their actionability obsolete. The versatility of cross impact analysis made it possible to also quantitatively represent the hierarchy and interrelationships between the qualities and thus, improved the credibility of the findings.

7.5 Future Research and Further Reflections

New generation electronic musical instruments and the dimensions of interaction and user experience that surround them is a fairly young area. There are very few user-centred research studies – even fewer that are carried out with professional musicians – and most of them involve prototypical research aimed at providing solutions for practical design issues. However, as these new species of instruments improve in technology and thus, 'talent'; so do the 'unknowns' in terms of new music-making paradigms. Therefore, further user-centred studies are needed in order to add theoretical knowledge to the literature. In the mean time, a lot of research effort is also going into bringing together amateur musicians with easy to use new instruments. The findings of user-centred research carried out with professional musicians could potentially be beneficial for those works as well.

This thesis presents a set of strategies and guidelines to improve musicians' interaction, user experience and performance with new generation electronic musical instruments. A direct continuation of this work could be carried with a Research through Design (RtD) approach in order to explore the usefulness of the aforementioned strategies. Designing and constructing prototypes through these strategies and user-testing them with professional musicians could generate further theoretical knowledge to the field.

Additionally, certain limitations that were mentioned in the previous section also present themselves as new research opportunities. Conducting a hands-on user-centred research with actual new musical instruments would reveal musicians' more detailed post-use impressions rather than their perceived pre-use evaluations. In addition to generating design relevant information, observing and shadowing musicians during their actual interactions with the musical instruments would reveal essential insight in regards to how professionals approach and handle new musical instruments, in other words, their individual and unique performance habits. The differences and commonalities of performance behaviours could further inform the design and development of new generation electronic musical instruments.

A cross-cultural study may also be useful for revealing the similarities and diversities in musicians' construing when they are exposed to these instruments. Furthermore, if the recruitment strategy was adjusted to consult musicians that perform local/ethnic music genres rather than mainstream music (e.g. classical, pop, rock, jazz) the effects of differences in culture and musical background could be better understood.

Even though this thesis is a generative research study, the constructs that were utilized to create the strategies and guidelines can also be used for evaluative purposes. In other words, the hierarchy and interrelationships of the constructs, which were revealed in the findings, could be used for developing a scale for measuring and rating existing new generation musical instruments as well as design proposals at various stages of development.

This research was carried out specifically within a live performance context in mind because a musician's 'relationship' with a musical instrument is radically different in a musical composition context. First and foremost, composing music is free of temporal constraints. In other words, the composer is not obliged to play the instrument within a specific time frame (i.e. real-time), at a specific tempo or in simultaneous/synchronous communication with other musicians (unless in a solo performance). The composition process is also not continuous, interrupted with various activities such as writing and editing notation, recording and playback, repetitions and re-composition based on trial and error. However, the majority of the findings of this research may be relevant for private practice, rehearsals and more importantly; studio recording. As the name suggests, a studio musician (also called a 'session musician' or 'session player') is a musician whose primary professional musical activity involves playing in recording studio sessions. Since recording is effectively a (sometimes live) performance without an audience, many of the dimensions of musical interactions in a live performance may be applicable to a performance context during a recording session. Even though recording sessions always give the musicians freedom to have multiple takes and infinite number of edits on a musical piece, the actual recording performance is bound with real-time constraints, which also requires flawless synchronisation between the musicians. Hence, a musician's attitude towards the musical instrument in a studio context is very similar to a live performance. Additionally, while musicians may have different choices of ‘recording instruments’ and ‘live performance’ instruments, new instruments designed based on the strategies proposed in this thesis ought to be applicable to both. On the other hand, the emotional dimensions of playing in an isolated space versus in front of a live audience may be very different, and what the musician ‘feels’ during either of the scenarios and the possible effects of these scenarios on the performer’s interactions would be just speculation and beyond the findings of this research.

Further Reflections on the Findings of this Thesis

The immediate reflections from a holistic perspective concerning this work proposes the following projections:

Firstly, new generation electronic musical instruments offer unorthodox designs and never-before-seen interaction models. They also equip the musicians with features and functions, which are not available in traditional musical instruments. Hence, musicians expect more from them.

However, musicians also don’t want to sacrifice the fundamental qualities of acoustic instruments, which have become in a way – inbuilt – to their ‘DNA’ throughout the centuries. In other words, essential qualities of acoustic musical instruments which have been time-tested to enable and improve basic musical interactions should not be considered as ‘trade-offs’ in order to realize certain features and functions available in new generation musical instruments.

The stakeholders are changing and evolving. A new species of musicians emerged in the current music scene who are designer-makers, designer-performers or designer-performer-composers. These individuals could very well be considered as a new generation of ‘Renaissance’ makers who display high levels of expertise on diverse areas. On the other hand, questions concerning adoption, longevity and isolation surrounding the instruments designed by these makers and inventors are yet to be addressed. The audience, who retained a passive role for many centuries, are given completely new roles such as co-creators and active participants of live performances and new musical interactions. Additionally, with the emergence of unconventional instrument designs, the once transparent and obvious musician-instrument interactions have become opaque and incomprehensible for the audience, causing engagement and immersion problems during live performances. The complications and opportunities created by this paradigm shift are still being explored.

While it is still possible to perform traditional music genres and styles with the majority of these new musical instruments, new music genres and styles will inevitably evolve in parallel with the paradigm shift concerning new musical instrument design. This projection is actually not wholly a speculation because it is already happening as of this moment as well as being a historical fact. Previous paradigm shifts in musical instrument design have already created new music genres (e.g. there would be no rock and roll, heavy metal or electronic/computer music without the actuation oscillation and amplification of sound through electrical energy).

> Many new instruments are being invented. Too little striking music is being made with them (Jordà, 2004).

Re-visiting Jordà's critical statement – which is one of the main reasons for the author to decide to undertake this research work – inevitably brings certain questions, which could be answered in relation to the findings of this thesis:

Will the musical instruments, which are designed based on these strategies make striking music?

A better and in-depth understanding of musicians' mind-sets may have a higher chance of designing musical instruments, which may deliver better results in relation to those musicians' intentions. Naturally, this is only the start of a 'journey', whose next step is to create the actual instruments through these strategies. (Good) musicians already have what it takes to create (good) music. Hence, a good instrument (i.e. 'good design' (Rams, 1976)) should be a <u>facilitator</u> and <u>enabler</u> rather than <u>obstacle</u>. In other words, the musical instrument should never get in the way of the musicians' creative expressive or performative intentions. The author proposes that setting the right direction by understanding what is 'essential' for the musician, it is almost inevitable the (striking) music will follow.

What kind of 'instruments' will these strategies help to design?

Even though the versatility of the proposed design strategies gives designers plenty of freedom to take diverse concepts to very different directions, the controllers' overwhelming domination of the current music scene for the past few decades cannot be ignored. Hence, new instruments will most likely be new 'interfaces' (i.e. controllers) that support the contemporary situation of decoupled sound generation and sound manipulation. On a side note, these design strategies can also be viewed as a way for designers to navigate and be careful about new interactive technologies (which inevitably enter the 'picture' in relation to these new generation of musical instruments). After all, technology intervention does not necessarily guarantee better instruments nor better music.

Why would a musician invest time and effort into a new musical instrument?

It is a well known fact that long-term engagement is a prerequisite of becoming fluent in the language of the instrument. Hence, while it is important to understand the motivation behind engaging with a new instrument, the dimensions concerning how the musicians 'know' which instrument is the 'right' one to invest in, might be too complex and well beyond the scope of this research. It could be speculated that as with any art form, achieving uniqueness; through virtuosity, creativity and expressiveness might be a strong motivation for musicians while making that critical decision (of picking up the 'right' instrument). From this perspective, it could be argued that after all these centuries of accumulated legacy, it may not be easy for any musician to be able to create a unique 'tone' on a violin or piano. Similarly, existing instruments may fall short of realizing musicians' imaginations and intentions on many different levels (i.e. expressive, creative, technical). New instruments may offer new 'ways' (i.e. new sounds, new tones, new expressions) for uniqueness, presenting musicians new possibilities to set themselves apart artistically through various dimensions of new musical interactions.

To conclude;

Although there is an overwhelming similarity between the musicians' (who participated in this research) personal construings regarding new musical interactions, the diversity of musical intention, creativity and expressiveness among musicians indicates an important fact: It is not possible to design the 'ultimate' musical instrument that can satisfy and please all musicians. This hypothesis proves to be true even for existing musical instruments, which have been around for centuries. After all, how could one compare the abilities of a piano to a violin when there are infinite musical contexts and equally endless creative possibilities? Hence, the search for 'good' instruments and 'striking' music is an endless journey; which, its travellers can only consider themselves lucky to be a part of…

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APPENDIX A

STIMULI: IMAGE TEMPLATES OF THE ELEMENTS USED FOR THE RGT EXPERIMENT

In this Appendix, the five image templates, which were used as the main stimuli for the RGT study are presented.

The details of the stimuli, which were used for the RGT experiment are as follows:

A: Percussa ‘AudioCubes’ (2007)

B: Reactable Systems SL ‘Reactable’ (2005)

C: Yamaha ‘Tenori-on’ (2007)

D: Wizdom Music ‘MorphWiz’ (2010)

E: MIT Media Lab ‘Beatbugs’ (2000)

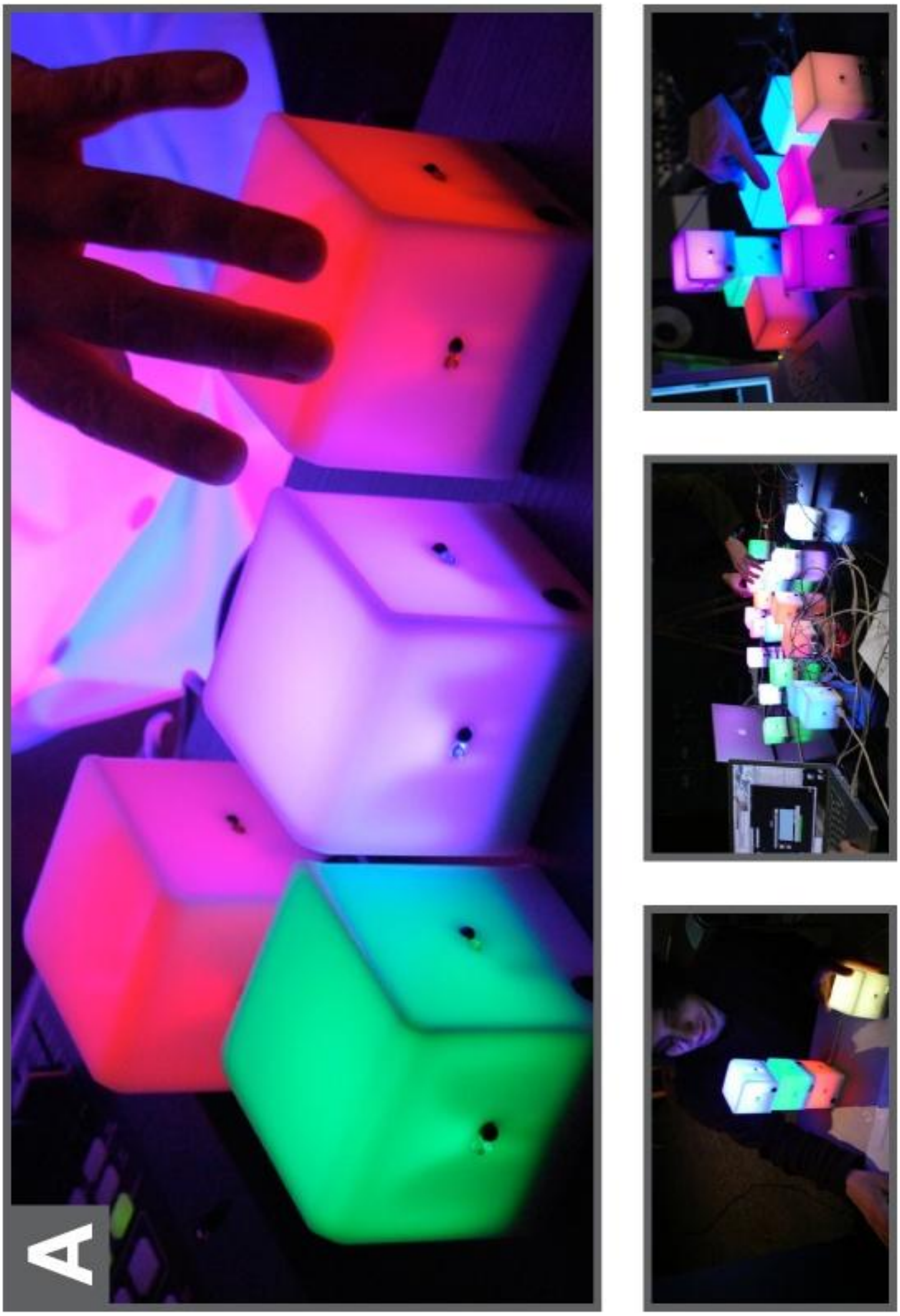

Figure A.1 Element 1: Percussa 'AudioCubes'

Figure A.2 Element 2: Reactable Systems SL ‘Reactable’

Figure A.3 Element 3: Yamaha 'Tenori-on'

Figure A.4 Element 4: Wizdom Music 'MorphWiz'

Figure A.5 Element 5: MIT Media Lab ‘Beatbugs’

APPENDIX B

VERBAL TRANSCRIPTION OF THE INTERVIEW PROCEDURE

In this Appendix, the transcription of the interview procedure and walkthrough of the experiment's phases are presented as verbally explained to the participants below:

First of all, thank you very much for accepting to take part in this research. Your contribution is invaluable for this experiment and my overall PhD research. My research is about new generation electronic musical instruments. You might or might not have seen any or all of these instruments but this will not matter for the outcome of the study. You can consider this experiment as an interview.

In this interview you will evaluate five new generation electronic musical instruments and interpret your evaluation with your own words and expressions. Your personal constructs (I call them your 'personal attitudes') are very valuable for this study.

Since the musical instruments themselves are not physically present, your interpretation and construction will be based on your 'perceived' evaluation of these instruments. Thus, to help you understand these instruments better I am going to play you five short videos of five musical instruments. I will not talk about them or make any explanation. After you have seen them, if you believe that there is something you have missed, you are welcome to watch any or all of them again. Also, you can ask to watch them as many times as you wish, partially or completely, at any moment during the whole interview so please feel free to tell me right away if/when you have such a request.

After the videos, I will present you triads of cards with the images of the musical instruments, which you watched on the videos, printed on them. I want you to look at these triads and group them in such a way that two of these instruments are alike/similar and the third one is different from the other two. I will then ask you what it is about those instruments that makes two of them alike/similar and the third one different. I am expecting you to tell me which attribute of the instrument makes you decide that two of them are alike/similar and the third one is different. The likeness or difference can be about any aspect of these instruments.

I expect you to evaluate the triad of instruments and find as many attributes to group as possible and express them to me in your own words. On this empty template, you can see two poles. These poles represent two ends of a spectrum which will be filled with the opposite attitudes that you will provide while you evaluate these instruments. So I will be noting them down while we talk. When you make a grouping and tell me based on which attribute you elicit that attitude, I will then ask you for the polar opposite of that attitude and note it down on the other pole. The complete set of bipolar attitudes will represent your personal perceived evaluation regarding these musical instruments. During our conversation I may ask you some questions in between your elicitation in order to better understand your reasoning behind your evaluation. When you realize that you cannot elicit new attitudes based on the specific triad of instruments which you evaluate, I will then present you with a new triad of instruments. The process will continue until you are no longer able to elicit a new attitude or when you are tired or bored and decide that you do not wish to continue any longer. There is no time limit or an expected duration for this interview. After this phase is completed, we will have a final procedure where you will rate the musical instruments based on the attitudes, which you have elicited and our interview will be finished. I would like to thank you very much again for participating in this study.

APPENDIX C

RGT GRID SHEET TEMPLATE

In this Appendix, an empty RGT Grid Sheet template is presented.

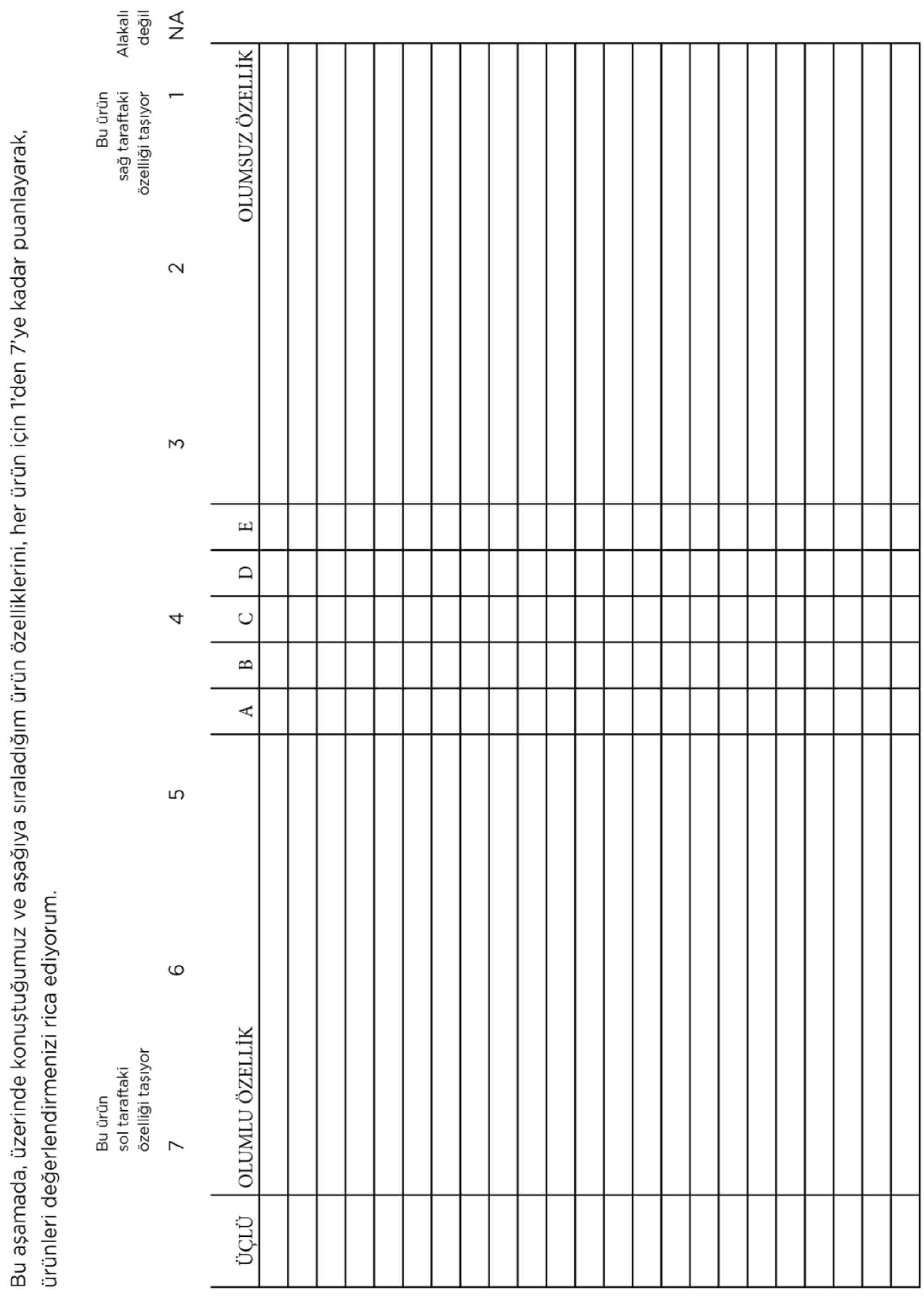

Figure C.1 Empty RGT Grid Data Sheet template

APPENDIX D

MUSICIANS' BIPOLAR CONSTRUCTS

Table D.1 Musicians' Bipolar Constructs

No.	Positive-Pole Construct	Negative-Pole Construct
1	2D interaction	3D interaction
2	3D interaction	2D interaction/planar interface
3	Accessible	Not accessible
4	Acoustic instrument interaction	No acoustic instrument interaction
5	Adaptable	Unadaptable
6	Adaptable to different settings and environments	Can be used only on stage and in ideal conditions (e.g. Lighting)
7	Adaptable to East AND West scales	Adaptable to East OR West scales
8	Adoptable	Not adoptable
9	Advanced sound generation	Restricted sound generation
10	Aesthetic	Ugly
11	Affordable	Overpriced
12	Analogue sound generation	Poor sound quality
13	Antropometric	Injury-prone
14	Appealing sonic output	Unappealing sonic output
15	Appropriate materials	Inappropriate materials
16	Artifically intelligent	Dull
17	Assignable parametres	Closed System
18	Attractive	Over-complicated
19	Attractive colours	Boring
20	Beat AND pitch oriented	Only pitch oriented
21	Blind interaction	No blind interaction
22	Bodily interaction	Hand and finger control
23	Can play classical repertoire	Can not play classical repertoire
24	Can produce articulation	Cannot produce articulation
25	Can use musical notation	Can not use musical notation
26	Charming (interaction)	Not charming
27	Clear	Embellished
28	Collaborative OR Solo performance	Solo performance
29	Collaborative interaction	Solo performance
30	Colour coded	Not colour coded
31	Colour identification	No colour identification
32	Colourful	Colourless
33	Compact	Bulky
34	Compatible with computer	Not compatible with computer
35	Compatible with other instruments	Not compatible with other instruments

No.	Positive-Pole Construct	Negative-Pole Construct
36	Comprehensible	Incomprehensible
37	Comprehensible input-output relation	Incomprehensible input-output relation
38	Comprehensible input-output relation for the audience	Incomprehensible input-output relation for the audience
39	Computer based	Dedicated hardware
40	Conceptual simplicity	Restricted
41	Connected (*musician and instrument*)	Disrupted relationship
42	Continuous pitch space	Fixed (*discreet*) pitch space
43	Controllable	Unchanged outcome
44	Controllable (*physical*)	Difficult real time control
45	Conventional hardware	Dedicated hardware
46	Cool	Cheap looking
47	Creative	Uncreative
48	Cross-platform	Dedicated hardware
49	Customisable system	Closed system
50	Cute	Cold
51	Dedicated platform	Conventional platform
52	Dedicated sound processor	Computer CPU
53	Desirable	Undesirable
54	Digital recording	Acoustic recording
55	Direct input-output relation	Incomprehensible input-output relation
56	Direct interaction	Indirect interaction (*secondary interface e.g. mouse, keyboard*)
57	Discoverable	Consumable
58	Diverse sound generation	Fixed sound generation
59	Durable	Fragile
60	Durable materials	Short-lived materials
61	Easy gesture control	Uncontrollable through gestures
62	Easy interaction	Requiring physical competence
63	Easy set-up	Complicated set-up
64	Easy to control	Complicated control
65	Easy to learn	Requiring manuals
66	Easy to use	Requiring practise
67	Efficient	Inefficient
68	Effortless	Time-consuming
69	Empirical interface	Deterministic interface
70	Enabling new compositions	Repetitive compositional output
71	Enduring (*supports virtuosity*)	Evanescent
72	Engaging	Not engaging
73	Entertaining	Complicated
74	Enticing	Unenticing

No.	Positive-Pole Construct	Negative-Pole Construct
75	Ergonomic	Not ergonomic
76	Expandable features	Fixed features
77	Expandable performance space	Restricted performance space
78	Expandable pitch space	Fixed pitch space
79	Expandable sound range	Restricted sound generation
80	Expressive	Limited expressivity
81	Surprising	Cliché
82	Facilitates connection with music	Obstructs connection with music
83	Facilitates creativity	Canonical
84	Facilitates virtuosity	No space for virtuosity
85	Familiar interaction	Novel interaction
86	Fascinating	Ordinary
87	Fewer controls	Too many controls
88	Fingertip interaction	Bodily interaction
89	Flexibility in timbre	Cliché
90	Flexible	Closed System
91	Flexible interface	Restricted interface
92	Flow	No flow
93	For all user levels	For musicians
94	Free movement space	Restricted movement space
95	Fully controllable	Temporary instrument
96	Fun	Ordinary
97	Function-dominated	Appearance-dominated
98	Functional	Over-designed (*visual design*)
99	Futuristic	Ordinary
100	Gestural interaction (Spatial)	Physical interaction only
101	Gestural interaction (Touch-Based)	Key-button interface
102	Global language	Not standardized
103	Graphical representation of interactions	No graphical representation of interactions
104	Graphical representation of sound output	Only audio output
105	Hand-held	Not hand-held
106	Hand-operated	Bodily interaction
107	Hand-sweat tolerant	Hand-sweat intolerant
108	Hardware	Software
109	Harmony based	Frequency and loop based
110	Has musical instrument counterpart	No musical instrument counterpart
111	High ceiling for virtuosity	Narrow musicianship range
112	High quality materials	Low quality materials
113	High resolution gesture capture	Low resolution gesture capture
114	Human creation	Created by device
115	Immediate interaction	Over-functional

No.	Positive-Pole Construct	Negative-Pole Construct
116	Immediate sound generation	No immediate sound generation
117	Immediate sound modification	Time consuming sound modification
118	Inbuilt power supply	Not mobile
119	Inbuilt sound generator	Controller
120	Infinite possibilities	Repetitive
121	Infinite sound generation	Limited sound generation
122	Infinite time-span	Short time-span
123	Inspiring	Uninspiring
124	Instantaneous sound generation	Pre-made sounds
125	Instrument to instrument interaction	No instrument to instrument interaction
126	Interaction through user interface	Physical interaction with sound generator
127	Interaction with the audience	No interaction with the audience
128	Interface visibility for audience	No interface visibility for audience
129	Internal timeline	Only real-time
130	Intriguing	Dull, ordinary
131	Intuitive	Calculative
132	Intuitive interaction	Requiring training
133	Inviting	Complicated
134	Learning through play	Technically demanding
135	Legible instrument	Functionally ambiguous
136	Light (illumination) feedback	No light feedback
137	Lightweight	Heavy
138	Low cost/high performance	High cost/low performance
139	Low effort/high reward	High effort/low reward
140	Mass-market	Specific user-group
141	Matching input-output relation	No matching input-output relation
142	Minimal	Too many parametres
143	Mobile	Restricted mobility
144	Modifiable (sounds)	Fixed sounds
145	Modular	Unibody
146	Modular learning	Learning from scratch
147	Monochrome	Colourful
148	Multi dimensional; fewer interactions	Single dimensional; too many interactions
149	Multi-touch	Discrete controller matrix
150	Multidimensional time management	No multidimensional time management
151	Multifunctional	Single function
152	Multiple hand positions	Restricted hand positions
153	Multiple parametres	Toy-like
154	Music-focused	Colourful
155	Music oriented	Sound and timbre oriented
156	Musical Instrument semantics	No musical instrument semantics

No.	Positive-Pole Construct	Negative-Pole Construct
157	Musical instrument	Toy
158	Musical instrument AND controller	Only musical instrument
159	Mysterious	Ordinary
160	Natural interaction	Distant (*interaction*)
161	Natural materials	Synthetic materials
162	Natural posture	Not ergonomic posture
163	Neat	Embellished
164	New medium	Imitation
165	No maintenance; only updates	Requiring maintenance
166	No screen	Screen-like (*computer*, *laptop*)
167	Not commercial	Technology-driven
168	Not complicated	Many buttons
169	Not funny	Funny
170	Not limited to layered loops	Limited to layered loops
171	Not requiring technical skills	Requiring technical skills
172	Novel	Familiar
173	Novel concept	Ordinary
174	Novel ensemble type	No novel ideas
175	Novel features and interactions	Restricted features and output
176	Novel functionality	Restricted functionality
177	Novel hardware	Software
178	Novel sound generation methods	Traditional instrument sounds
179	Novel symbolic language	Text-based language
180	Novel tactual experience	Fixed tactuality
181	Novel techniques	Time consuming
182	Novel creative feast	Ordinary design
183	Nuanced	Repetitive
184	Obvious interaction	Obscure interaction
185	Online interaction compatibility	No online interaction compatibility
186	Open to creativity	Limited sound palette
187	Open-ended	Restricted
188	Open/unpredictable	Pre-defined
189	Original	Imitation
190	Parametrically predictable outcome	Improvisational
191	Performance visible to audience	Performance not visible to audience
192	Performer in limelight	Instrument in limelight
193	Personalizable	Not personalizable, restricted
194	Personalizable outcomes	Similar outcomes
195	Personalizable space	No personalizable space
196	Physical interaction	Virtual interaction
197	Physical musical instrument	Music software/app

No.	Positive-Pole Construct	Negative-Pole Construct
198	Pitched instrument	Non-pitched instrument
199	Playable	No immediate sound generation
200	Playful	Boring, looks too engineered
201	Pleasurable	Steep learning curve
202	Plug&Play	Time consuming
203	Polyphonic	Monophonic
204	Portable	Not portable
205	Powered by computer	Requiring adaptor and cables
206	Practical	Time consuming set-up
207	Pre-configured	Requiring configuration
208	Precise pitch control	No precise pitch control
209	Problem-free wiring	Over-cabled
210	Problem-free	Technically demanding
211	Procedural	Experimental
212	Professional	Home use
213	Professionally suitable	Toy
214	Promising	Dead end
215	Purposeful (*utilitarian*) design	Unnecessary features
216	Quick results	Time consuming
217	Quick set-up	Time consuming set-up
218	Real	Theatrical
219	Real time sound visualization	No real time sound visualization
220	Real-time sound generation for audience	Pre-made sounds for audience
221	Reconfigurable	Fixed
222	Reconstructable	Not-reconstructable
223	Repeatable	Unrepeatable
224	Repeatable performance	Entertainment
225	Requiring mastery	Fixed outcome
226	Requiring minimal movement/gesture	Requiring larger movements/gestures
227	Resembles a traditional musical instrument	Toy-like
228	Respectable	Mockery (*resembling objects which can be mocked*)
229	Retains monetary value	Loses monetary value
230	Rhythm AND pitch control	Rhythm OR pitch control
231	Rich content	Inadequate
232	Rich sound generation options	Limited sound generation options
233	Rich tactility	Homogeneous (*problematic*) surface
234	Safe (*i.e. malfunction etc.*)	Risky
235	Self-explanatory	Without logic
236	Sensitive working surface	Virtual working surface
237	Serendipitous	Predictable
238	Serious	Toy-like

No.	Positive-Pole Construct	Negative-Pole Construct
239	Short learning curve	Steep learning curve
240	Simple	Complex
241	Simple design	Complex design
242	Simple interface	Unnecessary complexity
243	Simple interface (*visual*) feedback	Tiresome (*too many colours*)
244	Single input-output interface	Individual (*multiple*) input-output interfaces
245	Single OR two-handed interaction	Two-handed interaction only
246	Single purpose (*music*)	Multi purpose device (*e.g. laptop*)
247	Single user operation	Requiring additional personnel
248	Small design impact on sound	Big design impact on sound
249	Social interaction	Asocial interaction
250	Software	Hardware
251	Solo performance	Collaborative performance
252	Sonically stimulating	Requiring visual support
253	Sophisticated	Simple
254	Sophisticated music	Limited sound generation
255	Sound and timbre oriented	Pitch oriented
256	Sound is the purpose	Sound is the means
257	Sound modification	Fixed sound generation
258	Sound-synthesis	Pre-set sounds
259	Specific playing position/posture	No playing position/posture
260	Stable system	Unstable system
261	Stand-alone	Dependant
262	Standardized interaction	Random interaction
263	Stimulating design	Unconvincing performance (*impression*)
264	Stimulating through sound	Requiring visual support
265	Supports improvisation	Requires training
266	Supports musician's image	Degrades musician's image
267	Surface (*planar*) interaction	3D interaction
268	Surprising/novel timbres	Similar sounds
269	Sympathetic	Unsympathetic
270	Tactile feedback	No tactile feedback
271	Tactile interaction	Not interactive
272	Tactual	Not tactual
273	Tactual and Non-Tactual interaction	Tactual interaction only
274	Tactual controls	Digital controls
275	Tactual feedback	Unresponsive
276	Tactual interaction	Distant
277	Tangible	Intangible
278	Tangible interaction	Surface interaction
279	Technically capable	Technically incapable

No.	Positive-Pole Construct	Negative-Pole Construct
280	Technically demanding	Technically undemanding
281	Theatrical performance	Key-button interface
282	Timbre modification	Fixed timbre
283	Total control	Toy-like
284	Total control over sound	No total control over sound
285	Touch surface	Buttons and knobs
286	Touchscreen interaction	Key-button interface
287	Toy-like	Old PC-like
288	Traditional	Nontraditional
289	Traditional interaction	Unfamiliar interaction
290	Traditional visual references	Unattractive
291	Trial-error based interface	Pre-prepared (*pre-compositional*) interface
292	Unforeseen use	Restricted use
293	Unibody	Modular
294	Unique	Imitation
295	Unique interaction	Classical instrument simulation
296	Unique sounds	Acoustic sound samples
297	Universal visual language (*icons shapes colours*)	Not universal visual language (*text*)
298	Unlimited	No novel ideas
299	Unlimited creativity	Limited creativity
300	Unlimited sound generation	Limited sound generation
301	Unlimited user control	Limited user control
302	Unobtrusive	Distracting
303	Unobtrusive visuality	Exaggerated lights and colours
304	Unpredictable	Pre-defined
305	Unrestricted	Restricted
306	Unrestricted music style/genre	Restricted music style/genre
307	Unusual	Ordinary
308	Usable	Difficult
309	Useful	Useless
310	Useful visual feedback	Insufficient visual feedback
311	User creates music	User modifies music
312	User-defined limitation	Instrument-defined limitation
313	User-generated sound	Sequenced pre-sets
314	User-driven	Unpredictable
315	User-friendly	Difficult to learn
316	Utilitarian	Imitation
317	Versatile	Restricted, limited
318	Versatile sounds and timbres	Limited sounds
319	Vibrotactile feedback	No tactual feedback

No.	Positive-Pole Construct	Negative-Pole Construct
320	Virtual interaction	Tangible interaction
321	Visibile gestures	Gestures not observable by audience
322	Visible to audience	Hidden from audience
323	Visible controls	Not visible controls
324	Visible interaction	Incomprehensible input-output relation for audience
325	Visible pitch	Not visible pitch
326	Visual Feedback	No visual feedback
327	Visual feedback to performer AND audience	Visual feedback to performer only
328	Visual guidance	No visual guidance
329	Visual guidance for audience	No visual guidance for audience
330	Visual references to sound	Irrelevant visuals
331	Visual representation of music/sound	No visual representation of music/sound
332	Visual representation of musical notes	No visual representation of musical notes
333	Visual representation to audience	No visual representation to audience
334	Visual traditional interaction references	No visual traditional interaction references
335	Visualization of sound output	No visualization of sound output
336	Visually and sonically appealing	Below average visuals and sound
337	Visually appealing	Dull, unappealing
338	Visually engaging	Low quality visual output
339	Visually subdued	Visually dominated
340	Volume and frequency control	No individual parametre control
341	Wi-Fi	Bluetooth enabled
342	Wide movement space	Limited performance space
343	Wide pitch space	Limited pitch space
344	Wide range of body gestures	Limited body gestures
345	Wide range of controls	Limited controls
346	Wide range of features	Restricted features
347	Wide range of possibilities	Limited possibilities
348	Wide range of sound generation	Limited sound generation
349	Wide sonic experiences	Limited sonic experiences
350	Wide sound register	Narrow sound register
351	Wide timbre and sound spectrum	Limited timbre and sound spectrum
352	Wide work space	Narrow work space
353	Widespread	Not widespread
354	Wireless	Wired
355	Wireless OR hidden wires	Cables in workspace
356	Wood	Plastic
357	Works everywhere	Requires specific environment

APPENDIX E

GLOSSARY OF TERMS BASED ON THE CONCEPTUAL FRAMEWORK FOR MUSICAL INTERACTION

In this glossary, for the purposes of meaning the ‘user’ is referred to as the ‘musician’. Similarly, ‘musical instrument’ is referred to as ‘instrument’. The L2 codes are written in **bold** where as, the L1 codes are <u>underlined.</u>

SECTION I: MUSICIAN IX

Anthropometry (L2)

<u>Anthropometrically Appropriate (L1)</u>

The instrument’s form, dimensions and other design features (e.g. placement of the user interface, dimensions of interface elements, weight) are anthropometrically appropriate to the musician.

<u>Ergonomic (L1)</u>

The instrument and user interface (including its elements and components) features an ergonomic design.

Appeal (L2)

<u>Sonically Appealing (L1)</u>

The musician considers the instrument’s **sound** to be **appealing** (i.e. attractive, likeable).

<u>Visually Appealing (L1)</u>

The musician considers the instrument’s **visual features** (visual design, form, elements of visual feedback such as illuminations, text, icons) to be **appealing** (i.e. attractive, likeable).

<u>Aesthetic (L1)</u>

The musician considers the instrument’s visual features (visual design, form, elements of visual feedback such as illuminations, text, icons) to be **aesthetically pleasing** (i.e. gratifying, stimulating).

<u>Attractive (L1)</u>

The musician considers the instrument’s visual features (e.g. visual design, form, elements of visual feedback (e.g. lights, text, icons)) to be **attractive** (i.e. appealing, welcoming).

Collaborative Interactivity (L2)

Collaborative Interaction (L1)

Multiple musicians can interact with the same instrument simultaneously.

Multiple musicians can collaboratively interact with identical multiple instruments.

Multiple musicians can collaboratively interact with different multiple instruments.

Instrument to Instrument Interaction (L1)

To what degree multiple instruments (either identical or different instruments) can interact with each other through hardware and/or software protocols.

Comprehensibility (L2)

Comprehensible (L1)

The user interface, set-up/configuration of the instrument and performable musical actions can be **comprehended** (i.e. understood, intelligible) by the musician.

Learnable (L1)

The user interface, set-up/configuration of the instrument and performable musical actions can be **learned** (i.e. become knowledge, familiar) to the musician.

Discoverable (L1)

The user interface, set-up/configuration of the instrument and performable musical actions can be **discovered** (i.e. realized, exposed) without need of a user manual.

Predictable (L1)

The user interface, set-up/configuration of the instrument and performable musical actions can be **predicted** (i.e. foreseen, anticipated) by the musician.

Controllability (L2)

Controllable (L1)

The musician can control the instrument, the user interface, performable musical actions and the sound generation process (including the sonic outcome).

Creativity (L2)

Supports Creativity (L1)

The instrument's user interface, features, technology and performable musical actions **support** (i.e. enable, encourage) the musician to achieve her/his **creative** (i.e. artistic, original) intentions.

Ease of Use (L2)

Easy to use (L1)

The musician considers the user interface, performable musical actions and performance model (interaction model; in regards to how sound is generated) to be easy.

Efficiency (L2)

Efficient (L1)

The musician can achieve a musical goal (in relation to the operation of the user interface and performable musical actions) in minimal time and with minimal effort (i.e. physical, gestural, mental).

Practical (L1)

The musician can carry set-up (live performance and rehearsal), configuration, disassembly, and transportation use the interface and perform on the instrument in a practical manner.

Engagement (L2)

Adoptable (L1)

The instrument can be **adopted** (i.e. accepted, approved) by the musician.

Engaging (L1)

The instrument's design (visual appearance and form), performance model (interaction model, regarding how sound is generated and manipulated), technology, or sound quality (musical outcome) is **engaging** (i.e. enduring, for long-term, in-depth, intense and frequent use alongside her/his inventory of musical instruments/tools.) for the musician.

Achieves Flow (L1)

The musician can **achieve flow** (i.e. one-ness, transcendency) with the instrument regarding operation of the user interface and the performable musical actions.

Expressiveness (L2)

Expressive (L1)

The musician can achieve **expressive** (i.e. meaningful, sensitive, emotional, communicative) musical performances with the instrument.

Familiarity (L2)

Familiar (L1)

The instrument's visual design, form, user interface and performance model (interaction model, regarding how sound is generated and manipulated) is **familiar** (i.e. known, recognizable) to the musician.

References Traditional Instruments and Interactions (L1)

The instrument's visual design, form, user interface and performance model (interaction model, regarding how sound is generated and manipulated) **references** (i.e. alludes to, mirrors) a traditional acoustic or electric instrument (e.g. plucked, percussive, blown instruments).

Standardized-Universal Language (L1)

The instrument offers a **standardized** (i.e. conventional, traditional) performance model and a universal communication language (e.g. musical notation, keybed), which are already in wide use by musicians.

Intuitive (L1)

The musician can use the instrument's interface **intuitively** (i.e. without thinking, instinctively) to perform musical actions.

Natural (L1)

The musician considers her/his interaction with the instrument to be **natural** (i.e. normal, absent of unusual requirements).

Novelty (L2)

Novel (L1)

The musician considers the instrument's user interface, features, technology, performance model (interaction model; in regards to how sound is generated) or performable musical actions to be **novel.**

Surprising (L1)

The musician considers the instrument's user interface, features, technology, performance model (interaction model; in regards to how sound is generated) or performable musical actions to be **surprising.**

Mysterious (L1)

The audience considers the instrument's design, user interface, features, technology, performance model (interaction model; in regards to how sound is generated) or performable musical actions to be **mysterious.**

Unique (L1)

The instrument features a **unique** design, user interface, technology, performance model (interaction model; in regards to how sound is generated) or performable musical actions.

Novel Interactions (L1)

The instrument features **novel (i.e. never-seen-before) interactions**

Novel Features & Functions (L1)

The instrument embodies **novel (i.e. never-seen-before) features and functions**

Novel Sounds (L1)

The musician can generate **novel (i.e. never-heard-before) sounds** (i.e. timbres) with the instrument

Novel Expressions (L1)

The musician can generate **novel musical expressions** (including expressive performable gestures) with the instrument.

Performable Actions (L2)

Gestural Interaction (Contact) (L1)

The musician can interact with the instrument through **physical contact** (i.e. using touch-based gestures of hand and/or body).

Gestural Interaction (Non-Contact) (L1)

The musician can interact with the instrument using **non-contact** (i.e. spatial) gestures (i.e. without actually touching the instrument; e.g. Theremin).

Bodily Interaction (L1)

The musician can interact with the instrument using the **whole** or **part of her/his body** (i.e. limbs, head, feet, breath) through a broader range of bodily gestures.

Multiple Hand Positions (L1)

The musician can hold or interact with the instrument using **more than one hand position** (i.e. the user interface allows for alternative/diverse hand positions for proper operation of its full capacity).

Single OR Handed Interaction (L1)

The musician can interact with and perform on the instrument in its full capacity with **either a single hand or both hands.**

Minimal Movement/Gesture (L1)

The musician can interact with the instrument through **minimal** movement and/or gestures (i.e. performing and interacting inside a minimal space).

Fingertip Interaction (L1)

The musician can interact with the instrument using **only fingertips** (without the need to use large hand gestures; e.g. touchscreens).

Pleasure in Use (L2)

Pleasurable Interaction (L1)

The musician considers visual, interactive and sonic performance with the instrument to be **pleasurable** (i.e. desirable, congenial).

Repeatability (L2)

Repeatable (L1)

The musician can **repeat** (i.e. replicate, reproduce) musical actions of a performance/composition (e.g. musical notes, melodies, intervals, chords) and user interface related actions (e.g. configuring/assigning parameters, saving settings, finding menu elements).

Memorable (L1)

The musician can **memorize** (i.e. internalize, recall) the operation of the user interface, set-up/configuration of the instrument and performable musical actions.

Simplicity (L2)

Simple Design (L1)

The musician considers the instrument's form, visual design, and user-interface design to be **simple.**

Simple Interaction (L1)

The musician considers the instrument's interactions (i.e. user interface operations and sound generation methods) to be **simple.**

Simple Feedback (L1)

The musician considers the instrument's feedback and feed forward (e.g. visual, tactile, haptic, sonic) to be **simple.**

Tactile/Haptic Interactivity (L2)

Tangible Interaction (L1)

The musician can interact with the instrument by **holding** the user interface, its components, modules or the whole instrument.

Tactile Interaction (L1)

The musician can interact with the instrument by **touching and/or holding** the user interface (including the reception of haptic feedback from the instrument) or the whole instrument.

Tactual Interaction (L1)

The musician can interact with the instrument by **only touching** the user interface or the whole instrument.

Blind Interaction (L1)

The musician can interact with the instrument **without looking** at the user interface or the whole instrument constantly (i.e. the musician is free look at the instrument from time to time, but s/he can still use the instrument in its full capacity without looking at the instrument).

Planar Interaction (L1)

The musician can interact with the instrument on a **single-plane axis** (e.g. a flat surface not necessarily limited to touchscreens).

Touchscreen Interaction (L1)

The musician can interact with the instrument through a **touchscreen.**

Usefulness (L2)

Useful (L1)

The musician considers the instrument's overall features, functionality, interaction model, performance and sonic outcome to be **useful.**

Professional Use (L1)

The musician considers the instrument's overall features, functionality, interaction model, performance and sonic outcome to be suitable for a **professional** use context.

Visual Connotations (L2)

Respectable (L1)

The musician and the audience considers the instrument's overall visual character to be **respectable.**

Cool (L1)

The musician and the audience considers the instrument's overall visual character to be **cool.**

Serious (L1)

The musician and the audience considers the instrument's overall visual character to be **serious.**

Not Funny (L1)

The musician and the audience considers the instrument's overall visual character to be **serious.**

Utilitarian (L1)

The musician and the audience considers the instrument's overall visual character to be **utilitarian.**

Musical Instrument Semantics & Semiotics (L1)

The musical instrument's visual character communicates an identity (i.e. gives the impression of) related to **music-making paradigms.**

Neat (L1)

The musician and the audience considers the instrument's overall visual character to be **neat.**

Organic (L1)

The musical instrument features an **organic design** (i.e. organic product design, form factor, interface elements).

Playful (L1)

The musician and the audience considers the instrument's overall visual character to be **playful.**

Colourful (L1)

The musical instrument (visual design, form, user-interface, visual feedback) features **a wide spectrum of colours** (i.e. chromatically varied, mixed).

Illuminated (L1)

The musical instrument (visual design, form, user-interface, visual feedback) features **illumination** (i.e. lights, electroluminescent paint).

Monochrome (L1)

The musical instrument (visual design, form, user-interface, visual feedback) features **no variation in colour** (i.e. monochrome, flat).

SECTION II: INSTRUMENT SPECIFICATION

Accessibility (L2)

Accessible (L1)

The instrument is easily **accessible** (i.e. available to purchase, download, update).

Direct Input-Output Relation (L2)

Direct Input-Output Relation (L1)

The instrument features **a transparent mapping** (i.e. the musician and the audience can immediately perceive the relationship between input (i.e. performance gestures, user-interface elements) and its resulting sonic outcome (generated sound)).

Flexibility (L2)

Flexible (L1)

The musician can **'bend'** the user interface or the whole of the instrument (in relation to the instrument's physical and technological features, functions, sound generation) in order to better achieve her/his musical goals.

Personalizable/Customizable (L1)

The musician can **personalize** and/or **customize** the user interface or the whole of the instrument (in regards to the instrument's physical and technological features, functions, sound generation) in order to better achieve her/his musical goals.

Expandable (L1)

The musician can **expand** the user interface (i.e. physically, virtually, or through adding modules) or the whole of the instrument (in regards to the instrument's form, dimensions, technological features, functions, sound generation) in order to better achieve her/his musical goals.

Adaptable (L1)

The musician can **adapt** the user interface or the whole of the instrument (in relation to the instrument's physical and technological features, functions, sound generation) to new settings and environments (e.g. different multi-instrument settings, performance environments (e.g. indoors, outdoors) ensembles, performance dynamics of different musical styles and genres) in order to better achieve her/his musical goals.

Compatible (L1)

The instrument is **compatible** with other instruments and devices (e.g. instrument to instrument, cross-platform, wireless/wired communication protocols, physical adapters).

Modifiable (L1)

The musician can **modify** the user interface or the whole of the instrument (in regards to the instrument's physical and technological features, functions, sound generation) in order to better achieve her/his musical goals.

Re-Configurable (L1)

The musician can **re-configure** the user interface (in regards to mapping, functions, features and sound generation) in order to better achieve her/his musical goals.

Assignable (L1)

The musician can **assign** new functions and/or features on the user interface in order to better achieve her/his musical goals.

Materials (L2)

Appropriate Materials (L1)

The instrument's construction and components are made out of materials, which are **appropriate** for their dedicated functions.

Natural Materials (L1)

The instrument's construction and components are made out of **natural** materials (e.g. woods, metals, glass).

Product Architecture (L2)

Compact (L1)

The instrument features a **compact** design.

Uni-Body (L1)

The instrument features a **uni-body** (i.e. single-piece construction) design.

Modular (L1)

The instrument features a **modular** (i.e. multiple pieces or components) design.

Standalone Instrument (L1)

The instrument features an **inbuilt** (i.e. embodied) user-interface, sound generator and power supply.

Wireless (L1)

The instrument runs on **wireless** communication (e.g. Wi-Fi, Bluetooth).

Powered Through Computer (L1)

The instrument can be powered through a computer (PC or Macintosh)

Dedicated Platform/Hardware (L1)

The instrument has its own **dedicated hardware** and **platform.**

Pre-configured (L1)

The instrument is pre-configured (i.e. plug & play, ready to perform)

Real-Time Sound Generation (L2)

Real Time Sound Generation (L1)

The musician can generate and modify sounds in **real-time** (i.e. instantaneous, as opposed to triggering pre-recorded sounds).

Set-Up (L2)

Portable (L1)

The instrument is **portable** (i.e. mobile, transportable).

Easy/Quick Set-Up (L1)

The instrument can be set-up **easily** and **quickly** (for personal practise, rehearsals and live musical performances).

Hidden Wires (L1)

The musician (or technician) can **hide** the wires/cables of the instrument on the stage.

Maintenance-Free (L1)

The instrument is **maintenance-free** (i.e. the instrument does not require periodic maintenance).

Visible Set-Up (L1)

The instrument, its user-interface, feedback and interactions are **visible** to the performer (or the technician) (i.e. in different environments and light conditions).

Reliability (L2)

Reliable (L1)

The musician can **rely on** (i.e. depend on) the instrument to function properly during a performance (including rehearsals and Set-Up).

Durable (L1)

The instrument’s design, construction, materials and technology are **durable** (i.e. appropriate for long-term use).

Safe (L1)

The musician considers the instrument's design, construction, materials and technology **safe** to use (i.e. preventing injuries or any other danger (e.g. electric shortcuts etc.) while in use).

Enduring (L1)

The musician considers the instrument to be enduring (i.e. long lasting, not ephemeral).

Versatility (L2)

Versatile (L1)

The instrument is **versatile** (i.e. instrument's ability to quickly switch between/adjust to different musical tasks and performance settings, its capability to be used for many different purposes in musical context).

Multifunctional (L1)

The instrument features **multiple** functions (e.g. sound synthesis, sound sampling, sequencing, live/signal processing, recording).

Versatile Sound Generation (L1)

The sounds generated by the instrument have a **versatile** character (i.e. analogue, timbral versatility, polyphony, high-quality sound samples)

Continuous Pitch Space (L1)

The instrument features a **continuous** (i.e. fretless, uninterrupted (e.g. violin, violoncello as opposed to piano).

Supports Virtuosity (L1)

The instrument features a high ceiling of virtuosity (i.e. is capable of supporting all artistic and technical demands of a virtuoso*; it is possible to further improve/progress through practise)

* For the purposes of this thesis, a virtuoso is defined as: A musician who has transcended all technical and artistic boundaries of a musical instrument, in other words someone who is completely fluent in the 'language' of a musical instrument

Supports Collaborative Interactivity (L1)

The instrument and user-interface is technically capable of supporting a **multi-musician** (i.e. collaborative, collective) performance.

Controller (L1)

The instrument can be used as a **controller only** (i.e. decoupled, e.g. through MIDI or OSC)

Visual Interactivity (L2)

Visual Feedback/Feed Forward (L1)

The instrument (or the user interface) features **visual feedback** and/or **feed forward** during the interaction (including set-up, configuration, and performable musical actions).

Visual Guidance (L1)

The instrument can **visually guide** the musician (i.e. with graphic signifiers, reference/origin points, icons, text, geometric objects) during the interaction (including set-up, configuration, and performable musical actions).

Colour Coded (L1)

The instrument's (or the user interface's) functions, features and components are **colour coded** (i.e. meaningful and functional use of colour).

Light Feedback (L1)

The instrument (or the user interface) features **light feedback** (i.e. illumination; static or blinking lights) during the interaction.

Sound Visualization (L1)

The instrument can **visualize** the generated sound (i.e. enhance the overall experience by supporting the music through visualization of the sound).

Virtual Instrument (L2)

Software Instrument (L1)

The instrument is a **software** (e.g. software synthesiser (softsynth) or a similar musical software that runs on computers, smart mobile devices, musical plug-in or musical app).

SECTION III: AUDIENCE PX

Audience Experience (L2)

<u>Comprehensible for Audience (L1)</u>

The musician's interaction with the instrument is **comprehensible** to the audience (e.g. relationship between the physical gestures and the generated sound, what the musician does with the instrument, the sonic experience).

<u>Interactive with Audience (L1)</u>

The musician's interaction with the instrument enables her/him to interact with the audience (i.e. co-creation, participation, communication through gestures, social interaction)

<u>Engaging for Audience (L1)</u>

The overall live musical performance (i.e. the musician's interaction with the instrument, visual experience, sonic experience) is **engaging** (i.e. immersive, capturing) for the audience.

<u>Visible to Audience (L1)</u>

The musician's interaction with the instrument –including the instrument itself- is **visible** to the audience (i.e. either through placement of the instrument on stage or by the help of a projector (e.g. interaction being projected on a larger screen)).

<u>Visual Feedback for Audience (L1)</u>

The instrument can generate **visual feedback** for audience (directly or through a projector).

<u>Sound Visualization for Audience (L1)</u>

The instrument can generate visualizations to accompany the sound for audience (not in the context of feedback or feed-forward but to enhance the audience's overall experience in the form of an audiovisual display).

APPENDIX F

PARTICIPANT FREQUENCY DISTRIBUTION BASED ON THE FRAMEWORK FOR MUSICAL INTERACTION

Table F.1 Participant Frequency Distribution

DESIGN QUALITY	PARTICIPANT (P)
MUSICIAN'S INTERACTION EXPERIENCE	
Anthropometry (4)	P05, P11, P12, P24
Appeal (23)	P02, P03, P04, P07, P09, P10, P11, P13, P14, P15, P16, P17, P18, P19, P20, P22, P23, P24, P25, P26, P28, P29, P30
Collaborative Interactivity (20)	P01, P02, P03, P04, P06, P08, P09, P10, P11, P12, P13, P14, P16, P17, P19, P22, P24, P28, P29, P30
Comprehensibility (29)	P01, P02, P03, P04, P05, P06, P07, P08, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30
Controllability (29)	P01, P02, P03, P04, P05, P06, P07, P09, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30
Creativity (23)	P01, P03, P04, P05, P08, P09, P10, P11, P12, P13, P14, P15, P17, P19, P20, P21, P22, P23, P24, P25, P26, P28, P29
Ease of Use (28)	P01, P02, P03, P04, P05, P06, P09, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30
Efficiency (29)	P01, P02, P03, P05, P06, P07, P08, P09, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30
Engagement (28)	P01, P02, P03, P04, P05, P07, P08, P09, P10, P11, P12, P13, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30
Expressiveness (26)	P01, P02, P03, P04, P05, P06, P08, P10, P11, P12, P13, P14, P15, P16, P17, P19, P20, P21, P22, P23, P24, P25, P26, P28, P29, P30
Familiarity (21)	P01, P03, P08, P09, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P21, P23, P24, P25, P28, P29, P30
Novelty (17)	P03, P05, P08, P09, P10, P11, P13, P15, P17, P18, P19, P22, P23, P25, P26, P27, P28
Performable Actions (18)	P04, P06, P07, P08, P09, P10, P11, P13, P14, P15, P20, P21, P24, P25, P26, P28, P29, P30
Pleasure in Use (23)	P02, P03, P05, P06, P07, P09, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P22, P23, P25, P26, P27, P28, P29

Repeatability (16)	P03, P06, P07, P09, P10, P12, P16, P17, P18, P19, P20, P23, P24, P25, P27, P30
Simplicity (22)	P01, P02, P03, P04, P05, P06, P07, P08, P10, P11, P12, P13, P14, P15, P16, P17, P18, P20, P21, P22, P26, P29
Tactile/Haptic Interactivity (23)	P01, P02, P03, P04, P05, P10, P11, P12, P13, P15, P16, P17, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29
Usefulness (30)	P01, P02, P03, P04, P05, P06, P07, P08, P09, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30
Visual Connotations (24)	P02, P03, P04, P05, P06, P07, P10, P11, P12, P14, P15, P16, P17, P18, P19, P20, P22, P23, P24, P25, P26, P28, P29, P30
INSTRUMENT SPECIFICATION	
Accessibility	P01, P04, P08, P18, P23
Direct Input-Output Relation (13)	P02, P08, P10, P13, P14, P15, P17, P18, P20, P21, P23, P24, P29
Flexibility (27)	P01, P02, P03, P04, P05, P06, P07, P08, P09, P10, P11, P12, P13, P14, P15, P16, P17, P18, P20, P21, P22, P23, P24, P25, P26, P29, P30
Materials (8)	P07, P12, P15, P18, P22, P23, P24, P26
Product Architecture (25)	P01, P02, P03, P04, P05, P06, P07, P10, P11, P13, P14, P15, P16, P17, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30
Real-Time Sound Generation (17)	P01, P03, P05, P08, P09, P10, P12, P13, P16, P19, P20, P22, P23, P24, P28, P29, P30
Reliability (20)	P01, P02, P05, P06, P07, P10, P11, P12, P14, P17, P18, P20, P21, P22, P23, P24, P25, P26, P27, P29
Set-Up (28)	P01, P02, P03, P05, P06, P07, P08, P09, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P30
Versatility (30)	P01, P02, P03, P04, P05, P06, P07, P08, P09, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30
Virtual Instrument (8)	P01, P07, P08, P17, P18, P21, P22, P23
Visual Interactivity (28)	P02, P03, P04, P05, P06, P07, P09, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30
AUDIENCE EXPERIENCE	
Audience Experience (17)	P05, P06, P07, P10, P11, P12, P13, P15, P19, P21, P22, P24, P25, P26, P27, P28, P29

CURRICULUM VITAE

PERSONAL INFORMATION

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EDUCATION

Degree	Institution	Year of Graduation
MM	ITU MIAM Centre for Advanced Studies in Music, Sound Engineering and Design	2006
MSc	ITU, Industrial Design	2006
BSc	ITU, Industrial Design	2000

WORK EXPERIENCE

Year	Place	Enrolment
2017 - Present	Işık University, Dept. of Industrial Design	Full Time Instructor
2015 October	University of Liverpool, Dept. of Industrial Design	Full Time Lecturer
2012 October	Işık University, Dept. of Industrial Design	Full Time Instructor

LANGUAGES

Turkish (native), English (Advanced).

INTERESTS

Piano, electro-acoustic composition, sound design, reading (fiction, sci-fi and fantasy literature), designer toys, aikido, wing chun, basketball.