DEPARTMENT OF
COMPUTER SCIENCE

INTERACTIVE SOUND IN PERFORMANCE ECOLOGIES: STUDYING CONNECTIONS AMONG ACTORS AND ARTIFACTS

RAUL GIANCARLO MARIA MASU

Master of Music
Diploma in Harmony, Counterpoint, Fugue and Composition
(Master Level Equivalent)

DIGITAL MEDIA

NOVA University Lisbon
June, 2022

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Acknowledgements

First of all I want to thank my partner Mela Bettega, who played a central role in my development as a person and as an academic over the past years.

A special thanks has to go to Nuno N. Correia who has been more than a supervisor over the past years, he has really been a guide during this path. I am also grateful to Teresa Romão, for her precise and accurate feedback.

I wish to thank my coauthors as I learned a lot by collaborating with each of them: Paulo Bala, Ardan dal Rí, Stephan Jurgens, Jochen Feitsch, Nuno Nuñes, Valentina Nisi, Ivana Druzetic, William Primett, Maurizio Teli, Nicolas Gold, Cecile Chevalier, Adam Pultz Melbye, Johnny Sullivan, and Alexander Refsum Jensenius. A special mention goes to Fabio Morreale who has been a research companion and a friend since before I started the PhD.

I would also like to acknowledge the members of the members of the Cat committee for the useful suggestions that helped me to fine-tune the direction of this work: Thor Magnusson, Gilberto Bernardes, and Nuno Correia.

A note of acknowledgment goes to all the artists who were involved in the work presented in this thesis: Hannah Pajala-Assefa, Francesca Zanghellini, Margherita Berlana, the students by the Conservatory of Madeira, Madli Paves and Christin Taul. I am really grateful for their participation in this research. I also acknowledge the Moving Digits project (597398-CREA-1-2018-1-PT-CULT-COOP1) team for the collaboration in the the research on dance ecologies.

I want to thank my mum, my dad, my grandmother and my cousin. A big thanks goes to my friends, in particular Valentina Massetti and Riccardo Terrin, they know why. A special thank goes also to my former mentors Antonella de Angeli and Mauro Graziani.

A special thanks to Lorenzo Angeli and the CRIT Lab at DISI, University of Trento for hosting the Overleaf instance that I used to write this thesis.

Finally, I wish to acknowledge ARDITI - Agencia Regional para o Desen-volvimento e Tecnologia for funding this research under the scope of the Project M1420-09-5369-FSE-000002 - PhD Studentship. I would also like to acknowledge the author of this template (and the manual [185]).

Abstract

This thesis's primary goal is to investigate performance ecologies, that is the compound of humans, artifacts and environmental elements that contribute to the result of a performance. In particular, this thesis focuses on designing new interactive technologies for sound and music. The goal of this thesis leads to the following Research Questions (RQs):

- RQ1 How can the design of interactive sonic artifacts support a joint expression across different actors (composers, choreographers, and performers, musicians, and dancers) in a given performance ecology?
- RQ2 How does each different actor influence the design of different artifacts, and what impact does this have on the overall artwork?
- RQ3 How do the different actors in the same ecology interact, and appropriate an interactive artifact?

To reply to these questions, a new framework named ARCAA has been created. In this framework, all the Actors of a given ecology are connected to all the Artifacts throughout three layers: Role, Context and Activity. This framework is then applied to one systematic literature review, two case studies on music performance and one case study in dance performance. The studies help to better understand the shaded roles of composers, performers, instrumentalists, dancers, and choreographers, which is relevant to better design interactive technologies for performances. Finally, this thesis proposes a new reflection on the blurred distinction between composing and designing a new instrument in a context that involves a multitude of actors.

Overall, this work introduces the following contributions to the field of interaction design applied to music technology: 1) ARCAA, a framework to analyse the set of interconnected relationship in interactive (music) performances, validated through 2 music studies, 1 dance study and 1 systematic literature analysis; 2) Recommendations for designing music interactive system for performance (music or dance), accounting for the needs of the various actors and for the overlapping on music composition and design of interactive technology; 3) A taxonomy of how scores have shaped performance ecologies in

NIME, based on a systematic analysis of the literature on score in the NIME proceedings; 4) Proposal of a methodological approach combining autobiographical and idiographical design approaches in interactive performances.

Keywords: Performance Ecology, NIME, Sonic Interaction Design, Interactive Dance, Affordances, Artifact Ecology, Design Methods, Human Computer Interaction

Resumo

O objetivo principal desta tese é investigar as ecologias performativas, conjunto formado pelos participantes humanos, artefatos e elementos ambientais que contribuem para o resultado de uma performance. Em particular, esta tese foca-se na conceção de novas tecnologias interativas para som e música. O objetivo desta tese originou as seguintes questões de investigação (Research Questions RQs):

- RQ1 Como o design de artefatos sonoros interativos pode apoiar a expressão conjunta entre diferentes atores (compositores, coreógrafos e performers, músicos e dançarinos) numa determinada ecologia performativa?
- RQ2 Como cada ator influencia o design de diferentes artefatos e que impacto isso tem no trabalho artístico global?
- RQ3 Como os diferentes atores de uma mesma ecologia interagem e se apropriam de um artefato interativo?

Para responder a essas perguntas, foi criado uma nova *framework* chamada ARCAA. Nesta framework, todos os atores (Actores) de uma dada ecologia estão conectados a todos os artefatos (Artefacts) através de três camadas: Role, Context e Activity. Esta framework foi então aplicada a uma revisão sistemática da literatura, a dois estudos de caso sobre performance musical e a um estudo de caso em performance de dança. Estes estudos ajudaram a comprender melhor os papéis desempenhados pelos compositores, intérpretes, instrumentistas, dançarinos e coreógrafos, o que é relevante para melhor projetar as tecnologias interativas para performances. Por fim, esta tese propõe uma nova reflexão sobre a distinção entre compor e projetar um novo instrumento num contexto que envolve uma multiplicidade de atores.

Este trabalho apresenta as seguintes contribuições principais para o campo do design de interação aplicado à tecnologia musical: 1) ARCAA, uma *framework* para analisar o conjunto de relações interconectadas em performances interativas, validado através de dois estudos de caso relacionados com a música, um estudo de caso relacionado com a dança e uma análise sistemática da literatura; 2) Recomendações para o design de sistemas interativos musicais para performance (música ou dança), tendo em conta as necessidades dos vários atores e a sobreposição entre a composição musical e o design de tecnologia interactiva; 3) Uma taxonomia sobre como as partituras musicais moldaram as ecologias performativas no NIME, com base numa análise sistemática da literatura dos artigos apresentados e publicados nestas conferência; 4) Proposta de uma abordagem metodológica combinando abordagens de design autobiográfico e idiográfico em performances interativas.

Palavras-chave: Performance Ecology, NIME, Sonic Interaction Design, Interactive Dance, Affordances, Artifact Ecology, Design Methods, Human Computer Interaction

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1

Introduction

Since the early stages of electronic music, the act of composing a new musical piece and the act of developing new technology have often overlapped. Early notable examples span from Stockhausen, who developed a rotating speaker table to create a spinning effect using multiple tape recorders [133], to the Sonic Art Union, an American collective of composers/designers who created their own instruments [188].

In the digital domain, this tendency consolidated with the spread of interactive technology, as discussed for instance in [85, 293, 200] (more details in subsection 2.2.2). For instance, in a large part of the music performances presented at the New Interfaces for Musical Expression (NIME) conference, the creator of the instrumental/piece is also the main user/performer [236]. NIME is one of the main venues in interactive music technology, and is situated in the intersection of the fields of Human-Computer Interaction (HCI) and music computing. The term NIME has entered the academic jargon also as a field of study.

Still, there are contexts where the users and the creator are not the same person, or contexts in which the technology impacts a complex ecology that is composed of several people. Indeed, the idea of an ecology of musical creation has emerged to account for the complex interrelations of both human and non-human agents. Various authors have discussed these performance ecologies or ecosystems (e.g. [314]). Further detail on the discourse on performance ecology can be found in subsection 2.2.2). Overall the importance of accounting ecologies in performances that involve digital technology has been discussed by various authors (e.g. Waters [314], Keller [163], Gurevich, Michael and Treviño [122]). Performance ecologies are relevant also in the case of interactive dance as these scenarios are usually composed by many people with different roles such as dancers, choreographers, musicians and technicians (see for instance, [92], more details in section 2.3.5). Although the topic of ecology has already been part of the interactive music debate for some years, there is a lack of formalised models to investigate them.

The goal of this thesis is to investigate music technology design within the scope of performance ecology in a formalised way, by combining concepts and approaches from the fields of Human Computer Interaction (HCI) and New Interfaces for Musical

Expression (NIME), and to propose suggestions for best design practices. ARCAA, a new framework to study performance ecologies is proposed to fulfil this goal (chapter 4). This framework is designed based on existing literature on music technology and by borrowing concepts from third-wave HCI [29, 28], in particular: artifact ecology [157]; appropriation and design-in-use[37]; and ambiguity [109]. In addition, it borrows concepts that have been part of the HCI discourse for a longer time, such as affordance [245] and human actors [11, 162]. More details on the HCI concepts will be presented in section 2.1. In the framework, to better analyse how the act of composing a new musical piece and the act of developing new technology overlap in complex ecologies, the design phases are accounted as part of a given ecology.

The framework is subsequently used in one systematic literature review (chapter 5), two studies on music performance (chapter 6), and one study on sonic interaction design for dance (chapter 7). The framework in itself represents a new tool to study performance ecologies in a systematic manner. Finally, by comparing the various case studies, general design recommendation are proposed in the discussion of this thesis (chapter 8).

1.1 Previous Work and Personal Motivation

This work is deeply grounded on my personal previous experience, which combines a classic western music education and experience in HCI research. During my studies, I got used to playing and studying music that other people compose. In particular, I spent many years of this time as an undergraduate studying historical music where repetition is structural in the creation of the form of a piece, including counterpoint, canon, and fugue. As a composer, I primarily have composed music that involved various people during the performance, also playing different roles (e.g. instrumentalists, conductor, live electronics). As an electronic performer, I curated live electronics for many electroacoustic pieces (that involved acoustic instruments with digital manipulation of the sound), collaborating with instrumentalists and composers. I also performed collective improvisation using digital instruments. In the majority of my musical experience, the final artwork was not the result of the work of one individual, rather it expressed a collective effort.

Before commencing my doctoral studies, I had the opportunity to work as a research assistant in an HCI lab on projects focused on music interaction. In particular, I contributed to the Music Room, an interactive system that allows two partners to create music together [237, 233, 238]. Additionally, within the scope of the italian project Infazia Digit@les, I co-designed a tool to facilitate music education in preschoolers in collective activities [60, 222].

In most of these cases, I could observe various forms of collaboration among the various individuals involved, and the importance of a variety of different tools and instruments in the interaction. This previous experience constituted the basis on which I started my inquiry on ecologies of musical creation for this thesis.

1.2 Research Questions

The goal of this thesis is to investigate music technology design within the scope of performance ecology in a formalised way. In particular, this research focuses on those sonic artifacts whose design embeds the aesthetic of a given artwork, but at the same time are open to interpretation and provide space for improvisation, fostering a level of appropriation from the actual end-user. This angle can be particularly relevant for those contexts where the creator/author and the user/performer are not the same person. This goal can be articulate in the following research questions:

- RQ1: How can the design of interactive sonic artifacts support a joint expression across different actors (composers, choreographers, and performers, musicians, and dancers) in a given performance ecology?

To understand how to design systems, it is first important to understand how people behave in design and use phases. This lead to research questions number 2 and 3:

- RQ2: How does each different actor influence the design of different artifacts, and what impact does this have on the overall artwork?

- RQ3: How do the different actors in the same ecology interact, and appropriate an interactive artifact?

1.3 Main Thesis Contributions

Overall this thesis proposed the following contributions to the field of music technology design.

- ARCAA a framework to analyse the set of interconnected relationships among actors and artifacts in interactive (music) performances;

- Four design recommendations for designing interactive music systems for performance (music or dance) based on the various studies and supported by the ARCAA analysis;

- A taxonomy of score-based performance ecologies in NIME based on a systematic analysis of the literature on score in the NIME proceedings.

- A methodological approach that combines autobiographical and idiographical design for designing interactive systems for performance

Additionally to the four main contributions, this thesis presented the following **practical contributions**: 3 case studies on performance ecologies and Puffin, a new screen score system.

1.4 Publications

The author of this thesis authored a number of scientific papers related to the topic of this manuscript. These papers are listed below, in chronological order from the most recent.

1. Masu, R., Morreale, F. (2021). Composing by Hacking: Technology Appropriation as a Pedagogical Tool for Electronic Music. In Blake Stevens (ed). Teaching Electronic Music, 2021. Modern Musicology in the Classroom Series, edited by James Davis. Routledge, Taylor Francis Group. (pp. 157-171) [216]. This chapter discusses the relations between composing and building new technology from a pedagogical perspective. The chapter comprehend an historical overview of the relation between comping and creating technology which has been used as the basis for the development of section 2.2.2.

2. Masu, R., Correia, N. N., Romao, T. (2021). NIME scores: a systematic review of how scores have shaped performance ecologies in NIME [213]. This paper describes a taxonomy of how scores fostered different performance ecologies that results from a systematic literature review of the NIME proceedings. This study is presented in chapter 5.

3. Masu, R., Correia, N. N., Romão, T. (2021). Technology-mediated musical connections: the ecology of a screen-score performance. In Audio Mostly 2021 (pp. 109-116) [214]. This paper presents Puffin Version 1, a system for real time screen scores, and its adoption in a case study with two instrumentalists. The case study is analysed using ARCAA. The work is described in section 6.2.

4. Masu, R., Correia, N. N., Jurgens, S., Feitsch, J., Romão, T. (2020, September). Designing interactive sonic artefacts for dance performance: an ecological approach. In Proceedings of the 15th International Conference on Audio Mostly (pp. 122-129) [218]. This work presents a case study on a dance performance with one choreographer, two dancers, and one sound designer (the author of this thesis). The ecology corresponding to this performance is analysed using ARCAA. This work is described in section 7.2.

5. Masu, R. , Bala, P., Ahmad, M. A., Correia, N. N., Nisi, V., Nunes, N., Romão, T. (2020). VR open scores: scores as inspiration for VR scenarios. In Proceedings of the International Conference on New Interfaces for Musical Expression, NIME 2020 (pp. 109-114). Birmingham City University [223]. This paper presents a VR system that allows to interactively explore graphic scores. The system is not a direct contribution of this thesis; however, in this paper I developed some reflection on the parallels between Eco's work on Open Work (a term used to describe those musical pieces which have a final form open to interpretation) [87] and ambiguity in HCI, which entered the conception of artifacts proposed in in ARCAA, primarily in chapter 4.

6. Masu, R., Bettega, M., Correia, N. N., Romão, T., Morreale, F. (2019, October). ARCAA: a framework to analyse the artefact ecology in computer music performance. In Proceedings of the 9th International Conference on Digital and Interactive Arts (pp. 1-9) [217]. This paper presenters the first conceptualisation of the ARCAA framework which is initially proposed in chapter 4.

7. Masu, R., Correia, N. N., Jurgens, S., Druzetic, I., Primett, W. (2019, October). How do dancers want to use interactive technology? Appropriation and layers of meaning beyond traditional movement mapping. In Proceedings of the 9th International Conference on Digital and Interactive Arts (pp. 1-9) [220]. This paper presents a focus group study with dance artists that investigate the role of interactive technology in dance performance. Based on the results of the study, guidelines are suggested. This work is described in section 7.1.

8. Masu, R., Correia, N. N. (2018). Penguin: design of a screen score interactive system. Proceedings of Conference ICLI 2018, Porto; 06/2018. [212]. This paper presents an exploitative study on the use of screen score and it starts to look at how the interpersonal relations among the various actors impact the final artifact and the musical outcome. This work is described in section 6.1.

9. Masu, R., Correia, N. N., Morreale, F. (2018). Toward the adoption of design concepts in scoring for Digital Musical Instruments: a case study on affordances and constraints [211]. This paper analyses how concepts of affordances and constraints can be used to reflect on musical scores. This reflection has been integrated in the definition of ARCAA.

During the research period, 19 other papers that are not directly connected to the main research theme have been coauthored by the author of this thesis. The complete list of these papers can be fund in annex I.

1.5 Thesis Structure

The remaining chapters of this thesis are organised as follows.

- Chapter 2 presents a literature review of the main concepts and studies that are relevant for this thesis. This chapter is organised in three main parts. Section 2.1 introduces the main HCI concepts utilised in this thesis. Section 2.2 describes works related to music performance ecologies and the evolution of the relationships among the musicians, their roles, and the instruments with electronic and digital technology. Finally, section 2.3 presents how sonic interaction design has been applied to dance, and how the dance performance constitutes performance ecologies.

- Chapter 3 presents the methodology of this thesis. The works presented in this thesis primarily rely on a research through design approach [329], in particular combining autobiographical design [243] and idiographic design [134] approaches. This chapter also details how the various methodological approaches informed the various works presented in the following chapters.

- Chapter 4 describes ARCAA as a new framework to study performance ecologies by connecting all the Actors to all the Artifacts of a given ecology, using three levels of analysis: Role, Context, and Activities. The framework is based on existing literature from the field of music technology and HCI. This chapter presents the levels of the framework and connects it with exciting models.

- Chapter 5 presents a systematic literature review of the NIME proceedings, focusing on how scores have shaped performance ecologies in works presented at the conference. This analysis has been supported by ARCAA, which has been used to analise the various papers.

- Chapter 6 presents a set of case studies on performance ecologies where screen scores (scores that are displayed in real time on a screen) are used. In this chapter, Puffin, a new screen score system, is presented. The system allows the player to transform actions of one performer into a score by giving instructions to other instrumentalists. The first version of the system has been tested with two instrumentalists, while the second has been tested with four. These case studies have been analysed using ARCAA.

- Chapter 7 focuses on dance performance ecologies, and presents two main studies. The first one is a focus group with 10 dance artists on the role that interactive technology plays in dance performances. The second case study describes an artistic residency with one choreographer and two dancers, during which an interactive sonic system has been developed ad hoc for a performance. This case study has been analysed using ARCAA.

- Chapter 8 presents an overall discussion. In particular, the various levels of the ARCAA framework are analysed in light of the work presented in the previous chapter. Finally, some implications for designing interactive sonic artifacts that support a joint expression across different actors are suggested.

- Chapter 9, finally, summarises the thesis contribution, highlights limitations and point forward future works.

2

Literature review

The theoretical foundation of this thesis builds upon theories and concepts that emerged in the field of Human-Computer Interaction (HCI) during the last few decades, combined with music technology literature and academic text discussing the evolution of musical practices from the post World War II avant-garde to today, in particular, technology-mediated musical practices. This core foundation is then applied to inquire about the design of sound-oriented interactive technology in two main domains: music and dance performances. Therefore, the literature review of this thesis is organised in three main parts, respectively focusing on HCI (Section 2.1), music technology design (Section 2.2), and interactive technology for dance performance (Section 2.3).

In the HCI section, after an initial contextualisation of the phases that characterised the HCI debate, the related theoretical tools and concepts used in this thesis will be analysed and described. The second section of the literature review will focus on music technology literature. As the design of new music technology and the evolution of new musical practices (performative and compositional) are intimately intertwined, these two elements will be analysed in parallel. Particular attention will be paid to how the roles of the musician and the musical artifacts have evolved. Finally, in the third section of this literature review, interactive technology for dance performances will be analysed, particularly focusing on different roles in dance ecologies and systems for embodied interaction with sound. Although this thesis will mainly focus on sound and music-oriented technology for dance, a broader perspective will be swiftly covered in order to provide better contextualisation.

2.1 Theories and Concepts from HCI

In this section, a set of theories, concepts, and approaches that have emerged within the field of HCI will be present. Such a compound acts as a foundation of the inquiry developed in this thesis. Overall, all the concepts presented in this subsection are now commonly used in the field of HCI when it deals with an ecological appreciation of digital artifacts[1] and how different actors can relate to the same artifact in different manners. As HCI is itself a multifaceted area of knowledge that was born and continues to develop and thrive by constantly overlapping different disciplines, HCI concepts, terminologies and debates presented in this section often refer to theories from other fields. While discussing the various HCI concepts, some space is dedicated to highlighting these connections.

2.1.1 Setting the Tone: Waves, Paradigms, and Cycles in the Evolution of HCI

In the last decades, computing started spreading "into physical reality" [82], as pointed out for instance by Dourish, and into everyday life, including artistic and cultural aspects, as discussed by Bødker [28]. Therefore, as computing was entering multiple aspects of human life, the field of HCI has widely enlarged. Its methodology, objectives, and focus have expanded to the point that "HCI is now effectively a boundless domain" [14, p. 221].

Many scholars have proposed different models to analyse the evolution of the field of HCI. Already in early 1990, Grudin has observed a substantial evolution within the field and proposed different levels of interface focus [117]. By considering the period that ranges from the fifties to the early nineties, the author identified five different levels of interface design, targeting different types of "principal users". In the first two levels (early development of the field), the users are identified with the specific category of programmers of engineers, while from the third level, users are generally "end-users", and in the fifth level, "groups of end-users". It is interesting to see how, already in the nineties, the tendency toward a social and collective usage of computing systems started to emerge. This change marked the beginning of new reflections about different HCI stages. Indeed, in recent years, various models to analyse the evolution of the HCI field have been proposed; in particular, Bødker spoke about HCI Waves [29, 28], Harrison and colleagues introduced the idea of HCI Paradigms [127], and Rogers used art history periods as metaphors to discuss the evolution of HCI phases [271].

The three waves of HCI, conceptualised by Bødker [29, 28] can be summarised as follows. The first wave primarily focused on individual users. In the scope of this individual interaction, primary attention was paid to test and model the individual's perceptions, cognition and behaviours. The focus of the second wave (that has also been called Post-cognitivist HCI [162]) spanned from studying individual interactions to analysing social behaviours and multiple interactions within workplaces. Consequently, work settings, context, and situational analysis started to be accounted for in the debate of interactive technology. In such a context, it has been argued to move from the idea of human factors in computing to a more three-dimensional conception of users as human actors [11]. The third wave, finally, has further burgeoned this scope, as "Technology spreads from the workplace to our homes and everyday lives and culture."[29]. In this context, an individual piece of technology can assume a variety of different meanings, and ambiguity can

[1]Despite the spelling "artefact"is more common in standard British, in this thesis this lemma will be spelled with the 'i', as this is the standard spelling in HCI literature related to artifact ecologies

be a resource [109]. Additionally, within the frame third wave HCI inquiry, interactive digital artifacts started to be used in combination, leading toward the conceptualisation of ecologies of artifacts [30].

Harrison and colleagues proposed that “the commonly acknowledged waves of influence into HCI can be usefully seen in terms of paradigm shifts” [127, p. 2]. By building upon the theory of paradigms by Kuhn [169], the authors, indeed, proposed three main paradigms to scrutinise the evolution of HCI. The first paradigm “saw interaction as a form of man-machine coupling” [127, p. 3], aiming at optimising the fit between humans and machines, with the objective to solve concrete problems that occur during the interaction and avoid disruption. The second paradigm takes form around the view of “mind and computer as coupled information processors” [127, p. 3]. In this second paradigm, the central focus is on the information processing model between computers and users. Finally, the authors suggested that the third paradigm comprises several different perspectives sharing the idea of “interaction as phenomenologically situated”[127, p. 8], as a common metaphor. The aim of the third paradigm is to support situated actions, where the meaning is bound to a specific context of use.

Finally, by building upon the frameworks mentioned above by Grudin [117], Bødker [29], and Harrison et al. [127], Rogers proposed to read the evolution of the field of HCI using different periods of art history as metaphorical lenses to analyse the spirit or mood of the three eras of HCI [271]. The “Classical HCI period” adopted a cognitive approach rigorously; the “Modernist HCI period” explored a broader palette of approaches and theories, including sociology and ethnography; and “the Contemporary period” became more value-oriented [271, p. 7].

An important conception of HCI that emerged in the last decade is also the idea of Humanistic HCI, as a research and practice that looks at HCI topics supported by humanistic theories, methods, and practices [13]. In this view, humanistic and philosophical theories need to play a central role in producing new knowledge on interactive technology.

The different frameworks classifying the evolution of HCI have been used to reflect on music technology. For instance, in a recent essay, Tanaka traces the evolution of computer music using the lenses of the three waves of HCI [291]. According to the author’s proposition, we can identify similarities between the practice of the first pioneers of electronic music and the third wave HCI. Indeed, the early electronic music pioneers (such as Risset, Mathews, and Chowning [2]) relied on formal mathematical methods to compute analysis or synthesis of sounds, we can observe that their practice is consistent with the engineering approach that characterised the early stage of HCI. Tanaka afterwards highlights parallels between the development of real-time signal processing (that allowed the rise of new interfaces for musical performance) and the second wave HCI, as much of this work was developed for performance settings. Despite appearing unorthodox as a

[2] A complete account of the early steps in computer music practice is beyond the scope of this thesis. An introductory description of the period can be found in the third part of the book "Electronic and Experimental Music"by Holmes [132]

workplace, such contexts "ultimately adhere to traditional performance, and therefore "workplace"contexts"[291, p. 142]. Indeed, from a performer perspective, a performance context is a workplace. Although music performances, or digital performances in general, following the proposal by Tanka, by being workplaces, fit the definition of second wave HCI, it is also true that interactive performance falls in a category that shares commonality with the creative use of technology that characterises the third wave HCI. For instance, the concepts of task, usability, and achieved objective are quite shaded in music performance [270], and some recent discussions on music technology borrow concepts from the third wave HCI (an example being the work by Zappi and McPherson [326]). While discussing the transition from the second to the third wave, Bødker has argued in favour of a practice that connects the two approaches.

> “I suggested that in bridging between the second and third waves, there was a need to strike the balance differently between individual experience (third wave), on the one hand, and sharing, learning from each other within communities of practice, and participation in shared development and appropriation of technology (second wave)” [28].

The work presented in this thesis will follow such an approach borrowing conceptual tools from the second and the third wave HCI. In the rest of the section of this literature review dedicated to Human-Computer Interaction literature, these concepts will be examined.

2.1.2 Human Actors in a Complex Network of Interactions

In their textbook on interaction design, in the chapter on "Understanding Users", Preece and colleagues focused on the cognitive aspects of human perception, attention, learning memory and so forth [259]. This cognitive approach has proved to be of value in the design of one-to-one task-based interactions. However, this perspective might not be the most appropriate to consider the complex set of interrelations and motivations that occur in complex scenarios where multiple people interact with multiple objects (as discussed for instance in [11, 162]). Additionally, the term "user"embeds some early HCI approaches, such as the idea of tasks and, therefore, correct use. For this reason, the term "user"has been recently criticised in the contest of musical interaction by Rodger et al. The authors claim that as there is no correct "use"of a musical instrument: "there may be no such person that can be picked out as the instruments’ ’prototypical user’"[270, p. 406].

It can be acknowledged that the term user has also been used to study technology in complex scenarios, where people appropriate technology in unexpected ways (e.g. [77, 80]). However, in this thesis, the term actor will be used. The lemma ‘human actor’ was introduced by Bannon to HCI discourse [11]. The author argued in favour of considering the “set of skills and shared practices based on work experience with others” [11, p. 1], and poses the attention to understanding the relationships between humans, computers and environments. The term actor underlines that people are not merely users of a system but complex human beings with sets of values and backgrounds that influence their relationships with the technology. Bannon proposed the term actor to overcome a problem he identified with the current understanding about "users"of computers. The author claimed that the problem is in the implicit view that "treat people as, at worst, idiots who must be shielded from the machine, or at best, as simply sets of elementary processes or "factors"that can be studied in isolation in the laboratory."[11, p. 1] .

The perspective of considering humans as complex human actors operating in a socio-cultural context “was strengthened in HCI through the influence of what became known as the Scandinavian participative design” [10, p. 52]. Early achievement of such an approach can be found in [26]. As pointed out by Bannon [10], further development to such a holistic perspective arised with the emergence of the area of Computer Supported Cooperative Work (CSCW). The emergence of this area of inquiry introduced, within the debate on interactive technology, a move from “a psychological to a sociological perspective on human work and activity, emphasizing field observation methods rather than lab studies” [10, p. 52]. Such a tendency made way for considering technology as experience [224] [3], and to the idea of embodied interaction, intended as “interaction with computer systems that occupy our world, a world of physical and social reality, and that exploit this fact in how they interact with us” [81, p. 3].

To underline the emergence of these new perspectives that consider a person not as merely a user of a system but as an actor operating in a world of physical and social realities, the idea of human-centered computing (or design or systems) has emerged. “The terms ‘human-centered computing’ and ‘human-centered design’ have been touted as possible replacements for HCI, a term many see as beyond its sell-by date” [10, p. 52].

2.1.3 Affordances and Constraints

Affordance is a central concept that has characterised the HCI debate across different phases. Reflections about constraints often accompany the concept of affordance. As we will see in this section, affordances intrinsically lead toward considering the reciprocal and mutual relation between agents and the environment in which they operate. The concept of affordance was introduced to the field of Interaction Design by Don Norman [245], who borrowed the concept from American psychologist James Gibson [112].

2.1.3.1 The Theory of Affordance

Gibson introduced the concept of affordances in 1979 in his book “Ecological Approach to Visual Perception” [112]. In this original proposal, an affordance is a relational property that exists between the environment and an agent (either human or animal), consisting of the pairing between the intrinsic properties of an environmental element and the actions

[3]The idea of technology as experience also builds upon the importance of experience in pragmatism see. Dewey’s works on experience [71, 72]

that an agent could potentially perform with it. In detail, the author proposed the idea of environmental affordance is "what it offers the animal, what it provides or furnishes, either for good or ill." [112, p. 127].

Affordances are relational in nature. The relational perspective is intrinsic in the Gibsonean conception of affordances; as Heft pointed out: "properties that exist only when one simultaneously considers two (or more) entities" [128, p. 4]. Discussing this perspective, Heft observed how it resonates with Dewey and Bentely idea of 'transaction' (the process of knowing as an act that accounts for the full situation of organism(s)-environment relationships, not as a mere interaction between entities) [90]. Indeed, while discussing "transactions", Dewey and Bentely have pointed out that "no one [constituent of an inquiry] can be adequately specified as fact apart from the specification of other constituents of the full subject matter" [73, p. 137]. Based on this, Heft worked further on affordances and proposed that affordances have three properties:

> "Affordances are (1) continuous rather than disjointed or segmented; (2) reciprocal - in as much as typically affordances offer particular possibilities for action, and perceptual functioning, by virtue of its intentional character, realises one (or more) of these possibilities; and (3) cumulative - in that person-environment interactions at one point in time provide an historical basis for subsequent perceptual development and environmental discovery." [128, p. 10].

Many authors have subsequently reflected on affordances in relation to the social structures that characterise humans. An important example is offered in the aforementioned work by Heft, who proposed "to consider the applicability of the affordance concept to features of the human world whose meanings are sociocultural in origin." [128, p. 1]. The author speculates that we learn affordances in a social context: affordances are revealed, either directly or indirectly, by other members of our social context. Heft further suggests that "the individual learns particular situated, intentional acts in social contexts" [128, p. 18].

Another reflection on affordances from a social perspective is offered by Costall, who overall agrees with Heft and argued that affordances should be accounted for as a social element [64]. An affordance in his view is an element that can be learned within a given culture. The author started by observing that we are surrounded by multiple artifacts: "the first point is that we are surrounded by artifacts [...] they invite and constrain us to use them in a certain way, even if this use does not correspond to their intended function" [64, p. 471] . Costall then continued by underlying how we relate with such a multitude of artifacts within the boundaries of a community: "We experience objects in relation to the community within which they have meaning." [64, p. 472]. In this context, Costall argues that we can learn from other people by being instructed, but we can also learn things through people without the need to be instructed. The author does not aim to claim that all affordances are social, rather including social consideration in the way we learn and experience affordances.

Vera and Simon, on the contrary, proposed a view of affordances as merely subjective: "an affordance is a symbol stored in the central memory denoting the encoding in functional terms of a complex visual display"[309, p. 20]. However, more recently, other authors reinforced the intrinsic relational nature of affordances. For instance, Stoffregen argued that affordances are "properties of the animal–environment system, that is, that they are emergent properties that do not inhere in either the environment or the animal"[286, p. 115]. In a recent reflection on the interconnection between affordances and agency, Withagen et al. proposed that affordances are not “mere action possibilities but that they can also invite behavior”, by building upon a relational conception of affordances [319, p. 250].

2.1.3.2 Affordances in HCI

The concept of affordance was introduced to the field of design first and HCI later by Don Norman. By building upon the proposal of affordance by Gibson, Norman narrowed the concept to perceived affordances that are properties of a given object that a person perceived [246]. Applying the idea of affordance to computer technology, the author proposed: “The computer, with its keyboard, display screen, pointing device, and selection buttons (e.g. mouse buttons) affords pointing, touching, looking, and clicking on every pixel of the screen.” [245, p. 39]. Norman’s vision established itself as a standard and has been highly influential in HCI, to the point that affordance is usually part of the reasoning toolkit of most contemporary HCI scholars and practitioners. A consequence of the diffusion of this concept is that many different perspectives about what affordances are have emerged also within the HCI debate.

An important perspective on affordances that became quite relevant in the HCI debate was introduced by Gaver [108]. The author proposed a broad view over affordances compared to Norman, which, to a certain extent, mirrors the initial Gibsonian conception of affordance. The author classified the affordances in a two-dimensional diagram encompassing the existence of the affordance as one dimension and the perception of the affordance as the other (table 2.1). In this model, we can find perceptible affordances, if the affordance exists and is perceived; hidden affordance, if the affordance exists but is not perceived or exposed by design; and false affordances, if the agent believes perceived an affordance that actually does not exist.

Bærentsen and Trettvik [7] reflected on affordance in combination with activity theory, particularly referring to the work by Leontyev [178]. In the view of activity theory, the fundamental object of psychology is the activity of an individual in the world. Such activities are composed of actions that can be separated into operations. Bærentsen and Trettvik argued that HCI needs a type of psychology that understands human actions and motivation in a manner that is “inherently integrated in and adapted to the environment”

Table 2.1: Two-dimensional diagram considering the existence of the affordance as one dimension and the perception of the affordance as the other as in [108].

		affordance	
		no	yes
Perceptual information	yes	false affordances	perceptible affordances
	no	correct rejection	hidden affordance

[7, p. 59]. To this end, the author underlined how affordances are not properties of an object in isolation, rather relational properties and should be studied as such. Vyas and colleagues proposed an "interaction-centered" perspective of affordances [311]. The authors proposed a distinction between two main broad classes of affordances: affordance in information and affordance in articulation. Affordance in information refers to how technology is understood on the basis of semantic and syntactic interpretation; affordance in articulation refers to the interpretations related to the use of a piece of technology. Kaptelinin and Nardi compared several existing visions of affordances presented in HCI, and outlined a proposal of technology affordances as relational property of a three-way interaction among the person, mediational means, and the environment [161].

In the edge between affording possibility and limitations, an affordance can also assume a normative value: when it makes certain types of behaviour more or less performable, defining a limited set of possibilities of actions that suggest what users can or cannot do [282].

The concept is overall still very present and used in the current HCI debate (for instance, Petersen er al. based on affordances their inquiry on Shape-Changing Interfaces [255], and recently Morrelale and Eriksson used the concept of normative affordances in their critical analysis of the Spotify platform [232]). In 2020, Hunag and colleagues performed a scientometrics analysis of affordance research in the field of interaction design (using the ISI Web of Science Core Collection) [143]. Their results show that, in the considered dataset, the number of papers in the field on interaction design focusing on affordances is growing.

Affordance as relational property between artifacts and actors operating in an environment is a crucial concept in this thesis that tackles sonic interaction design from an ecological perspective. In particular, it is relevant as different actors can perceive different affordances in relation to the same object, therefore performing different actions.

2.1.3.3 Constraints

As we have seen, the concept of affordances has been introduced to the field of interaction design by Norman (initially in The Psychology of Everyday Things, [246], but also with successive articles, e.g. [244, 245]. Along with bringing the concept of affordances to the attention of HCI scholars, Norman has the merit to have introduced a reflection about constraints to the interaction design community. Affordances and constraints have often been used in pairs, especially within the music technology debate. Constraints can be defined as action/interaction boundaries or physical limitations. In particular, Norman discriminates between physical, logical, and cultural constraints [245]:

- Physical constraints are the actual physical limits that an object has; such a typology of constraints is the one that is more closely related to the affordance of the object. “Locking the mouse button when clicking is not desired would be a physical constraint” [245, p. 40];
- Logical constraints involve the use of reasoning to determine the alternatives; this typology of constraint is helpful in guiding behaviour. “If we ask the user to click on five locations and only four are immediately visible, the person knows, logically, that there is one location off the screen.” [245, p. 40];
- Cultural constraints are conventions shared among the members of a cultural group. “The fact that the graphic on the right-hand side of a display is a “scroll bar” and that one should move the cursor to it, [...] is a cultural, learned convention. ” [245, p. 40];

Constraints can also have a positive impact on human creativity; as advocated by Margaret A. Boden: “People often claim that talk of ’rules’ and ’constraints’...must be irrelevant to creativity, which is an expression of human freedom. But far from being the antithesis of creativity, constraints on thinking are what make it possible [...] Constraints map out a territory of structural possibilities which can then be explored, and perhaps transformed to give another one” [27, p. 95].

2.1.4 Ambiguity and Appropriation in Interaction Design

In the reflection on affordances by Gaver [108] described above, we can find one dimension that describes those affordances that are discovered during the use of a system but not intended by design. Gaver defined this particular category as ‘hidden affordance’. These affordances occur when no information is clearly exposed for an existing affordance and it needs “to be inferred from other evidence” [108, p. 80]. Therefore, such a conception resonates with the concept of appropriation.

2.1.4.1 Appropriation

In the last two decades, unexpected uses of digital artifacts started to be studied and conceptualised in HCI literature. Indeed, HCI scholars started to focus their attention on phenomena such as interface appropriation [80, 77], or cases in which the use of interactive systems can be subverted (e.g. [278, 136, 111]). Dix proposed that appropriation refers to forms of “improvisations and adaptations around technology” [77, p. 1]. According to the author, such improvisations should be seen as positive elements, and are evidence that “technology has been domesticated, that the users understand and are comfortable enough with the technology to use it in their own ways” [77, p. 1]. To facilitate and promote appropriation, Dix proposed to provide users with space for their own personal meanings over some elements of the design artifacts [77], while Dourish suggested supporting multiple perspectives on information [80]. In both papers, the importance of avoiding pushing for one defined interaction strategy emerged [80, 77].

2.1.4.2 Open Interpretation and Ambiguity

Appropriation reflects the idea that multiple interpretations of a given interactive system can fruitfully coexist. The idea of an "interpretively flexible"artifact first appeared in a piece of research by Sengers and Gaver [278], who proposed that the meaning of an "interpretively flexible"artifact is co-constructed by users and designers. Such an artifact is described as resulting in a sort of "'Rorschach' system that maximally supports users in projecting their own personal meanings onto it."[278, p. 9]. This type of artifact should provide and expose information about the topic without specifying or suggesting how to relate to it and, on the contrary, stimulate original interpretations. In this context, Leon identified randomness as a valuable element [177]: randomness supports rich experiences as the experience of unpredictability can capture the imagination.

In a similar manner, the idea of ambiguity of an interface emerged as a valuable element in the reflection on appropriation and multiple interpretations of interactive artifacts (e.g. [109, 15, 240]). Gaver and colleagues suggested that to foster "openness and ambiguity"of an artifact, "designs should avoid clear narratives of use"[111, p. 888].

Gaver Proposed three main types of ambiguity [109]:

- Ambiguity of information - occurs when the information is presented ambiguously;
- Ambiguity of context - arises when elements of artifacts assume different meanings depending on the context of use or of interaction;
- Ambiguity of relationship - is related to the specific relationship between a person that is using a design artifact with the artifact itself.

Uncertainty, openness, and ambiguity have also proved to be of value in the use of cultural probes [110]. Cultural probes are objects, such as "packages of maps, postcards, and other materials - [...] designed to provoke inspirational responses"[106, p. 22]. Thanks to their openness, cultural probes are effective to collect "inspirational data"that helps participants to express an "impressionistic account of their beliefs and desires, their aesthetic preferences and cultural concerns"[106, p. 25].

2.1.4.3 Different Forms of Appropriation: Design-in-Use

Appropriation of computational and interactive technology can occur at different levels within a design space. Botero and colleagues [37] argued that "a design space is always actively co-constructed and explored by multiple actors through their social interactions with and through technologies and the participating actors, resources, conditions and supporting strategies frame the design space available."[37, p. 25].

In a so defined design space, therefore, all the actors continuously appropriate and reinvent the meaning and the use of technology. To formalise such a process, the author proposed the *design-in-use* model, a framework consisting of two main dimensions: "Use-Create"and "What People Do". The "Use-Create"dimension is composed of three main categories that identify different levels of appropriation:

1) Reinterpretation: this category is at the "Use"end of the Use-Create spectrum and "refers mostly to possibilities that exist for surpassing the semantic associations that are proposed to people in relationship to a given structure"[37, p. 6]. It relates to finding a different usage of a given artifact.

2) Adaptation: this second category, in the middle of the spectrum, "implies a certain degree of flexibility in the underlying technology coupled with a sense of violation of intended purpose"[37, p. 6].

3) Reinvention: this category is at the "Create"end of the Use-Create spectrum. Reinvention implies that "manipulation of semantics, use and structure is usually achieved and new functions are created". A true reinvention usually "produce(s) changes and alterations to the original structures"[37, p. 7].

The "What People Do"dimension is composed of nine possible activities, spanning from "Program / write modules"to "Evolve social practices"[4].

2.1.5 Artifact Ecologies

With the progressive spreading of computing into multiple aspects of everyday life, the importance of context and multiple interactions increased. For this reason, it may not be sufficient to focus the inquiry on the interactions between one person with a single artifact to understand her relationship with it [157]. The concept of artifact ecology has emerged as a valuable tool to investigate the intertwined net of relations that emerges from the multitude of artifacts that we often use in parallel.

2.1.5.1 Conceptualization(s) of Ecologies of Artifacts

The idea of artifact ecologies was introduced in the HCI debate by Jung and colleagues, who proposed that an artifact ecology is the "set of all physical artifacts with some level of interactivity enabled by digital technology that a person owns, has access to, and uses"[157, p. 201]. Since then, the concept has been widely adopted in HCI. For instance, in her reflection on third wave HCI ten years after she proposed the term, Bodker discusses artifact ecologies as a concept to "help us focus on multitudes of artifacts that users bring together when carrying out particular activities."[28].

[4]The complete list of activities comprises: Program/write modules, Use modules and libraries, Assemble components, Aggregate/remix, Integrate, Configure/personalise, Create workarounds, Make social agreements, Evolve social practices.

The word ecology used in the proposal of the concept artifact ecologies [157] was primarily borrowed from Gibson [112] (as it had been with the term affordances). Gibson has advocated that our physical ecology defines our (visual) perception and that, therefore, individual objects and instances cannot be analysed in isolation. Jung and colleagues built the concept of artifact ecology by combining the reference to Gibson with a few other inquiries on ecological appreciation of reality. In particular, the authors refer to the works by Nardi and O'Day on information ecology [241], the idea of product ecology by Forlizzi [99], and the ecological meaning of artifacts by Krippendorff [168]. Nardi and O'Day have proposed information ecology as a concept to describe the set or the system of people, practices, values, and technologies in a specific environment [241]. Forlizzi has introduced the concept of product ecology relying on social ecology theory [99] as a framework to investigate "how products evoke social behavior"[100, p. 11]. Krippendorff has focused on the ecological meaning of artifacts, which consists of the possible interrelations among the various artifacts [168].

Since the initial proposal by Jung, further developments of the concept have emerged. For instance, Raptis [263] proposed three specific levels to study artifact ecologies: 1) the first level focuses on the relationship between a single person with a single artifact; 2) the second-level analyses the specific sub-ecology that a person develops within a specific activity; 3) finally the third more comprehensive level accounts for all the digital artifacts belonging to an entire ecology.

Turner discussed the various perspectives on information related to artifact ecologies aiming at developing a broader understanding of the role and use of technology in everyday life. The author stressed the importance of the "Interconnectedness of activities and use of tools in the broader context of other people, other technologies and other contexts"[304, pp. 40-41].

In a recent meta-analysis on studies that specifically focus on supporting cross-device interaction, Lyle and colleagues identified, along with artifact ecologies, other three concepts that can be useful to investigate ecologies: information ecologies, device ecologies, and communicative ecologies [189]. Information ecologies have been initially conceptualised by Nardi and O'Day, who defined it as "a system of people, practices, values, and technologies in a particular local environment. In information ecologies, the spotlight is not on technology, but on human activities that are served by technology"[241, p. 49]. The category of device ecologies builds upon the initial definition by Loke as "consisting of devices (in the environment and on users) interacting synergistically with one another, with users, and with Internet resources, undergirded by appropriate software and communication infrastructures that range from Internet-scale to very short-range wireless networks."[183, pp. 559–560]. Finally the term communicative ecologies, in the categorisation by Lyle and colleagues "include work that focuses primarily on communication technologies in relation to practices and communities"[189, p. 7]. The authors decided to use the name "communicative ecologies", since a reference to Altheide [5] who introduced it is a standard in this discourse .

2.1.5.2 What Can Compose an Artifact Ecology

The initial definition by Jung [157] primarily focused only on digital artifacts. This vision has been subsequently extended, and according to several authors artifact ecology can also include non-digital tools alongside digital ones (e.g. [31, 268, 6, 22]). The rationale for including non-digital artifacts while studying artifact ecologies reflects the increasingly overlapping relationship between physical and digital environments [31, 30]. Indeed, as the distinction between the physical and the digital domains is increasingly blurred, the actions we perform in our everyday life rely on a combination of digital and non digital tools and artifacts.

Since its introduction, the concept of artifact ecology has been used to study both individual usage of sets of artifacts [31], or social interaction in groups using such a set of artifacts [172, 32]. Artifact ecology can also be applied to study an ecology of people interacting with one single artifact [31].

2.2 Music Ecologies and Interaction Design

In this section [5], literature related to musical aspects of this dissertation will be introduced; particular attention will be paid to interactive technology for music performance. As we have seen in the literature review dedicated to HCI (section 2.1), the relation between humans and artifacts cannot be understood in isolation, rather in their ecologies of use.

Understanding the historical legacy of contemporary musical technology practice can be important to frame such ecologies. For this reason, this section will start by examining the evolution of the various roles and functions of the various components that characterised a musical ecology in the western classic tradition.

After this introduction, an overview of the composing and designing practices since the middle of the last century will be provided. This section will then focus on how the practice of composing new music has often overlapped within the electronic music practice, and on how the roles of composers, performers, and designers have been blurred. The following two subsections will primarily focus on some aspects of music technologies design. First, how the concept of affordances has been used in the electronic music debate will be analysed. Then, an overview of the different types of scores emerged in the debate on interactive music will be proposed. The choice of focusing on score is determined by the fact that scores, as musical artifacts, have been pivotal in music practice. After analysing all these elements, the specific literature that has discussed music or performative ecologies will be analysed.

As one of the contributions of this thesis is a new framework, in the last subsection, an overview of the existing framework will be presented.

[5] Parts of the text of this section have appeared in the co-authored publication [216].

2.2.1 Musical Roles and Musical Scores: an Overview of the Fundations

This first subsection of the literature review on music presents an overview of the evolution of some musical elements that are relevant to investigate performance ecologies, such as the different roles of composers and performers and the role of the scores as a mediator. This subsection does not aim to provide the reader with an exhaustive understanding of the evolution of Western Music practice. Such an effort would be out of the scope of this thesis. On the contrary, this section wishes to contextualise relevant elements for this thesis within their historical legacy.

The rhetoric over Western music has been often characterised by the clear-cut distinction between composition and performance [6]. This distinction implies a static and distinct conception of the roles of musicians (those who write and those who read).

Despite being slightly naive, this model well represents how ancient, classic and romantic repertoire is perceived today, how instrumentalists are trained, and the role that scores played for centuries. However, the roles throughout the history of western music have not always been so distinct. For instance, in many cases, the composer and the performer can be the same physical person: this has been true for most composers from the renaissance to the classical and romantic period. Many composers were also virtuoso players of their instruments, to name a few Giovanni Girolamo Kapsberger (1580 – 1651) was virtuoso on the Theorbo, Johann Sebastian Bach (1685 – 1750) on the keyboard (harpsichords and organ), Wolfgang Amadeus Mozart (1756 – 1791) on the fortepiano and piano, Niccolo Paganini (1782 – 1840) on the violin, Frédéric Chopin (1810 – 1849) on the piano. All these musicians were both performers and composers, and composed some of their music works primarily or initially for themselves. It is also true that from the XIX centuries the musical jobs increasingly specialised, still many composers continued to perform, many had parallels careers as conductors and composers, e.g. Gustav Mahler (1860 – 1911), Bruno Maderna (1920 – 1973), Pierre Boulez (1925 – 2016). Finally, a group of musicians had a music activity primarily as composers, e.g, György Sándor Ligeti (1923 – 2006), (however they have also been teachers and academic writers). In the last century, the figures of composers who are also instrument designers have emerged, in those cases where a musician creates or hacks pieces of technology for a specific musical objective (see for instance [188, 293]. This trend will be further analysed later. This list is far from being exhaustive; it simply wants to point out that the distinction among the various musicianship roles has always been blurred. In the last century, therefore, the distinction between composers and performers as complete separate entities has been harshly criticised; as composer Poul Laknsy pointed out:

"Music-appreciation mavens used to wield an old saw about the composer-performer-listener triangle. We laughed at its naivete, but it is a good simple model of a classical

[6] This is a truism that lay at the base of classical education in most of the western music schools, and lay behind the development of many musicological many cultural reflections, see for instance with the History of Western Music by Taruskin [297].

notion of musical-social interaction. In this model the composer is genius/author, the performer is genius/servant, and the listener respectfully adores both." [171, p. 103].

The critique by Lansky about the fact that a clear cut distinction between the roles is not useful nor representative of the real musical practice is very relevant; and overall the work presented in this thesis is aligned with such a perspective. However, the distinction between the act of composing and the act of performing is helpful as a starting point to study performance ecologies. Therefore a few more traits of these elements will be analysed here.

2.2.1.1 Composers, Performers, and Scores as Mediators

It has already been clarified that the composer-performer model is an oversimplification of what the job of making music has meant in the course of the development of the European music tradition. However, it is a model that works and is undoubtedly part of the reasoning about music. The composer-performer distinction, indeed, also has some primary merits. In particular, it identifies the distinction between composing and performing as two separate activities. The composer and the performer can be separated based on the moments in which they relate themselves with a music piece: composers write music before a performance, and performers then play this music during the performance. Improvisation – i.e. inventing the music at the very moment of his performance – shares characteristics of both composing and performing. While in the traditional distinction, the composer is responsible for the creation of the music, and the performer is responsible for playing it, the improviser is responsible for creating and playing a piece at the same time [275]. An improvisation can, of course, be transcribed afterwards, and then it will become a piece that can be performed again at any time. A famous example of this possibility is the case of Musikalisches Opfer by Bach. Frederick II of Prussia had asked Bach to improvise a piece based on a theme that he previously composed; Bach improvised a Ricercar a 3 voices, and later he included a transcription of this piece in a collection of works that he donated to Frederick II [7].

Identifying the distinction between the various moments is also important in those composers who performed their own music, as it helps to highlight how they can perform multiple times a piece previously composed. The time span that disjoints composing from performing is deeply connected to the invention and use of musical scores. The role of scores is so fundamental in the Western music tradition, that the musicologist Richard Tarouskin, decided to begin his titanic "history of western music" with the invention of the first forms of musical notation, in medieval time in the 8th century [297]. Scores also allow composers to do their work without the presence of the actual music, as pointed out by Gurevich: "Although the composer is situated as the authorial creator, in this model they are not the "maker," neither of instrument nor of sound. Rather, the composer

[7] the description of the episode when Frederick II of Prussia asked Bach to improvise on a theme, and how the improvisation later became one initial part of the Musikalisches Opfer can be found in the book Gödel, Escher, Bach: an Eternal Golden Braid by Hofstadter [131].

creates an abstract representation of music, an instruction for execution—a score.” [118, p. 164]. A final remark on score related to the relation to authorship. With the invention of print, the composer started to be considered the author of an artwork [307]: such an artwork exists without the need of the musician to perform it, in a similar way to poetry or literature. In this thesis it will be explored how, with digital technology, the characteristics of a score can be moulded to the point that the score can be created in real-time, while performing, therefore reducing the distinction between composing and performing.

2.2.1.2 Different Scores and Conception of Pieces: Werktreue and Open Work

With the consolidation of music notation, the score became more and more a representation of an ideal artwork. The idea of Werktreue (a German word that could be translated into True Work) represents such an idealisation of a piece of music that contributed to consolidate the distinction between the composer and the performer:

> "The ideal of Werktreue emerged to capture the new relation between work and performance as well as that between performer and composer. Performances and their performers were respectively subservient to works and their composers."[114, p. 231]

Despite being dominant in our society (or at least in that part of society that relates to classical music), suc a perspective is overly rigid. As Paul Lasky has pointed out:

> "From a certain perspective, this view describes a very rigid social structure. It is highly conservative in that it provides a conceptual framework which discourages evolution and promotes institutional stability. The degrees of passiveness and activeness of the individual nodes are relatively fixed and the environments in which they behave are designed to accommodate their habits without much fuss or bother."[171, p. 103].

In the last century, indeed, experimental composers and performers have started questioning such a clear distinction. Among the avant-garde experimentations that emerged in the last century, aleatoric music is particularly relevant in this sense. Aleatoric music composers developed a novel approach to the use of scores. Indeed, in an aleatoric piece, the score no longer encoded the pieces in their final form; rather, it prescribes and defines a set of possibilities among which the performer can choose from. Consequently, the performer is granted a high degree of freedom of invention, interpretation, and even improvisation. To express the indeterminacy of the final musical form, typical of the aleatoric score, often relied on non-traditional graphical elements fostering a "new and imaginative way of interpretation"[299, p. 611]. This approach expresses a different conception of music creation in itself, as the composer and writer Cardew has pointed out:

> "a composer who hears sound will try to find a notation for sounds. One who has ideas will find one that expresses his ideas, leaving their interpretation free". (Cardew in [247, p. 4]).

While discussing 20th century art forms, the Italian philosopher Umberto Eco introduced the term Open Work (Opera Aperta) [87]. A central characteristic of such a piece is that the final form is not entirely determined by the decision process of their creators. Indeed, artists (in the musical case, composers) decided to leave the arrangement and organisation of a number of the piece's constituents open either to a performer, the audience, or chance. The composers were not imposing to the artwork a single definitive order, but a multiplicity of possibilities. Eco enlisted aleatoric music and graphic scores as one important example of open works.The philosopher mainly analyses the works of many composers operating at the Studio di Fonologia Di Milano (this includes many of the most influential post-second world war avant-garde composers, such as Berio, Maderna, Boulez, Pousseur, Stockhausen). Eco also underlines that the openness of Open Works is possible thanks to the characteristic of being "ambiguous"and subject to the interpretation of the performer [87].

2.2.2 Composing Instruments: Evolving Practices and Technology

At this point, the main characteristics of the core elements that compose the ecology of a performance, in relation to the western legacy, have already been introduced. This subsection will zoom in to provide a closer look on the relation between composing, performing, and instrument building in electronic and digital music. By referring to the analysis by Ihde [146], Tahıroğlu and colleagues pointed out that:

> "In Western art music, composition and performance have become seen as separate activities: according to this model a composer encodes her ideas in musical notation, and the performer then executes this score in sound. Later, some of these separate activities began to overlap [...] for example, via editing and manipulating tapes (and later desktop computers), guided by the probing ears"[290, p. 68].

This section will also look at how a music technology system can embed a precise idea about a piece itself. Before analysing such a relation in the digital domain in detail, a few examples that predated it will be discussed.

2.2.2.1 The Origin: Electronic Domain

With the development of electronic technology, from the middle of the last century, the act of composing has started to overlap with the act of performing with the act of creating or appropriating technology.

An early example of how the interaction with a piece of electronic technology overlaps with the creation of the piece can be found in the domain of so-called tape music. Tape music is an electronic music genre where the piece is created through synthesis or sound manipulation and stored on a tape, the piece does not require any performative action after it is composed, only for the reproduction (see [133], in particular chapter 5). This is particularly relevant in the case of the piece "it's gonna rain"(1965) by Steve Reich [265]. In this piece, the composer started to explore the compositional potential of phasing two loops that began in unison, moved completely out of phase, and then gradually returned in unison [133]. Discussing this piece, Reich reported that he was playing with two different tapes when he discovered the phasing effect of the sound [265]. The act of experimenting with technology (an audio recorder) in a way different from how it was intended by design resulted in developing a technique and piece. A recording artifact became an instrument for composing electronic music. In this piece, the relation with the technology occurred during a compositional phase, meaning away from a stage, and the exploration of the technology is entirely part of a pre-compositional moment.

In the piece Imaginary Landscape No 4[8]), the American composer John Cage used a set of radios as musical instruments. The score prescribes how to tune them and change stations during the performance, but of course, no prediction is possible about the actual sonic content of the output of this operation. In this case, we can also see how a piece of music technology designed for listening activities is appropriated and transformed into a musical instrument, a performative musical instrument.

Another piece worth mentioning in the evolution of the relationship between composing, performing, and making/appropriating is "Rainforest"(1968) by David Tudor. The score of this piece consists of a flux diagram describing the connections needed for the piece, but no prescription about what to do with it is imposed to the performer; it is also worth noticing that Tudor initially composed the piece with himself as a performer in mind [9].

The practice of building custom electronic music instruments or systems has been widely developed by the Sonic Art Union, a collective of experimental musicians who pioneered many electronic music practices. A representative piece of their production is Hornpipe (1967) by Gordon Mumma. This piece is performed by Mumma himself with a custom made set of electronic devices that processed a horn. Mumma was both operating the devices and performing with the horn. Discussing the piece, the composer reported: "I consider that my designing and building of circuits is really composing"[247], chapter 5. Moreover, the composer Alvin Lucier, another member of the Sonic Art Unions, wrote about this work that "the scores were inherent to the circuits"[188].

We have seen few representative examples of how, already in the electronic domain, the various relationships among composers, performers, scores, and instruments started

[8]For a better overview of the piece see [305]

[9]for a more detailed overview, see [83]

to be blurred in the electronic practice. This tendency thrived with the introduction of interactive digital music technology, which will be addressed in the next subsection.

2.2.2.2 Interactivity and Design: Digital Domain

With the development of digital technology that allows for real time interaction from the end of the last century, the number of projects and practitioners working in the field of interactive music rapidly peaked. Digital musical artifacts in the digital domain include a wide variety of technologies, among which: algorithms that compose/improvise music (e.g. [273]), Digital Musical Instruments (DMIs) (important example being the Reactable [156], and The Hands [300]), augmented instruments (for instance the Magnetic Resonator Piano - a system that allow to play piano strings with amagnetic system [225], augmented guitars for percussive guitarists [208], the Bionic Harp that combines different technologies to augment the expressive possibilities of an harpist [288] or feedback instruments where the instrument is amplified with speakers mounted on the body of the instrument like the Self-Resonating Cello [88] and the Feedback-Actuated Augmented Bass [227]), audiovisual tools (e.g. [134, 62]), screen score systems (e.g. [140, 310]), live coding (see [57, 320]), mixed (e.g. [327]) and virtual reality [279] musical instruments, and installations (e.g. [170]). The idea of digital lutherie was introduced to reflect on the practice of digital music technology creation (e.g. [154, 153]).

The New Interfaces for Musical Expression (NIME) conference rapidly became a central hub to discuss the design and the use of this variety of interactive musical tools. The conference began as a workshop at the Conference on Human Factors in Computer Systems (CHI) in 2001 [10]. Since then, it has become an annual event gathering together researchers, musicians, designers, and makers, becoming one of the leading international communities debating music technology. In today's jargon, NIME is used to both identify the conference and the musical interface itself. A NIME can be a DMI, an augmented instrument or any form of interactive music technology, mostly used for performance; however, tools specifically designed to support non-performative musical activities have also been proposed.

Since the earliest edition of the conference, the intertwingled relation between composing, performing, and designing new music technology has been debated. In the first edition of the conference, Cook proposed a set of principles to design new digital musical instruments [59]. One of these principles reads: "make a piece, not an instrument or controller"[59, p. 1]. This principle underlines the fact that it is important to think about specific musical results while designing a piece of new music technology, therefore thinking about the musical piece that will be performed with it, rather than the instrument itself. In the following edition of the conference, Schnell and Battier proposed the concept of composed instrument [277]: a musical artifact that embodies the notion of an instrument, a machine, and a representational system. As a musical instrument, "it

[10] https://www.nime.org/

should enable the performer enough degrees of liberty to explore personal and original ways of playing with it."[277, p. 2.]. As a machine, it is made of computational and algorithmic layers. Finally, the representation layer can be used by composers to "define events, write scores and specify the computational and algorithmic layers"[277, p. 2.]. It has also been pointed out that in electronic and digital instruments, composing by building instruments is easier in comparison to acoustic instruments [38], as it is possible to almost freely decide how to couple sound-producing mechanisms and control interfaces [52].

Similarly, Tanaka has proposed that the software "is at once the score of the piece as it is part of the instrument definition"[293, p.398]. The author indeed specifies that the "inner contents of the [interactive system] - the specific mappings of gesture to sound and their development in time - form the score of the composition"[293, p. 393]. Another interesting reflection about this matter is offered by Dudas, who proposed the term "comprovisation"to discuss the "composed improvisation"that were developed by electronic and computer musicians [85]. In this work, the author points out that: "Although we were truly improvising music and sounds together freely without any pre-composed or previously notated material, we certainly pre-composed the kinds of electronic processing we were doing"[85, p. 29].

Starting from reflecting on those DMIs "where the distinction often blurs between instrument and composition on the one hand, and performance and composition on the other [199, p. 168], Magnuson proposed the idea of an epistemic tool as "a designed tool with such a high degree of symbolic pertinence that it becomes a system of knowledge and thinking in its own terms"[199, p. 168]. The author built upon the ideas of enactment by Varela [308], and extended mind, by Clark [56]. Enactment refers to the idea that cognition is the enactment of a mind and world on the basis of the variety of actions performed [308]. Learning to play is, therefore, an enactive activity. Clark's idea of an extended mind supports the idea that humans can extend the cognitive process outside the head, offloading the part of the process on tools [56]. Magnusson further reflects that the technologies that we use as part of practices of making and thinking music incorporate musical ideas of its author(s): "Writing digital musical interfaces therefore necessarily entails the encapsulation of a specific musical outlook."[199, p. 173]. The musical ideas are blackboxed in the interface itself, using a terminology from Latour [173]. In his book "Sonic Writing", Magnusson has further developed his inquiry on musical technology.

The book analysed how those DMIs, or pieces of music technology in general that carry the notion of a score as well of an instrument, are assemblages of software and hardware components, resulting in artifacts that carry a defined and specific vision on how a specific piece of music could be thought, expressed, and performed [200].

Bown et al. have pointed out that the intuitive distinctions between the activities of musical culture (composing, performing and instrument making) are a legacy of the acoustic model and can be inappropriate for digital music performance [38]. The same applies to the clear role distinction for both the humans (performers, composers and luthiers) and objects (scores and instruments) [38]. The authors also acknowledge that these terms persist within the current musical debate. To overcome such a limitation in the language, the authors proposed the term behavioural objects as those pieces of musical software that can "exhibit complex behaviours like machines and organic structures, but can also be exchanged between people as rapidly and effortlessly as ideas."[38, p. 189].

2.2.2.3 Blurred Roles: Composers/Performers/Designers Using Composed Instruments

We have seen how several authors discussed the overlapping of musical ideas and design of music technology. In this , the ideas of Composer-Designer and Performer-Designer emerged to underline the designing roles of both musicians [34], and the idea of the performer composer has also emerged to study how a single live musician performs and compose with computers [306].

In a recent paper analysing the ecology of musical instruments in the NIME practice, Gurevich compared the traditional composer-performer model – where a composer creates a score, a performer interpret it, and the listener listens to it – with the Shannon model of communication [118]. In this comparison, the composer is the information source, the performer the transmitter, and the listener the receiver. The author claims that this model is inadequate to reflect on contemporary practice, particularly in relation to digital technology. In particular, the author refers to Lansky's reflection of the network of agents that compose a performance where "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"[171, p. 108].

Johnston, who proposed that "Digital instruments are as much composition as instruments, as their behaviour, appearance and responses to input are able to change over time."[151, p. 82], reflects on the impact of this tendency over the different roles of a music performance:

> "in NIME research, music as an artform is often spoken of as if it were a static field, where the roles of composer, performer and instrument are well-defined, uncontroversial and unambiguous. The reality, however, is that all of these terms are contingent and dynamic." [151, p. 82].

Recently, Tahiroğlu [289] has explored the current relationship that musicians, instrument builders, and composers have with music. The author proposed that such relation is composed of 'ever-shifting roles':

> "musicianship, technology, composition and the performance environment are all often conceptualised to the degree that they become embedded in people's musical instrument building practice, thinking about music, themselves and their relationship with their communities"[289, p. 156].

Morreale et al. [236] , conducted a survey, asking members of the NIME community about their practice in relation to the design of musical instruments. In this study, different possible roles have emerged (as in Table 2.2), and in some cases, the participants played more than one role. Additionally, it emerged that in the majority of the cases, (78% of their sample of 78 participants), the performers also designed the NIME they use in their performances. This percentage raises to 97% if we consider the participants involved in the instruments' design. In another study, Morreale and colleagues investigated the longevity of NIMEs; in this study, it emerged that almost half of the DMIs have been played by less than three musicians [235].

Table 2.2: Role in NIME performances with number of responses and relative percentage as in [236, p. 2].

NIME player	46	45%
Composer	24	23.5%
Live coder / live sound processor	10	10.2%
Traditional musical instrument player	9	8.8%
Software instrument player	6	5.8%
Visual artist	5	4.9%
Dancer	2	1.9%
Total	102	

2.2.3 Affordances and Constraints in Interactive Music Technology

Since the birth of the field of New Interfaces for Musical Expression (NIME), many HCI concepts have been borrowed and applied to the domain of interactive and digital music creation. Affordances and constraints are among these concepts.

On a theoretical level, an important contribution about affordances is provided by Tanaka, who combined the notions of affordance with the idea of embodiment. With this combination, he reflected upon the characterisation of gestural instruments, intending to consider mapping processes and instruments together as part of a whole[292]. The author proposes that "in order to broach issues of affordance, we must consider both the physical object as well as its software based sound synthesis capabilities." [292, p. 92]. Another important theoretical contribution is offered by Magnusson , who developed the concept of subjective constraints "referring to the expressive limitations that face the thinking, creative, performing human." [196, p. 64], and used this concept to analyse a number of case studies with a variety of digital musical instruments.

A few researchers have applied the concept of affordance to networked music systems. For instance, Gurevich used it to inform the design of his Jam Space [119]. Braasch focused on the affordances of telematic music systems, arguing in favour of "need to encourage musicians to interact with their new environment more directly" [39, p. 426]. Dillon and Brown [76] focused on the pedagogical uses of networked music systems, identifying interactional and relationship affordances. According to the authors, the "relational affordances of collaborative media performance with generative media include access to high-level personal, social and cultural experiences" [76, p. 5316].

Another use of affordances can be found in a paper by Cook and Pullin, who applied affordances to "inform the design of a new interface that explores [...] the interaction possibilities in computer music beyond the prescriptiveness of most standard Interfaces" [58]. Affordances have also been used to study the musicality of human gestures. In this area, the contribution by Tanaka and Altavilla is particularly relevant. The authors investigated in detail gestural musical affordances [294], by comparing different interfaces to control sound, and gestural sonic affordances and studying whether a sound can suggest specific gestures [4]. Recently Wakefield and colleagues used affordances and constraints to reflect on modular synthesis in virtual reality [312]. Affordances have also been used by Magnusson to inform the interaction design of screen-based music instruments [193]. Gurevich and colleagues offered an important contribution about constraints in the area of musical interfaces [121]. The authors investigated the development of personal style in a performance with "a highly constrained musical instrument". The authors developed a one-button instrument and asked several musicians to develop a solo performance; a wide variety of stylistic variations has been observed. The combination of affordance and constraints has also been used to inform the design of hackable and open-ended musical interfaces. For instance, Zappi and McPherson have relied on hidden affordances [325], and on multiple dimensionalities [326], to promote appropriation. These works [326, 325] offers notable examples in the design of ambiguous musical instruments that rely on the idea of hidden affordances by Gaver [108].

2.2.4 Specific Types of Score in Digital Music Ecologies

We have seen how the function of a score, in many cases, has been subsumed into pieces of technology. In general, within the music technology debate, a number of different approaches to music scores and even types of scores have emerged. A taxonomy of the different roles that scores have played in performance ecologies is one of the contributions of this thesis. Such a taxonomy is based on a systematic literature review of the NIME proceedings and will be presented in chapter X. This section will focus on this topic.

Building upon the idea of composed instrument and the fact that scores are inherent to the instrument, Tomas and Kaltenbrunner developed "Tangible Scores", which are a new family of musical instruments where the"physical representation of a musical piece"modified as an extra "layer"embedded in digital musical instrument [299]. The authors, by building upon Lucier's sentence "the scores were inherent to the circuits"[188], proposed the term "inherent score". Reflecting on the idea of "inherent scores", Maestri has written:

> "Inherent scores are in this sense an expansion of what an instrument normally is: these instruments expand and reinforce their affordances, turning into

> objects acting in the sense of musical composition. The instrument implies gestures and sounds."[191, p. 3].

Another relevant reflection is offered by Magnusson, who discussed live coding as a form of musical notation. As a form of notation where the code is the score, live coding can be analyzed in light of the western art music tradition, from Guido d'Arezzo's Guidonian hand that established the basis for solfege at the end of the 10th century to the graphic experimentations of the 20th century. Live coding has the peculiarity of transforming the compositional process, and the creation of the score itself into a live performative event [194]. A live coding score usually takes the form of textual code; however, abstract graphic forms of notation can also be used [198, 195].

With computing systems, scores can also be generated or manipulated in real-time. Such typology of score opens a "Third Way"of interpretation between improvisation, and the execution of a paper-written score [318]. Hope and Vickery, who extensively worked on this idea, proposed the term Screen Score as a form of new media manuscript [140]. The author distinguished among four main types of screen scores: scrolling scores that move as a continuous notational form from left to right; permutative scores that allow the presentation of notated musical materials to the performer in a non-predefined order; transformative scores that altere during the performance a fixed score; finally, generative scores that are created and notate components of the score in real-time. Overall, screen score experiments can be rooted in 20th century musical avantgarde experiences with graphic and non-traditional notation [310].

2.2.5 Music Ecologies

The term ecology and ecosystems emerged in different contexts to discuss the complex net of interactions that occur in a music performance involving digital technology. For instance, the body and the computation in digital instruments are already an ecosystem that impacts how music is produced, as pointed out in the following question by Tahiroglu: "What does this ecosystem of body and computation in digital instruments have to say about the music that is being produced?"[290] p 67.

In the performance, however, an ecology can be a broader net comprising connections among multiple elements: human actors (e.g. instrument builders, composers, performers, audience), space, technology, scores etc. Gurevich and Treviño proposed the idea of an ecology of musical creation to account for the complex interrelations of both human and non-human agents. This accounts for the relationships among composers, performers, and listeners, also considering history, genre, and context [122]. Following a similar perspective, Waters has proposed the term performance ecosystem enfolding the variety of interactions among performers, instruments, and environment [314]. Water used this conception to analyse a number of works; a relevant example is Audible Ecosystemics by Di Scipio [75], a piece where performers' gestures are replaced by a 'structural coupling' of the environment with a digital system. Waters recently developed further his reflection on performance ecologies, looking at the situated co-development of player, instrument and environment. The author suggested that musicians tend to use and adopt instruments to explore self-other relations. Such exploration often occurs in dynamic, playful and improvised behaviours [315]. According to the author, musical instruments are usually designed with an environment and social condition in mind. Instruments are, therefore, assemblages within a variety of further assemblages (instrument-environment and player-instrument-social expectation). A socio-cultural conception of musical instruments is also at the basis of recent work by Magnusson, [201]. According to the author, musical languages are cultural products (i.e., genres and styles) that evolve over time. Such languages tend to be inscribed onto media, such as notation, computer code and phonography.

The ecological perspective is also at the basis of Gurevich's critique of the composer, performer, listener model [118]. When the author claims that a clear distinction among the roles is not representative of contemporary practice, he refers to an ecological conception of performance. An ecological perspective of music creation is also at the base of Rodger et al. conception of the relationship between humans and instruments, when the authors argue that musicians should not be accounted as users but rather agents in musical ecologies. [270]. It is worth noticing that Rodger et al. based their vision also on Gibson's ecological psychology [112]. In a recent study, it has been discussed that ecological conceptions are extremely valuable for digital musical instruments as assistive technology [187]. The idea of performance ecology is also relevant in Melbye's reflection on agency, analysing what is the felt sense of agency that musicians and improvisers encounter when "co-constructing complex performance ecologies"[226, p. 27]. Finally, the conception of performance ecology or ecosystem is fundamental in a recent reflection by Stapleton and Davis [283]. The authors considered their musical artifacts "Ambiguous Devices"as distributed musical ecosystems and discussed ambiguity as a positive element in relation to distributed agency among the various elements of the performance ecology [283].

The term ecology has also emerged in relation to ubiquitous music for instance to investigate the properties of musical activities and the design strategies related to distributed decision making [164]. In their model the authors claim that human agents and material resources are connected though relational properties (which are affordances). Such a conception, in the view of the authors, has the potential to support exploring the creative potential of the be Internet of Musical Things (IoMT). The IoMusT itself encompass manifold ecosystems [303]. The idea of ecology has been recently widely explored in relation to ubiquitous music including, multimedia design, education, and everyday objects [175].

2.2.6 Framework and Models for Designing Interactive Music Technology

Over the past two decades, various frameworks emerged for a wide variety of purposes. Many examples tackle specific types of NIMEs. For instance, frameworks have been proposed for Biomusical/Emotional Interaction [36], for timbre manipulation in digital environments [281], for modular VST-based NIMEs [253], for AI-Assisted Music Production [301].

Some frameworks have been presented to address the design or the use of interactive music systems from a broader and less topic-oriented but on the contrary aiming at modelling music systems in general, For instance, Drummond [84] proposed a set of definitions to classify interactive music systems. In particular the author analysed a list of concepts spanning from, collaboration (during the performance), to shared control, metaphors, mapping, and system responsiveness. Johnston [152] categorised musical interfaces based on the interaction modalities and distinguished among: instrumental interaction, when the musician has control over every aspect of the music; ornamental interaction, when the system has some level of control in adding layers to the musician sounds; and conversational interaction, when there is a shared control over the musical output in a dialogue, while performers can engage conversation with the system as they might with other musicians.

Other studies have aimed to pinpoint different relevant sets of factors when designing a new musical instrument or interface. For instance, Jorda [154] analysed design issues in relation to the need for balancing among a set of parameters: simplicity and complexity, playability, learning curve, and instrument efficiency. Similarly, Birnbaum et al. [24] based their design framework on several dimensions, which include: required expertise, musical control, feedback modalities, and degrees of freedom.

In her framework for the evaluation of DMIs, O'Modhrain identified several Evaluation Goals along the following dimensions: stakeholder, enjoyment, playability, robustness, and achievement of design specifications [248]. It is interesting to observe how the stakeholder includes the list of various actors orbiting around the DMI (audience, composers, performers, designers, manufacturers). The other dimensions are evaluated in relation to the DMI for each of these people.

Marquez-Borbon et al. proposed an alternative approach to evaluating DMI that is not based on evaluating features of an existing device. The authors proposed designing DMIs specifically to support research [207]. According to the authors, "the device needs to fill a specific role within an experimental context". To achieve such an objective, they argue in favour of an evolving qualitative methodology.

Finally, Morreale et al. [231] proposed a design framework (MINUET) for an interactive music technology interface focused on the experience of the performer. MINUET proposes to structure a design process into two main stages: the first stage analyses the goals, whilst the second focuses on practical specifications to achieve these goals. The goals are articulated around three main elements: People, Context and Activity.

All these works are particularly effective in analysing how an interactive system is related to the person(s) operating with it. This thesis will present a new model to formalise the multiple interconnections that occur among the various actors in relation to all the artifacts, including the piece, a score, and the instrument and the multiple roles performed by the same person, considering both preparative stages and performative moments. The various concepts presented in the HCI section 2.1 inform this model.

2.3 Dance Ecologies and (Sonic) Interaction Design

Dance performances can be a prolific performative scenario for interactive music technology. In this section, some central elements in this scenario will be explored. This section will commence by presenting an overview of reflections on the role of the body in interaction design to better contextualise the inquiry. After that, specific elements of technology for dance performance will be analysed (different types of technologies for dance and interactive sounds for dance). The last two subsections will deepen the scope to how different roles have been explored in interactive dance performance.

2.3.1 Designing For and With the Body

Interactive dance systems can be framed in a general reflection on interaction design with and for the body. Dourish, in his seminal book "Where the Action Is"(2001) [82], established the basis of embodied interaction as a way to bring computing back into the real world, defining the first theoretical framing for designing technologies with and for the body. This idea echoes the embodied cognition theory, which challenges the body-mind dualistic distinction of the Cartesian tradition (as proposed in the enactment theory by Varela [308], already mentioned in section 2.2.2.2). Dourish also widely refers to a phenomenological approach, referring to the idea that phenomena and experience are central to the questions about knowledge [82].

In Merleau-Ponty's book Phenomenology of Perception, the perception is presented with a specific focus on the body. Such a perspective can lead to an embodied understanding of the experience of human existence: "I cannot understand the function of the living body except by enacting it myself, and except in so far as I am a body which rises towards the world"[228], p. 87. Since the aforementioned book by Dourish, several different approaches have emerged. Particularly relevant is the idea of somaesthetics, a term by Shusterman to identify “a body-centered discipline” focused on “body's crucial and complex role in aesthetic experience” [280, p. 299]. Somaesthetics was introduced in the HCI as an approach brought to the embodied interaction design debate by Schiphorst [276] and Höök [138]. Such an approach emphasises the importance of bodily movements for existing in the world, as well as the human ability to train their bodily and somatic capacities [104].

H "o "ok has extensively worked on somaesthetic interaction design and has pointed out that "the only way to really "know"what soma-based designs are is to experience them through a first-person perspective"[135, p. 122]. The author continues presenting how "soma design is also an artistic practice"[ibid. p. 123]. The author had also pointed out four main qualities of the soma appreciation design: subtle guidance (as a way to point the attention inward focusing on specific bodily sensations), making space (involving slowing down the pace to make spatial and temporal space for reflection), intimate correspondence (creating interactions that follow the rhythm of the body), and provide means to articulate the bodily experience [137].

The centrality of body experience advocated in soma design has recently impacted many domains, including the design of interactive music systems. For instance, Avila and colleagues used soma design principles to perform a series of workshops to explore the relation between the body and the guitar in guitarists [209]. Additionally, in an installation by Bomba and Dahlstedt, where the participants' bodies are transformed into an instrument, was entitled Somacoustics, to refer to somatic experiences explicitly [33]. It is interesting to notice how in this case the authors refer to the idea of ecology, where the various elements mutually influence each other.

2.3.2 Technologies for Dance

The use of technology for dance has now a long and broad history, in terms of practice and research. This thesis will mainly focus on interactive tools for performances. The use of technology as a pivotal component of a dance piece predates the invention of digital technologies. For instance, Salter has analysed how technologies have been entangled with performances from works in the early XX century, such as Diaghilev's Ballets Russes in 1910s [274]. Such an entangled process continues with the current digital and interactive art practice, and in the last few decades, many relevant examples emerged. For instance, Mark Coniglio worked on MidiDancer (1989), a software that allowed a dance performer on stage to control music [11]. In the nineties, many other relevant works emerged; choreographers like Merce Cunningham and Bill T. Jones developed the aesthetic of the virtual body using a combination of motion tracking systems and computer animation. Relevant examples are works such as BIPED by Cunningham (1999) and Ghostcatching by Jones' (1999) [78]. A more recent example is offered by Frieder Weiss, who worked with the system EyeCon (2004), a system that allows controlling several aspects of performance through movement [316]. Since then, a variety of approaches to design interactive tools for dance performance have been proposed.

In the last decades, the Interaction Design community has increasingly paid attention to computational technology for dance, following a growing interest in the design with and for the body. Indeed, a number of different tools with a specific objective in mind has been developed, spanning from tools for documenting and annotating the choreographic

[11] http://troikaranch.org/artistic-directors/

process (e.g. [55, 44]); choreography generation itself (e.g. [45]), and real-time interaction (e.g. [94]).

In this area, Fdili Alaoui and colleagues have proposed a categorisation among different families of tools [1]. Such tools can be designed with different purposes: reflective tools that "depict movement information to provide different perspectives and Uses"; generative tools, "that generate movement material either autonomously [...] or manually"; interactive tools, that "allow dancers to interact with a digital media that responds in real-time to their performance"; and annotation tools that "allows choreographers to analyse, edit, play, and re-frame material in order to prototype it and craft it incrementally during the choreographic process" [1, pp. 3-5]. Another classification of technology for dance is proposed by Raheb and colleagues, who divided dance technologies into five main categories: choreographic tools; augmented performance; education; research and analysis; and games [261]. Finally, Zhou and colleagues have recently conducted a systematic review of the dance-related literature presented in HCI venues. In such a review, the authors identified three main application domains in interactive technology: creating, performing, and analysing dance [328]. This thesis will mainly focus on interactive tools according to the taxonomy by Alaoui et al. [1] or augmented performance according to Raheb and colleagues[261].

A central aspect of interactive tools is the definition of methods and strategies to extract information from the body. Alaoui et at. [95] distinguished among different approaches to gather information or data from a body: positional data recorded by motion capture; movement dynamics retrieved by inertial sensors; and physiological information obtained using biosignal sensors. Following a similar approach to adopt multimodal capture. Additionally, Camurri and colleagues have proposed a multimodal framework to analyse qualities in movement. Such a framework combines motion capture, physiological data, image and audio [47]. Another multimodal approach is offered by Fdili Alaoui and colleagues, who developed a methodology to combine multimodal data capture to recognise Laban Effort qualities [95].

Dance artists, alongside researchers, have been using interactive digital tools that extract information from the body in a wide variety of situations. Data collected analysing dancers' bodies for instance can result in visualisation (e.g. [142, 96]), interaction with any other element of a performance (e.g. dynamically and interactively changing the light [2, 93]), and particularly relevant for this thesis sonification (e.g. [3, 102, 51] - these and other examples of sonification will therefore be further analysed in section 2.3.3).

2.3.3 Interactive Sound Systems for Dance

Interactive sound systems for dance performance often rely on sonification; sonification is the transformation of data into sound [130], in this case, data from the body. Sonification is connected to the problem of how to transform (map) this data into sound parameters. In the music technology debate, Hunt and Wanderley have widely discussed the problem of mapping "as the act of taking real-time performance data from an input device and using it to control the parameters of a synthesis engine."[145], p 98. According to how the parameters are mapped, the authors distinguished between one-to-one mapping (one data to one parameter), one-to-many (one data to many parameters), or many-to-one (many data to one parameter).

There are abundant examples of interactive technology for dance and moving bodies. An important early example was offered by Camurri and colleagues who developed EyesWeb, a system for the analysis of body movement in real-time that can be used to manipulate sound and music [46]. The system used a set of metaphors to create sound based on the movement styles. Since then, many other examples have been developed. For instance, Alborno and colleagues proposed a sonification based on movement features; in particular, the authors focused on fluidity and kinetic energy; these features were afterwards mapped to five sonic parameters [3].

Another example is Choreomorphy [260]; this interactive system allows dancers to observe their own movement through sonification, which was achieved by transforming movements position and velocity into sound. Francoise et al. used Multimodal Hidden Markov Model for controlling granularization of voice samples [102]. Machine learning can also be used to perform the mapping from the body to sound; a tool like Wekinator offers support for such an approach [98]. A recent example of machine learning specifically designed for dancers is offered by Murray-Browne and Tigas [239]. Their system maps full-body movement to sound by leveraging on the latent space of an unsupervised machine learning system.

Movement sonification has also been widely used in installations. Bomba and Dahlstedt created an installation where the participants' bodies are transformed into an instrument, producing sound by moving into space [33]. Similarly, Morreale and colleagues developed a system where a couple of participants manipulates a music stream composed by an algorithmic agent through movement [237]. In both cases, the mapping process from movement to sound was not linear, Bomba and Dahlstedt speak about a "many to many mapping", where multiple data from the body affect multiple musical parameters, while Morreale and colleagues used an intermediate layer, as they mapped movement to emotions and emotions to music parameters.

2.3.4 Roles in Dance Performances

This subsection will outline some general traits of contemporary dance practice. A wide variety of different forms and styles of dance populate the contemporary dance panorama, with examples spanning from classical ballet to physical theatre and contemporary dance.

Within each specific dance genre, working methods are varied, and the roles played by dancers and choreographers can widely differ. For instance, dancers in today's contemporary practice can be easily asked by choreographers to improvise and thus actively and creatively participate in the creation process of a dance piece. Dancers can have different

Table 2.3: Didactic-Democratic spectrum model [42, p. 368]

	Process 1	Process 2	Process 3	Process 4	Process 5
Choreographer	expert	author	pilot	facilitator	co-owner
Dancer	instrument	interpreter	contributor	creator	co-owner
	Didactic Process				Democratic Process

degrees of freedom for improvisation also during a performance [43]. The term 'dance devising' is usually used to define the process during which the different roles of dancers and choreographers are defined. Butterworth has examined the different roles and the tasks associated with 'dance devising' rehearsal and performance ecologies. As a result of her analysis, she developed the Didactic-Democratic spectrum model [42, p. 368]. In such a model, she distinguished five kinds of processes (table 2.3).

At the one end of the spectrum (process 1 in table 2.3), the choreographer has control over every aspect of the creation of the choreography, and the dancer is an instrument who executes a predefined set of actions. At the other end of the spectrum (process 5 in table 2.3), the choreographer and the dancers act as collaborators; therefore, the dancer is involved at all stages of the creative work.

In dance and technology setups, the relationships among roles and tasks can become even more articulated. Indeed, dancers need to be aware, at least with an approximate degree, of the characteristics of the interactive artifacts. In light of these needs, Birringer has argued that there is a need for new specific performance techniques for dancers in these ecologies [25].

2.3.5 Different Roles in Interactive Systems for Dance

The multitude of approaches and roles described in the previous paragraph has started to be investigated in recent HCI literature. Fdili Alaoui [92] has thoroughly analysed a dance piece she authored [12].The project involved a musician, a second choreographer and the two dancers. In this study, many different perspectives have emerged, including the importance of appropriation, that is, the fact that technology can be either a partner or an instrument. The author argues for an anti-solutionist approach to dance technology design. Another example is offered by a recent work by Ciolfi Felice and colleagues, who had studied a creativity support tool for choreography in an extensive 5-month field study [97]. During the study, they observed a dance course involving a choreographer and six students. The study focuses on Knotation, a system for choreographic annotations that do not enforce any particular form of dance representation. From the observation, it emerged that "feeling of belonging to the group and to the creative process progressed throughout the course and increased their engagement with the piece" [97, p. 8]. However, the

[12] The piece is composed of three scenes: 1 - dancers triggering files 2: sonification of dancers' movements; 3 - dancer triggering the files.

"hierarchical roles were always present" [97, p. 9], showing that the distinction between the choreographer and the dancers in terms of tasks continued.

Some studies explicitly focus also on music creators in dance performance ecologies. For instance, by interviewing 23 choreographers and musicians working in the area of dance, Hsueh and colleagues observed that a creator can act as an author, a curator, a planner, or a researcher, while the performer can act as an interpreter, a creator, an improviser, or an informant [141]. Another interesting reflection is offered in work by Erdem and colleagues [89]. The authors offered a first-person analysis of a musician and a dancer co-creating a dance piece with interactive sounds. For the musician, the "dancer is the main source of gestural input, but the musician makes the decisions of the sound objects, data scaling, and mix levels in real-time" [89, p. 189]. For the dancer, performing with real-time sonification of her movement is profoundly different from normal dance as it "steers the movements at both conscious and unconscious levels, and provides a sense of coherence" [89, p. 189].

Different forms of collaboration among the various actors in an ecological inquiry have also emerged in papers focusing on interactive sound systems for dance. For instance, López and colleagues designed a system where the movement of a dancer influences processing effects applied over a drum played live by a drummer [184]. In the design of a DMI for dancers, Brown has paid particular attention to the cultural and social heritage of a specific dance style, and designed his system aiming at fostering social intimacy [41]. In this context, we can see how history and genre have entered the design dimension. History and genre are important elements of a performance ecology as already pointed out by Gurevich and Treviño [122].

According to what emerged in these studies, we can observe how important it is to account for the different perspectives of the various actors involved in a dance performance with interactive technology.

3

Methodology

This chapter will provide an overview of the Methodological approaches used in the development of the work presented in this thesys. The specific method used to collect and analyse data for each individual study will be presented in the corresponding chapter.

3.1 Overview of the Methodological Approach

This thesis is composed of an initial theoretical proposition of a framework to analyse performance ecologies, and a consequent evaluation. The design of the framework (presented in chapter 4) is based on a combination of existing theories, in particular on ecological perspective in HCI (see section 2.1, in particular 2.1.5), ecological perspective on music (see sections 2.2.1 - 2.2.5) and dance (see sections 2.3.4 and 2.3.5) performances (where different actors are accounted for), and design framework (see section 2.2.6). The framework is subsequently used in a 1) systematic literature review of how scores have shaped performance ecologies in NIME; 2) a set of case studies with music technology (in particular using screen scores, cfr. section 2.2.4) ; and 3) a case study on dance performance (in particular real time body sonification, see sections 2.3.2 and 2.3.3).

Whilst helping evaluating the theoretical framework, all these studies provide a vast variety of insights and information on performance ecologies. The case studies with music and dance technology primarily follow a research through design approach [329]. All the case studies were conducted primarily through field research in the wild (rehearsal and concert conditions) [53]. For the dance study, however, a focus group "in the lab" anticipates the field study in the wild. Indeed, it was important to first frame the research, and have contact with dance artists before going in the wild. This was not necessary in the case of music because of my background. In both the case studies a combination of autobiographical design [243] and idiographic design [134] is used. An overview of the methods used in this thesis is available in table 3.1.

Table 3.1: Overview of the methodology of this thesis

Chapter	**Content**	**Methodology**
4	Proposition of the ARCAA framework based on literature	
5	Systematic literature review of how score have shaped ecologies in NIME	Systematic literature review
6	Music - 3 Performances with screen scores (in the wild)	Research Through Design Mainly Autobiographical Design complemented by Ideographic Design
7	Dance - Initial framing and contact with dance artists (in the lab)	Research Through Design Mainly Ideographic Design complemented by Autobiographical Design
	Dance - 1 Performance with interactive sound for dance (in the wild)	

3.2 Research Through Design

In the last two decades, research through design established itself as a valid method to enquiry. As Zimmerman et al. pointed out, “the term design research implies an inquiry focused on producing a contribution of knowledge” [329, p. 494], not merely to design better products. The authors propose the following vision of Research Through Design:

“Interaction design researchers integrate the true knowledge (the models and theories from the behavioral scientist) with the how knowledge (the technical opportunities demonstrated by engineers). Design researchers ground their explorations in real knowledge produced by anthropologists and by design researchers performing the upfront research for a design project” [329, p. 498].

Such a combination of different knowledges is mediated in design research through the investigation of practical design artifacts.

Gaver has underlined the importance of the ability to manifest conceptually rich artifacts that research through design has, and can facilitate exploring, particularising, diversifying, and speculating as part of the research project [107]. The authors suggested that annotation (in particular, annotated portfolios) by taking the focus on the specificities of the case, without looking for standardisation, can “further our ambitions to produce relevant and rigorous theoretical work, while allowing multiple perspectives to flourish” [107, p. 10]. For the author, design examples prioritise theory.

In a study involving 12 leading interaction design researchers, Zimmermann and colleagues identified three main scope for research through design. Research can be about the design process, that focuses on understanding the human activity of design. A second type of research to improve design practices whose outcome include frameworks, design recommendations, methods, guidelines and implications. A third type of research that relies on design focuses on how a given future might be [330]. This thesis will primarily contribute to understanding the human activity of design and to improve design processes by offering a framework and a wide set of insights. As we have seen in section X, the design of a new system and the process of composing are intimately intertwined, therefore the contribution of this thesis can be useful for music creation/performance with interactive digital technology.

The work presented in this thesis widely relies on these different elements of research through design. Using the classification by Zimmerman et al. [329], true knowledge is derived from HCI theories and Design framework for music technology, and is produced in the form of a new framework, that can be used to analyse performance ecology; how knowledge is derived from the music technology (in particular screen score), and dance technology (in particular motion capture), and insights are produced from the lessons learned during the case studies. Finally this thesis primarily based his explorations on real knowledge, using observational methods derived from ethnographic and sociological approaches [1].

The research though openness valued by Gaver is fundamental in this thesis to observe the different forms of appropriation and how the various actors in a performance ecology develop specific affordances in relation to the various artifacts, suggesting some specific set of actions.

3.3 Research In the Wild

With the spreading of computing systems in a vast variety of real world context, a need to investigate it in such scenarios emerged. Dourish has promoted the advantages of using sociological and ethnographic approach [82]. According to the author, ethnomethodology can be particular relevant, as it pays "attention to the detailed analysis of actual practice [...] to find [...] evidence for the way in which people achieved orderly social conduct". Combining this idea with the need to study how people use computing systems Dourish proposed the idea of technomethodology an approach aiming to analyse how the "organisation of actions is a moment by moment, naturally occurring, improvisational response to practical problems" [82, p. 77]. An ethnographic approach proved to be of value to study artifact ecologies of musicians in a recent study by Avila et al. [6]. Overall in the past two decades a vast number of researchers started to move their research from lab-based environments out into 'the wild' [53]. The scope of research of interaction design is different from other approaches, as Rodger has pointed out:

> "One main difference is where the research starts and ends: unlike user-centred, and more specifically, ethnographic approaches which typically begin

[1] The specific method used for each study will be specified at the beginning of the dedicated chapter

> by observing existing practices and then suggesting general design implications or system requirements, in-the-wild approaches create and evaluate new technologies and experiences in situ" [272].

Benford and colleagues have explored the notion of artist-led research in the wild research, tackling those cases in which the interactive system is designed for artistic purposes "meaning that they originate with the creative vision of artists" [17, p. 2]. According to the authors such an approach is composed of three main activities: practice in which artists and researchers collaborate or to realise new artworks; studies of the artworks, in which researchers who may employ a variety of methods to investigate, document and analyse the practice; and theory (and framework), that on one hand are informed by studies, and on the other inform new practice. Practice and studies are mutually influencing each other and often part of a recursive process. In this thesis, I will start by proposing a new framework based on existing studies, theory and my previous experience. I will afterward use it to inform new practice as well as to analyse previous practice that will be finally used to refine the framework itself.

As we have seen in section 2.2.2 the roles of musician and technologists in the music domain can often overlap, and in many works presented at NIME, the researchers/technologists were also composers/performers. This thesis will follow a similar approach being involved in first person as a music technologist and musician. In the case studies, I will be involved also in the use of these systems, following an autobiographical approach to interaction design, the developed systems have also been designed or fined tuned according to the need of the other actors involved (musicians, cartographers, or dancers) therefore following an ideographic design approach.

3.4 Autobiographical and Idiographic Design

Autobiographical design is "design research drawing on extensive, genuine usage by those creating or building a system" [243, p. 1]. Such an approach shares similarities with autoethnography, that in HCI can be used "particularly in situations where a deep understanding of one's experience is critical to the development or evaluation of a new technology" [70, p. 754]. The essential difference between the two approaches is that the "autobiographical designer iteratively designs, builds, and uses her own designs" [70, p. 755]. In the field of music technology autobiographical design has been recently used in the design of a smart mandolin [302]. Additionally, a self reflective approach has been used (in combination with data collected from participants) to design augmented guitars for percussive fingerstyle [208].

Idiographic research, similarly to autobiographical design, aims at collecting data from one or few individuals, but differently from autobiographical approach, these individuals are different from the researcher. Parallels between the two approaches have been discussed by Hook et al. [134], the authors build their argument on the importance to study idiosyncratic interactions, on the experience of autobiographical design. It is important to notice that such individuals are not considered necessarily a representative part of any group. Such an approach is typical in medicine [258]. Bagnara and Pozzi have argued that idiographic design is a form of design "that draws insight from the detailed and particular consideration of individuals' practices and experiences" [258, p. 2]. Idiographic design is de facto a method used in all those studies in which the performers were involved in the design of a new DMI (see section 2.2.2). Additionally, Hook has recently directly referred to an idiographic approach to designing a project whose objective was to develop a live interface for audiovisual performance [134].

In all the case studies "in the wild" presented in this thesis, I will use both approaches. In the case studies on music 6, I will primarily use an autobiographical perspective on an aesthetic level, as the technological artifacts are based on my own view as a composer. However, I do not directly interact with these technologies during a performance, being these tools screen scores designed to complement instrumental practice. Therefore, an idiographic design approach is used to teilor the technology to the idiosyncratic characteristics of the participants (musician/instrumentalist) in the studies as performers of the pieces.

In the case studies on dance 7, I will primarily use an idiographic perspective, being the technological artifacts primarily based on the need of a choreographer. Such an approach will be complemented by an autobiographical design approach to also analyse my perspective as a sound designer developing the technology for the choreographer.

4 ARCAA

This chapter primarily introduces the *ARCAA (Actors, Roles, Contexts, Activities and Artifacts) Framework*, a model that aims to support musicians and designers in identifying, framing, and studying performance ecologies in a specific performance. In particular, it allows to frame the role of the different actors in relation to the artifact ecology of that performance [1]. Numerous design frameworks have been developed to investigate the design of interactive music systems, as further detailed in 2.2.6. However, most of the studies on the design of musical interfaces restricted their investigation to specific aspects of a piece of interactive music technology, for instance on the basis of the interaction modalities [152]; playability and learning curve, [154]; or expertise, control, feedback, and freedom [24]. Morreale et al. [231] propose a design framework (MINUET) centred on the experience of the player. MINUET is a design process structured into two stages: the first one analyses the goals of the interface; the second stage specifies how to practically achieve these goals. The goals are articulated around three main elements: People, Context and Activity.

Overall, considering the complex set of elements that compose scenarios in which the music performances take place seems to have been overlooked in the existing formalised models. Specifically, no previous work has tried to identify the ways in which different human actors are involved in the performance when they are not *using* it, in the sense that they are not directly operating the technology, nor are there frameworks that consider the different artifact ecologies in music performance. However, a piece of music technology is not used in isolation, and its use is often immersed in a complex ecology of other objects and other people (see section 2.2.5). ARCAA has been conceived to analyse in a formalised way such ecologies by visualising the interconnections among the various elements. ARCAA can be particularly relevant in those situations where there are multiple persons and/or multiple objects involved in the same scenario.

[1] Parts of the text in this chapter have appeared in the co-authored publication [217] and is based on reflections developed in [223] and [211].

4.1 Terminology Choice: Actors and Artifacts

Before detailing the various layers of the ARCAA framework, in this section, a brief outline of the terminology choice is presented.

Actors. In a recent paper, Rodger and colleagues have argued that “musicians are not users” p. 405 [270]. The authors claim that as there is no correct "use"of a musical instrument: "there may be no such person that can be picked out as the instruments’ ’prototypical user’"p. 406 [270]. In line with this reflection, the term *actor* has been adopted to identify the compound of persons involved in a given ecology. The term actor is borrowed from Bannon’s suggestion to switch from the idea of human factors to human actors. The author has claimed that the word user inherited an implicit view that "treat people as, at worst, idiots who must be shielded from the machine, or at best, as simply sets of elementary processes or ‘factors’ that can be studied in isolation in the laboratory."[11, p. 1]. For the author, the term actor puts the focus on the “set of skills and shared practices based on work experience with others” [11, p. 1], and highlights the relationships between humans, computers and environments.

Artifacts. Carey and Johnston have pointed out that in NIME research artifacts are often “considered both an outcome of the research, and also an integral part of the research method” [50, p. 378]. Aligned with this idea, the term *artifact* has been used in the ARCAA framework. Additionally, this term highlights the importance of ecologies of tools (see section 2.1.5), as it is directly borrowed from the term artifact ecology [157]. In section 2.2 it has been pointed out how a piece of music technology embeds a certain way in which music is intended, thought of and performed. In some cases a specific piece of technology is a music piece itself, becoming its score (e.g. Hornpipe (1967) by Gordon Mumma [247]). This idea is well formalised in the concept of the “composed instrument” by Schnell [277], as composed instruments often overlap the act of composing with the act of designing an instrument, consequently blurring the distinction between designers and composers [199]. This thesis proposes the term *Open Sonic artifacts* to define those sonic interactive systems that subsume the specific aesthetic of an art piece and at the same time, while at the same time allow for different persons (i.e. composers, designers, performers) to have a personal relationship with it. The term Open Sonic artifact is derived from the conceptualization of Open Work, proposed by the philosopher Umberto Eco to describe those musical pieces which have a final form open to interpretation [87].

4.2 The ARCAA Framework: Actors, Role, Contexts, Activity and Artifacts

ARCAA is the conceptual framework proposed in this thesis to facilitate the understanding of roles and the actions of the different human actors involved in an interactive music scenario, within their ecology of artifacts. In particular, ARCAA focuses on how each different human actor is related to the entire ecology of artifacts that composes a performance scenario.

The framework considers the scenario of one music performance from a holistic perspective. Rather than limiting the scope of its investigation to the physical space of the performance, this model includes those situations that anticipate the performance itself. The compound of these situations might also include compositional aspects and the design of the various technological elements involved, especially if the pieces of technology have been developed ad-hoc for a specific performance, performer, or set of performances. Additionally, ARCAA suggests accounting for the entire set of human actors that have a role in the ecology, including all those musicians performing alongside a piece of technology, composers, designers, developers, consultants and so on, not only including the actors who are physically operating the technology. Even if the primary purpose of ARCAA is to support the inquiry over digital music technology, the model also takes into consideration the non-digital artifacts as part of the scenario, including for instance acoustic instruments and scores. ARCAA differs from the existing frameworks primarily because of this focus on the entire set of human actors and artifacts, rather than only on those individuals directly operating a system. Additionally, by shading the light on the preparatory, compositional, and design phases of a performance, it proposes a wide conception of a performance ecology.

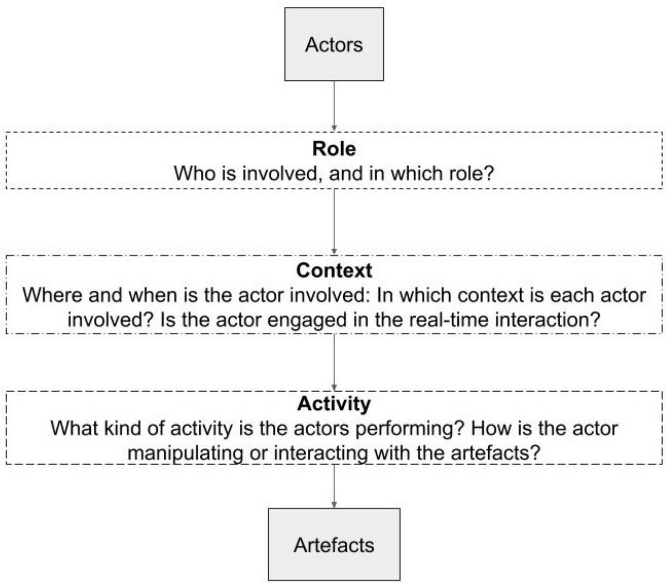

Figure 4.1: Structure of the framework: ARCAA (Actors, Role, Context, Activity, Artifacts). The framework connects all the actors (top in the scheme) to all the artifacts (bottom in the scheme) throughout the three levels: Role, Context, Activities. Each Level proposes different questions related to the actors: **Who** is involved, and in which **role**? – Where and when is the actor involved: In which context is each actor involved? Is the actor engaged in the real-time interaction? – What kind of activity is the actor performing? How is the actor manipulating or relating to the artifacts?

The structure of ARCAA is borrowed from the three top-level dimensions identified in MINUET that refers to the specific goals of a digital musical tool [231]: *People*, *Context*, and *Activities*. The MINUET framework specifically focuses on the individuals who are interacting with pieces of music technology and their needs, and it has already shifted the focus from the technology to people. Therefore it represented a grounding foundation for ARCAA. In ARCAA, the term *People* has been changed to *Role* as the same person can play more roles, while *Context* and *Activities* maintained the same terminology. In ARCAA, these three levels are used as lenses to progressively connect all the actors with all the artifacts.

The term *Role* aims at framing the roles played by the actors involved in the interaction; *Context* distinguishes among actions carried out in different stages, for instance discriminating from actions performed during the live interaction from those that are performed before; *Activities* probes into the specific actions performed by the different human actors in relation to the different artifacts. The objective of this model is to analyse the role of each actor through different levels and gradually define the different connections that they have with the technological artifacts at play. The overall structure of ARCAA is shown in figure 4.1.

An innovative aspect of ARCAA, compared to other DMIs design frameworks, is to look at the artifact ecologies of those actors that are not actually using the technology, but whose role is essential to, and whose activities are affected by, the interactive digital artifacts. Another novel aspect of this model is the inclusion of non-digital artifacts, such as traditional instruments.

4.3 First Level: Actor's Role

The first level focuses on identifying the *role* of the actors involved in the scenario. The actors include the individuals who can be considered *users* in the traditional HCI sense (those who use the artifact), but also other human actors whose presence is relevant in the music performance. Overall, the first level proposes this question:

> ***Who** is involved, and in which **role**?*

The following list shows the most typical roles. This list is not meant to be comprehensive of all the possible roles in music performance. Rather, we support that these categories depict some of the main distinctions in roles and can offer key concepts to be fine-tuned for each specific scenario.

- *The Designer/programmer* should be considered in those cases in which the design process occurred in parallel with the creation of a performance or a piece; this case is quite common, a recent relevant example being the LaptOpera "The Furies"[129].

- *The Composer* is responsible for creating a piece, in a way that its core characteristics are not bound to a single performance, and are, to some extent, repeatable. In many cases, the composer is also the designer/programmer as in Hornpipe [188], or with the Threnoscope [198]. However, the composer can also be separated for the designer [251].

- *The Performer of a digital instrument* can be considered the traditional *user*, she is the actor that directly manipulates the technology. However, it is important to consider that, with digital musical instruments, the idea of "user"is misleading, as this type of technology tends not to be task-oriented [270]. Therefore, it is important to consider the performer not merely interacting through ergonomically curated tangible interfaces or graphical tools, rather it is important to conceive them as musicians, with a wide variety of skills and knowledge (as internal ear, rhythmic abilities, non-verbal communication, and a set of musical references) that are involved in the performance.

- *The Instrumentalist* is a performer that plays a non-digital musical instrument. There are many scenarios in which traditional acoustic instrumentalists happen to play in situations where some type of interactive technology is involved, including for instance live electronic manipulation of the sound of acoustic instruments (e.g. many pieces by composers like Berio (see [113])[2], Stockhausen [285][3], Boulez see [147] [4]); pieces for instruments and tape, (e.g. pieces for solo instrument and tape[5]), or situations in which instrumentalists read scores generated or manipulated in real-time using computational systems (e.g. [140]).

- *Dance artist*, in case of dance pieces involving interactive music technology, as described in section 2.3.3 there are many interactive sound systems designed for dance performance.

- *The audience performer*, in case of audience participation. Recent developments of ubiquitous computing allowed audience participation in the performance (e.g. [317, 249, 321]). In these cases the audience actively manipulates the music using mobile applications, therefore can be considered a specific type of performer [6].

[2] An example by Berio is the piece *Altra Voce*

[3] An example by Stockhausen is the piece *Mikrophonie*

[4] An example by Boulez is the piece *Dialogue de l'ombre double*

[5] Relevant examples of pieces for solo instrument and tape are *Voilements* by Jean-Claude Risset, *Traiettoria... Deviata* by Marco Stroppa

[6] Despite the fact that audience participation, and overall the role of the audience, is relevant in performance ecology, this thesis do not focus on this aspect, therefore this element will not be explored in the rest of this thesis.

4.4 Second Level: Context

The second level of ARCAA aims at scrutinising the specific context(s) in which each actor is involved. In the first ARCAA level (Role), we have seen that a single actor might play different roles, and such roles could be performed in different contexts. Therefore, it is important to consider each different role while analysing the context(s).

The label *context* refers to the actual moment in time and space in which the actor is involved, and it proposes two main steps in the analysis that identify two main questions: where and when. Overall, the second level addressed this question:

> ***Where** and **when** is the actor involved: In which context is each actor involved? Is the actor engaged in real-time interaction?*

The context mainly distinguishes between *on-stage* and *off-stage* and reflects the preparatory moments of a performance and the actual performing time; this distinction echoes the composing-performing dyad (described in section 2.2.1). The terms *stage*, in *on-stage* and *off-stage* refer to the place in which the performance occurs, but not necessarily to the traditional stage, it can be any performative space. In the on-stage context, the actor is usually involved in real-time interactions, whereas this is usually not the case in the off-stage context. The contexts' characteristics can be summarised as follows:

Where:

- On-stage: the actors engage, live, in real-time interactions with the main pieces of interactive technologies and the other elements present on stage. Performances typically occur on stage, and also rehearsals usually occur, at least partially, on-stage, as they typically rely on real-time interactions.
- Off-stage: the actors are preparing the performance (e.g. designing the instrument, composing the piece) thus do not engage in live interaction.

When:

- In real-time: the interactions have a real-time impact on the performance, usually, in these cases, the interactions do not imply making modifications to the artifacts themselves. The on-stage context tends to imply real-time interactions.
- In non-real-time: the interactions do not have a real-time impact on the performance; these types of interactions include modifications to the technology for the objectives of the specific piece or performance. Usually, off-stage interactions do not occur in real time.

In general, the pair *on-stage* and *in real-time* tend to go together, and the same applies for the pair *off-stage non it real-time*. However, it is also worth pointing out that the creation of a piece and of an artifact often undergo a recursive process of trials, rehearsals, and redesign. Thus, the process continuously reiterates between on-stage and off-stage, and the distinction can become blurred.

4.5 Third Level: Activities

The third level finally connects the actors to all the artifacts. In this level, the net of connections between each actor and the artifact ecology emerge. These connections are expressed through the typologies of activities that the actors perform in relation to the various artifacts: the same actor might simultaneously perform different actions, and different actors can perform different actions in relation to the same artifacts. For instance, an acoustic instrumentalist may be playing the flute while reading a score from a screen score system, and a second actor can manipulate the screen score. The question that this level poses is:

> ***What*** *kind of activity are the actors performing? How is the actor manipulating or interacting with the artifacts?*

The following list presents some of the most common activities:

- *Designing* a digital artifact specifically for one performance. This is the case of many composed instruments [277], in those cases in which mapping is part of the compositional process [293].
- *Playing a DMI* that corresponds to directly *using* the interface in a more traditional HCI sense. This type of action characterises almost all the performances with interactive music technology, for instance, most of the performances presented at NIME[7].
- *Composing* a piece that includes the use of interactive music technology, this may include composing scores or creating sonic material. As largely discussed, designing and developing a new instrument are part of the compositional activities (see section 2.2.2). However, the term composing, in this list, refers to the activity of composing for existing DMIs, a relevant example being the case of the Magnetic Resonator Piano [251].
- *Dialogue with generative systems* that algorithmically produce music based on musical input (e.g. The Continuator [252] that engages improvisations with pianist playing on a MIDI keyboard, or SEMA that can create new musical elements based on codes written by a live coder [19], this type of interaction has been widely discussed by Lewis [179, 180]).

[7] https://www.nime.org/music/

- *Playing a non-digital instrument*, this happens in cases in which a traditional instrumentalist is involved – for instance, in pieces where the sound of acoustic instruments is electronically manipulated; pieces for instruments and tape; or with other interactive contexts of acoustic instruments alongside DMIs or screen scores.

- *Reading* a score. This can be a paper score, that has been previously composed and provides information about alignment of electronic sounds (for instance, in the same examples of pieces for solo instrument and tape just presented for the "playing" activity);scores that are automatically aligned using score following [250]; or real time generated/manipulated scores that are displayed on a screen [140].

- *Providing data* for an algorithmic system, this case is more typical, for instance in dance pieces, where the dancer is not actively playing the interface, but data from what s/he is doing is used for music and sound generation or manipulation (e.g. [3, 46, 130]) .

This list cannot be exhaustive of all the possible activities that happen in a performance, however, it provides an initial set of examples informed by literature, that can be used as a starting point to apply ARCAA to specific performances.

4.6 ARCAA and Interaction Design Literature

This section highlights connections between ARCAA and interaction design literature, in particular with artifact ecologies and the design-in-use model.

4.6.1 ARCAA and Artifact Ecologies

ARCAA connects all the actors with all the artifacts in a given performance ecology. Therefore it can help to understand how different persons are related to the various artifacts, and how the same artifacts are involved in different activities with different actors. From this perspective, the framework reflects the idea that artifact ecology can be applied both to study an ecology of people interacting with one single artifact [31], and social interaction in groups using such a set of artifacts [172, 32]. Overall, the different actions developed by the various actors in relation to the various artifacts correspond to different affordances. The model, by highlighting the various actions, can help to understand these affordances. It can also help to understand how the same object corresponds to different affordances in relation to different actors, as supported, for instance, in [128, 90].

4.6.2 ARCAA and Design-In-Use

This subsection highlights some parallelisms between ARCAA and design-in-use framework by Botero and colleagues [37]. As detailed in section 2.1.4.3, Botero's model is

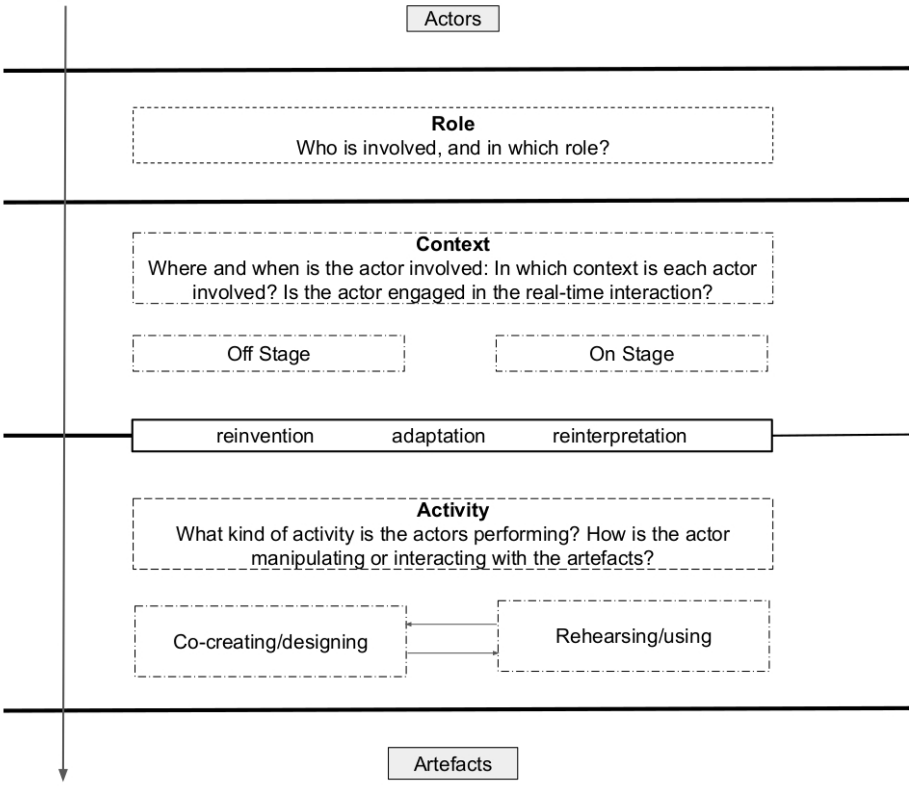

Figure 4.2: The ARCAA with the design-in-use model

composed of three main categories that identify different levels of appropriation: *Reinvention*, *Adaptation*, and *Reinterpretation*.

Referring to the design-in-use model, the reinvention category (design) reflects mainly the activity that will more likely happen off-stage, in the preparation of new technology for a specific piece. Adaptation can occur in the iteration of fine-tuning and rehearsing. Finally, the reinterpretation category by Botero reflects the perspective of the on-stage setting, where the technology is actually used for creative pour poses. An overview of these parallels can be seen in figure 4.2.

4.7 Conclusion

This chapter introduced ARCAA and connected it with the main elements derived from other design frameworks, with other existing literature in music (and dance technology), as well as with literature on Artifact Ecologies and the design-in-use model. The rest of this thesis will deploy the model in different contexts, as a tool: for systematic literature review (chapter 5), to study ecologies related to screen score systems (chapter 6), and to analyse dance ecologies that include interactive sonic systems (chapter 7).

5

A Taxonomy of Performance Ecologies of NIME Systems that Rely on Scores

As detailed in section 2.2, musical scores have influenced electronic musicians' thinking. At the same time, electronic musicians have appropriated the conception of scores, adapting it to new musical languages and new technologies. Scores can be central and even pivotal in music performance ecologies. Indeed, scores can act as elements that connect musicians, music, and instruments; usually, different categories of musicians: composers, who write scores, and performers, who read scores; or different performers that read and play the same score. From this perspective, scores can be understood as interfaces connecting different people and the music that can be central in determining inter-relations within performance ecologies.

This chapter will focus on how such relation reverberated in the papers presented at the International Conference for New Interfaces for Musical Expression (NIME) in which scores play a central role. In this analysis a taxonomy of the different performance ecologies that correspond to these papers is created. This taxonomy results from a systematic literature review of the NIME proceedings. Papers presenting systems and the corresponding ecologies have been analysed by using ARCAA (chapter 4). The articles have been based on similarities in the ecologies. This analysis produced a taxonomy of five main categories[1]. As a complementary contribution, this analysis also highlights the new different types and conceptions of scores that correspond to such ecologies.

5.1 Self-reflections Within the NIME Community

The NIME Conference is an annual event that focuses on late-breaking work on new musical interface design [2]. NIME community has been characterised by a distinctive

[1] Parts of the text in this chapter have appeared in the co-authored publication [213].

[2] "The conference started out as a workshop at the Conference on Human Factors in Computing Systems (CHI) in 2001. Since then, an annual series of international conferences have been held around the world, hosted by research groups dedicated to interface design, human-computer interaction, and computer music". From the NIME website: `https://www.nime.org/`.

attitude toward self-reflective research. For instance, in 2017 a compound book that comprises the most impacting and relevant papers presented at the conference has been edited [149]. The editing process of this book brought to the analyses of general trends in the conference [150]. Another overview of the evolution of the conference has been recently offered by Fasciani and Goode, who presented a detailed analysis of the various locations, attendance and geographic distribution of the participants in all the editions of the conference [91]. In the years, many self-reflective research articles have been presented at NIME, looking at specific aspects of interactive music technology. For instance, researchers have developed research that reflects upon the identity of new technologies in relation to the music performed with these instruments [236], creative and technical discourses surrounding DMIs design [49], the relation among control, limitations, and creativity in NIMEs [202], the value of community in interactive music research [206], practice-based research approaches [50], the use of thematic analysis [296]. In this context, systematic analysis of NIME proceedings has been used for different purposes, for instance to investigate the meaning of the word *gestures* for researchers publishing at NIME [148], or to classify the different evaluation strategies used [12]. Additionally, recently, proceedings from the NIME, ICMC, and SMC conferences have been analysed to explore how the issues of stability, reliability, and compatibility have been addressed [287].

5.2 Systematic Literature Review Methods

The systematic literature review was conducted using the search in Zenodo [3], using *score* as keyword.

According to the Zenodo guidelines [4], results match records of the selected term in any field of the repository. This research has been performed on the week of the 26th of October 2020. Zenodo returned 51 papers as the result of this research. Eight papers were excluded from the analysis, of which five were excluded because in these papers the term score is simply mentioned, but scores are not central in the interaction: [125, 190, 229, 242, 264]. Of the remaining three, one paper used the word score to indicate point counting in a game [69]. Finally, two other papers have been excluded because there is no relation between the musician involved in the interaction and the score [166, 323]. One of these papers [166] presents a system in which a score is used for musical elements that are played by different devices, however, there is no person-score relationship in this system, as the various devices autonomously interact among themselves. The other paper [323] presents a study in which piano scores have been used to train a system for automatic accompaniment, but there is no real interaction. Figure 5.1 presents the occurrences of the papers for every year after the exclusion.

[3]Zenodo is the official NIME proceedings repository: https://www.zenodo.org/communities/nime_conference/?page=1&size=20

[4]https://help.zenodo.org/guides/search/

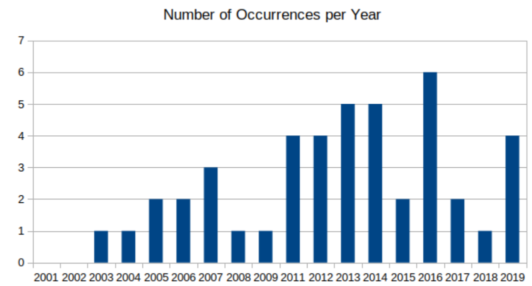

Figure 5.1: Number of occurrences per year after the exclusion.

The identified 43 papers have been analysed following a three-step procedure. In the first step, an ARCAA representation for each paper has been created. The second step focused on the type of actions that the musicians perform regarding the score and the main interactive system, also considering the context as emerged in ARCAA. In the third step, the codes have been recursively harmonised and clustered according to similarities in the corresponding schematic representation realised with ARCAA. This third step followed a procedure inspired by thematic analysis [40].

The analysis produced five main categories, two of them with sub-categories. It was not possible to cluster three papers. An overview of the results of the clustering process is provided in the table 5.1. In the following sections, categories and sub-categories are detailed, and the interactions that emerge in the various papers are briefly described. The

Table 5.1: The overview of the literature review results

Category	**Sub-categories**	**Papers**
Scores as instructions (15 papers)	Scores suggesting how to play a particular new DMI (3 papers)	[35, 124, 324]
	Scores suggesting how to play an acoustic instrument for pedagogical purposes (3 papers)	[126, 165, 192]
	Scores suggesting how to play an instrument in non-pedagogical contexts (9 papers)	[16, 48, 86, 123, 139, 160, 167, 230, 257]
Scores as an interface to play a DMI (10 papers)	Interaction with the score only in real-time (6 papers)	[74, 155, 176, 198, 256, 299]
	Interaction with the score in a two-step process (4 papers)	[54, 101, 205, 284]
Score as synchronization (6 papers)		[68, 116, 182, 186, 250, 298]
Scores creation (6 papers)		[103, 105, 174, 203, 266, 267]
Score as a recording (3 papers)		[18, 181, 254]
Non categorized papers (3 papers)		[144, 262, 269]

order of the various papers presented in paragraphs is based on similarities within the categories and sub-categories.

5.3 Scores as Instructions

The first category comprises 15 papers in which a score gives instructions in real-time to a performer who is playing an instrument (in most cases, a non-digital instrument), like in screen score systems [140]. In these papers, scores are one of the main outputs of the interactive music systems. Instrumental performers tend to be implicitly conceived as the primary (and in many cases the sole) actors, and the scores are conceived as the elements that provide instruction on how to play their instrument. In this category, all the interactions with the score and the system primarily occur in a real-time context either for concert or rehearsal. Figure 5.2 represents the core element of this ecology; some papers also have other actors (for instance, individuals manipulating a score in real-time), but in all cases, the configuration represented in figure 5.2 is at the core of the interaction. It is important to underline that these scores have a composer. However, these papers focus on the type of interaction that performers have with the score, not the relation with the composer. The sub-categories are defined according to similarities in the type of instrument performed (DMI or non-digital instrument) or in the specific context (a subset of papers developed systems for pedagogical and learning application).

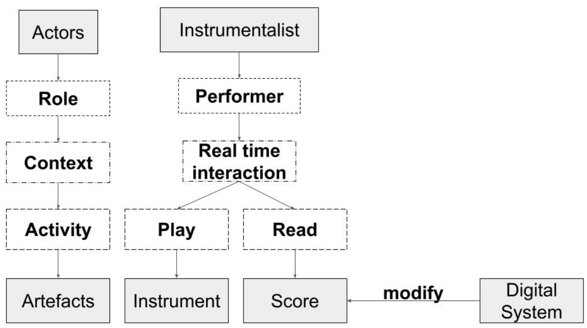

Figure 5.2: The core performance ecology of the first category.

5.3.1 Scores Suggesting how to Play a New DMI

In three papers, the score is used to give indications or support performances with a new musical interface or instrument. In two of these three papers, the musician reads the score while performing with a DMI. In one case, the DMI is controlled by a Brain-Computer Interface (BCI) [124] and in the second case it is a keyboard that controls a vocal synthesiser [324]. In both these cases, the ecology is relatively simple; there is one actor who plays the role of the performer in real-time and plays a new DMI while reading a score. The last paper in this sub-category presents MICON [35], an installation where visitors can control an imaginary orchestra while reading a score displayed on a screen. This example is slightly different compared to the other two as the context is not performative, and the notion of the performer is a bit stretched in this case. Indeed, in this case the main actor conceived in this paper is a visitor rather than an instrumentalist who controls an interface rather than plays an instrument. However, the connections in the ecology create a structure comparable with the other two papers presented in this subsection: the relation that the main actor has with the digital technology that produces the sounds (play/control) and with the score (read in real-time).

5.3.2 Scores Suggesting how to Play an Acoustic Instrument for Pedagogical Purposes

Three papers presented systems designed to support students or novices in learning how to play an instrument. Two of these papers [165, 126] present a system that listens to the performer/student and displays errors or alignment issues as an additional visual layer on the score in real-time. These two papers present the very same ecology: one actor in his rehearsal/study context plays his instrument while reading a score on a screen, which also provides information about eventual errors. The third paper in this category has a slightly more complex ecology, as it also includes a maestro who plays the role of the conductor [192]. In this paper, the system takes the time provided by the conductor and displays it on the score to facilitate beat counting to the pupils. This paper has been incorporated in the same category as it belongs to the same context, and the primary actor (the student) has a similar relationship with the score and the instrument.

5.3.3 Scores Suggesting how to Play a Non-digital Instrument in Non-Pedagogical Contexts

This last sub-category comprises nine papers in which an interactive system displays a score in real-time, and a performer plays an acoustic instrument. In some cases, the score is directly manipulated by some actors. For instance, in one case, the performer controls the score (with a pedal) [160], and influences it by her movement in another case [123]. In these two cases, the instrumentalist, while performing, reads a score and plays her instrument, but at the same time, her actions have an impact that affects the score. So the instrumentalist acts both in the input and in the output phases of the interactive systems. In the majority of cases, however, the score is not controlled or manipulated by the instrumentalist. Therefore, from the instrumentalist perspective, the score is only the output of the interactive system. These cases include papers where many instrumentalists read the score on screens in network performances [16, 48] and a case in which a pianist performs a screen score that is influenced by an audience member with a BCI [86]. In another case, the score is delivered to the performer in the form of temperature feedback [230], different keys of a piano keyboard change temperature according to the score's notes. The notion of reading is not literal with this paper, but still, the musician has to understand and interpret the information that the score gives him.

In the last three papers belonging to this category, composers are explicitly mentioned and briefly discussed. In one case, the composer is mentioned as the actor who adapts the score for a digital visualization [139]; in another case, the composer is mentioned as the main author of the piece [257]. However, both papers mainly focus on the experience of the performer, not deepening the description or the discussion of the role of the composers. In both cases, the performer relates to the score and the instrument in the same way as the other papers in this category. The last paper belonging to this category is a system in which the composer actively manipulates the score in real-time, and a pianist reads it and performs it [167]. This paper has been clustered in this category because, from the performer perspective, the situation is identical to the one described above where a screen score is influenced by an audience member [86], with the instrumentalist conceived as the main actor who reads the score, and the score as the output of the system.

In some cases, the overall ecology varies slightly (composers explicitly mentioned, or one audience member influencing the score). However, the core of all this category' ecologies is the same: the context is performative, and the performer plays her instrument while following the instruction on a digitally modified score.

5.4 Scores as an Interface to Play a DMI

The second category comprises ten papers presenting systems in which the score is used as an interface to control a new DMI. In these interactive systems the score is the input. In this category, there are two main sub-categories: 1) systems in which all the interactions with the score occur in real-time, and 2) systems in which there is a two-step process; before the performance, some actors define some element of the score, and during the performance, they explore them. The core relationship of all these papers - the score is manipulated as an interface to play a DMI - is the same, and for this reason, these papers have been categorised together. However, the two sub-categories present slightly different core ecologies, and for this reason, an ARCAA representation for each sub-category is presented in each of the following dedicated two subsections.

Overall in this category, a performer in a real-time performative interaction creates or manipulates a score as a way to perform with the DMI. The score is the input/interface and the DMI produces the sound. In some of these cases, the interaction with the score always occurs in real-time; in other cases, the musician can set up some elements before the performance and then interacts with them.

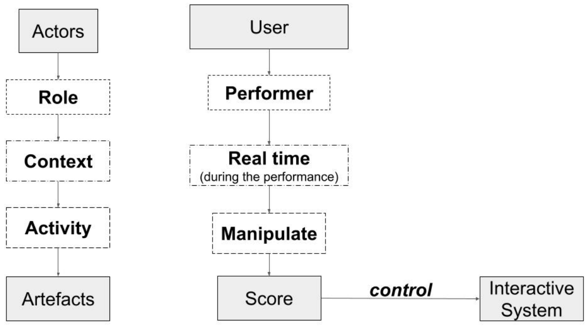

Figure 5.3: The core performance ecology of the first sub-category of the second category.

5.4.1 Interaction with the Score only in Real-Time

In this sub-category (six papers), the musician interacts with the score only during the performance (Figure 5.3). Examples include systems in which tangible elements are new forms of scores, such as physical objects representing notation that can be placed on a Reactable [155], or tangible plates with graphic elements engraved that can be explored through touch [299]. Such plates represent the score as an inherent tangible layer of the instrument. Graphic elements that represent the score have also been used as a representation of the music in live coding contexts; in this case, the performer modifies the score by using code [198]. The DMI Notesatz combines a mixed approach between tangible and graphical exploration of scores as a tangible interface is used to explore a graphic score [74]. In the last two cases, the manipulation of the score is collaborative, and different audience members can manipulate it via web networks [256, 176].

5.4.2 Interaction with the Score in a Two-Step Process

In this sub-category (four papers), the musician defines some score elements before the performance and interacts with them during the performance (Figure 5.4). Some systems use scores as visual elements; for instance, in LUSH, a preloaded score is transformed into a visual space that can be explored during a performance [54]. In another example, the performer can define their rules before the performance and use such rules to draw a score on a whiteboard and scan it to affect the musical output [284]. Similarly, CABOTO [205] takes as input a score created before the performance that can be explored during the performance. In the last example [101], before the performance, the performer defines the parameters of the score, and in real-time, she can explore them with a gestural controller.

5.5 Score as Synchronisation

Among the six papers belonging to this category, five papers present systems in which a score is used for synchronising or relating the performer's actions with other elements [68, 116, 250, 298, 186]. In all these papers, the system listens to the musician(s) for

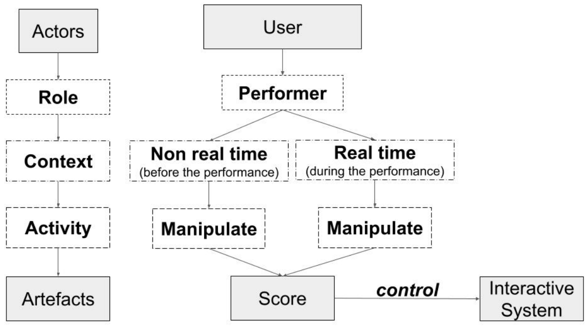

Figure 5.4: The core performance ecology of the second sub-category of the second category.

synchronisation purposes, therefore the score is neither an input nor an output of the system, as it is an element internal to the system. The score-following technique also belongs to this category. Orio et al. [250] presented a meta-review of score following rather than a specific system; however, the relation between interactive technology, score, and performer is aligned with the other papers.

Liang and colleagues presented a framework to cope with those situations where "improvisation prevents traditional score following, but where synchronisation is achieved at the level of beats, measures, and cues" and the score becomes dynamically adapted to the performer [182]. Overall, in this category, a performer plays an instrument in a real-time interaction and gives information to the interactive system that checks what the performer is playing against a score, synchronising it or creating dialogues with other elements (Figure 5.5).

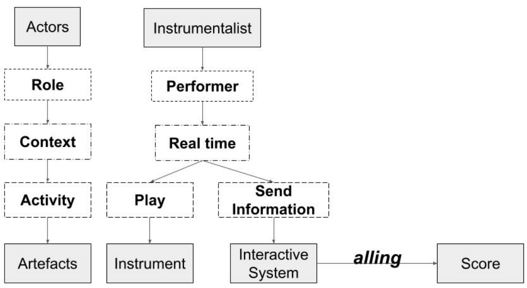

Figure 5.5: The core performance ecology of the third category.

5.6 Scores Creation

In the fourth category, six papers present systems designed to support the creation of scores. In all these papers, the main actors play the role of the creator/composer, the primary interaction occurs in a non performative context, not onstage, and the scores created with the system are usually supposed to be performed only in a second moment, which is outside of the focus of the paper. In some cases, there is one composer; in other cases, there are more than one, however, the core configuration of the ecology is the same (Figure 5.6).

Two papers present systems to create scores collaboratively via the web. In the first case, the audience creates a new score corresponding to a new version of the piece for each concert [103]. The second case describes an online tool for collaborative composition [203].

Other systems are meant for individual usage. An example is note, a tool created to help composers to use drawing as part of the score creation [266]. notẽhas also been used in a studio context to control virtual instruments [267]. Other examples span from helping composers to use drawing as part of their compositional process [105] to offering gestural control of a scripting language [174].

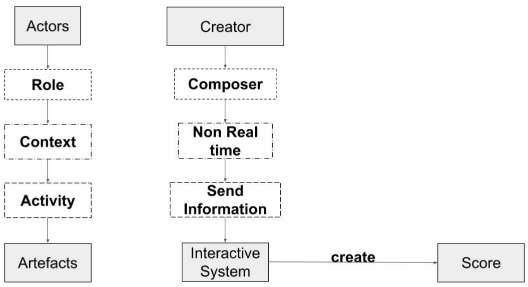

Figure 5.6: The core performance ecology of the fourth category.

5.7 Scores as a Recording

The fifth category (three papers) presents systems in which the main actor is a musician who improvises and interacts with a digital instrument. Simultaneously, the system records a score without affecting the interaction nor the performance (Figure 5.7). For instance, Beson and colleagues created a sound spatialization system and a shaping interface that allows musicians to record scores of what they perform [18]; Liang and colleagues developed a system that analyses piano pedalling and records a score of it [182]; finally, MuDI allows for real-time creation of scores for films [254].

5.8 Not clustered Papers

Three papers could not be clustered. The first paper presents a notation system for Gametrak-based computer music instruments [144]. In their paper, the notation process is not automated; rather, it is hand-made in a more classical way. This paper could not be clustered as it simply presents a new form of notation. The second non-clustered paper

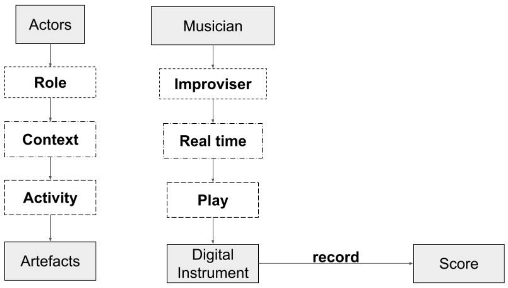

Figure 5.7: The core performance ecology of the fifth category.

presents a complex system, where a playback system, a live score system, a BCI controlled by an audience member, a conductor, and multiple performers interact to produce a live soundtrack for a film [262]. This system shares characteristics with Scores as Instruction category from the perspective of the instrumentalists. However, the number of different actors did not allow to select instrumentalists as main actors as it would have oversimplified the representation of the ecology that characterises the system presented in this paper. The last non-categorized paper describes a system to scan scores and optically recognize notation for transcription, this tool was primarily meant for transcribing existing music [269].

5.9 Toward a Taxonomy of Score Adoption in NIME

The analysis presented in this chapter identified five main tendencies in the use of scores in NIME that are briefly discussed here, contextualising them within other literature about scores. Using ARCAA supported an analysis that goes beyond simply classifying the scores' characteristics. On the contrary, this analysis allowed us to understand the role that the score plays in the entire performative scenario. The five categories could be interpreted as a taxonomy indicating possible approaches to adopt scores in future NIME practice, in relation to the actors and their roles. In particular, the first two categories can be considered to be richer as they are more profoundly linked to performative possibilities of interactive technology.

Scores as Instruction. This first category can be generally ascribed to screen scores. Although not all the systems rely on a screen to communicate the score, the fundamental interaction within this category matches well with the concept of screen scores [140, 310], an interactive digital system that gives instructions to musicians on how to play their instruments. Even the system that delivers the score in the form of temperature feedback [230] falls into this specific type of relationship. From this perspective, it can be argued that even this form of a score can be an extended version of the "new media manuscript"[140]. It is also interesting to see how, concerning the main interactive system, the score is primarily an output; and the main actor reads it.

Scores as an Interface to Play a DMI. This category represents the general trend in which the score becomes inherent to the instrument, described, for instance, by Magnusson [199, 200]. A straightforward consequence of the idea that creating interfaces to directly interact with such scores is "inherent to the circuits"[188]. A project like tangible score [299] was created precisely for this purpose: the score becomes a physical layer of the instrument. It is interesting to observe how, in this category, the score is the main input of the system, overall creating an opposite relation with the actor when compared to the first category.

Scores as Synchronization. To a certain extent, this conception of scores reflects the idea and function of a score in a classical orchestra (with the distinction between score and parts[5]). The score is the tool that shows all the individual parts on the same page, facilitating the understanding of time correspondences and synchronizations among the various instruments. In these cases, the system acts as a coordination tool, partially resembling a conductor.

Scores Creation. This category is less focused on real-time performative interaction. In this case, the score does not assume a new conception; on the contrary, it is aligned with the traditional meaning of score that consolidated throughout Western music history. Technology supports composers in their compositional process but does not change the overall relationship and function that scores have. Technology has helped composers ever since, being an algorithm that helps to compose, for instance, double counterpoints or canons [6] or more complex systems, as the ones analysed in this chapter. In the end, these scores have a similar function and relation with the piece and the performers than traditional scores.

Scores as a Recording. Similar to the Score Creation category, this last category does not change the traditional conception of scores. The score is a representation of a performance. The main difference between the two categories is that in this case, the score is resulting from performance - a recording - while in the previous category the score is resulting from a process that focuses only on the compositional activity.

5.10 Limitations

The choice of the keywords represents one limitation of this study. The term *score* has been selected, while others with similar meanings have not been included, such as notation or inscription, for one main reason: the concept of score (not that of notation) encodes and embeds the idea of a music piece. This element provides the basis for the idea that a DMI can embed a specific musical idea and the notion of the score [277].

[5]For instance, in an orchestral piece, the score is the book that comprises all the individual parts, which normally is read by the conductor, while instrumentalists read from their parts, not from the score

[6]See [204], for an overview of the use of mathematical techniques adopted for counterpoint composition.

6

Screen Scores and Authorship Case Studies

This chapter presents a set of studies conducted to investigate music performance ecologies involving scores. Screen scores were selected as scores are intrinsically an element that connects different actions (write-read; compose-perform) and different actors (composers-performers). The choice of using screen scores in particular is determined by the fact that this type of tools allows for real time manipulation of the score. Additionally, these scores are often adopted with non digital musical instruments. Therefore, this type of music technology would allow to study performance ecologies involving both digital and non digital tools, while keeping the digital element (score) in a central position in the ecology. In particular, this chapter expose how 1) a digital interactive system can connect multiple human actors in the performance and 2) an interactive system can subsume the role of a score.

This chapter first presents an exploratory study with one instrumentalist and the system (Penguin) that autonomously modifies the score based on its internal programming[1].

The core of this chapter is constituted of the two case studies. For these two studies Puffin, a new screen score system which generates a score based on the action of one performer, was created. The first version (Puffin V1) is designed for two instrumentalists, and the score is generated based on what one performer plays [2]. The second version (Puffin V2) is designed for four performers, in this second case, one actor plays a MIDI keyboard, and through that controls the manipulation of a screen score[3]. The other three performers play their own instrument while reading a dedicated stave on the score. At the end of this chapter, some general conclusions are presented.

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[1]Conspicuous parts of the text of the exploratory study have appeared in the co-authored publication [212].

[2]Conspicuous parts of the text of the first study with Puffin V1 have appeared in the co-authored publication[214]

[3]Conspicuous parts of the text of the first study with Puffin V1 have appeared in the co-authored publication currently under submission at the Personal and Ubiquitous Computing Journal

6.1 Exploratory study: one instrumentalist

For the exploratory study, a first screen score system (Penguin) was designed targeting a performance with one instrumentalist. Penguin is composed of two main modules: a module that manages a score in real-time – the Screen Score Module; and a module that generates a stream of synthesised audio – the Audio Module (Figure 6.1). The system is designed to be used in mixed performances with an instrument engaging in a musical dialogue with it. The system is implemented in SuperCollider, a platform for audio synthesis and algorithmic composition, and relies on LilyPond, a music engraving and file formatting program, for the generation of the score. Penguin organises the overall musical structure as a succession of "sections". Each section is characterised by a specific chord/harmony and a set of possible rhythms. The sequence of the harmonies, the typology of rhythms, and the length of each section are predefined and stored in the system before the performance. The system generates the actual rhythms in real-time, according to the given descriptions. During the performance, Penguin automatically generates the score and plots it on a screen, while generating the audio stream. The system also manages the sequencing of the sections. The instrumentalist is required to improvise on the given harmonies and the given rhythms, engaging in a musical dialogue with Penguin. During the participatory process it emerged that the performer needed some control over the system leading the implementation of a controller.

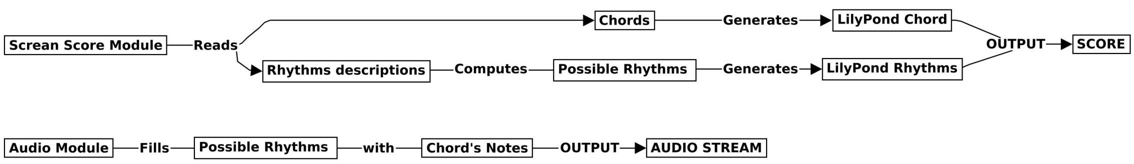

Figure 6.1: The two modules in Penguin

Screen Score Module The Screen Score Module uses almost standard musical notation (pentagram and notes), but harmony and rhythm are managed independently and plotted in different areas of the screen. The harmony is notated in the top part of the screen, and the rhythms are notated in the bottom part. Penguin generates the score relying on LilyPond, in three successive steps. In step one, it generates a .ly file that contains both the harmony and the rhythms. In step two, the .ly file is compiled, and in step three the resulting pdf is open and plotted on the screen. Steps two and three are automatized using the unixCmd method provided by SuperCollider, which executes a Unix command using a standard shell. The harmony is notated on a two-pentagram staff. Penguin automatically translates the chords stored as MIDI values into LilyPond notation. The generation of the possible rhythms requires creating the patterns. Each pattern fits in one or two 4/4 bars. The system reads the allowed values (quarters, eighths, triplets etc.), and creates four patterns that randomly combine the different rhythmic figures. In this process, the allowed values can also be slightly modified to complete the 4/4 bar.

For example, if the system combines a four-sixteenths pattern with 2 quarter notes, the 2-quarter is transformed into a 3-quarter note. Figure 6.2 shows a sample of the score.

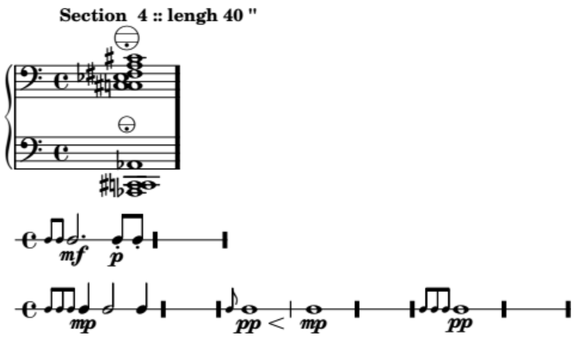

Figure 6.2: Sample of the generated score, with harmony in the upper part, and rhythms in the lower

Audio Module The sound module generates a polyphonic stream of four lines combining the harmony with the patterns. For each line it recursively selects one of the possible patterns and fills the notes based on the chord. The system reiterates this operation up to the end of the section, then applies the same principle to the material of the new section.

As mentioned earlier, the system is supposed to be used alongside classical instruments. The instrumentalist is the actual performer involved in the musical performance and he/she has the freedom to interpret the notated harmony and patterns by improvising on this given material. The role of the instrumentalist in the musical performance was not completely defined before the participatory process. Consequently, the interaction between the system and the performer was also undefined. As detailed in the next section, the role of the instrumentalist changed. Initially the instrumentalist was a soloist, who interacted with the technology only musically by reading the score on the screen. In this first scenario, the interaction occurs in the musical domain. During the participatory process, it emerged that the instrumentalist needed actual control over the system. Therefore, the performer was provided with a tool to manipulate the volume of Penguin.

6.1.1 The System in Use

Penguin has been used in a piece for accordion named *Studio I*. The creation *Studio I* relied on a collaborative process between the author of this thesis and the accordion player during a set of rehearsals and discussion sessions. The process had as a final practical objective a public performance of the piece. In this process, the relation between the performer and the system was re-framed, and the system was fine-tuned according to the needs of the performer. During the process the overall musical interactive metaphor between the accordionist and Penguin changed. This process was structured in several steps, using observation and interviews: 1) rehearsal with the first prototype of Penguin, where observation was conducted, followed by unstructured interview with the performer; 2) recursive prototyping of a study score for personal study; 3) final rehearsal for a public concert, and the concert itself, each followed by an unstructured interview.

6.1.1.1 Rehearsal Stage

The objective of the first rehearsal was to test the musical interaction between the performer and Penguin. This initial activity occurred in three moments. Initially, the accordionist was informed about the functioning of Penguin and her role. The piece was then rehearsed twice. The session concluded with a discussion regarding strengths and weaknesses of the interaction design of the system. From the rehearsal observation, it emerged that the more the performer became confident with the harmonies, the more she was able to dialogue efficiently with the music output of Penguin. This observation was also confirmed in the subsequent interview. In particular, she expressed the need to further study the piece, in order to find the right balance between her spontaneous creativity and the global form of the piece. To achieve this result, she explicitly requested to have a printable version of the score with all the chords and some indication about the overall musical form. Overall, the performer declared that performing alongside Penguin was stimulating, but also demanding.

6.1.1.2 Prototyping of a Study Score

According to the request of the performer, a printable study score was created. This score was composed of 13 pages (one for each section of *Studio I*) with an introduction that described how the rhythmic density evolves in the sequence of sections and how sections succeeded one another. In each page, the harmony and a sample of the possible rhythms were notated. After some private study, the performer requested to have a more compact version of the score, with all the chords on one page to have a better overview of the overall structure. One pattern for each section was generated as an example of its rhythmical structure.

6.1.1.3 Final Rehearsal and Concert

In the interview following the final rehearsal, the accordionist expressed the need for manipulating the volume during the performance. To cope with this issue a physical controller with a knob was set up to allow her to modify the volume of Penguin. Thanks to this modification, she could perform more expressively and dynamically. With this setting, the performer not only dialogues with the system, but also plays the role of the conductor, controlling the overall dynamic. In the final interview, following the public performance, the instrumentalist declared that she enjoyed the performance, both from a musical and from an interaction perspective. In spite of that, she expressed a difficulty in considering this a piece for accordion, performable by any musician, and that she felt that the piece was bound to her performance. The accordionist declared that she felt comfortable to perform the piece and that she liked the musical result. However, she did not think that another accordionist could feel the same confidence or achieve the same musical quality.

6.1.2 Main Outcomes

This preliminary study pointed out two main directions. Firstly, a new performing metaphor, that merges playing together and conducting elements has emerged. Secondly, some considerations related to the use of idiographic and autobiographical approaches and how this affects the ownership of the music aesthetic are presented.

6.1.2.1 Performing Metaphors and Background of the Performer

The confrontation with the instrumentalist led to two main modifications to increase the expressiveness of the interaction with Penguin: 1) creation of a printable score for private study, and 2) control of the volume. The need for a paper score can be found in the regular practice of classical musicians. Classical musicians are trained to study repertoire. In this process, musicians learn to articulate the phrasing of specific moments according to the global form of the piece. Although control of the volume can be seen as a slightly different modification of the system, it changed the overall musical metaphor. As declared by Schnell and Battier [277], a piece of interactive technology can have different interactive metaphors: playing, playing together, or conducting. Providing the instrumentalists with the possibility to manipulate the volume of Penguin shifts from the interactive metaphor of playing together to the metaphor of conducting and playing together at the same time. The accordionist switches from being a soloist to becoming a soloist and a conductor. The overall musical metaphor changed from the “Concerto” in the Romantic period, where the soloist is only a soloist and does not conduct the orchestra - playing together metaphor - to the idea of a “Concerto” for harpsichord and orchestra in Baroque time, where the soloist is also the maestro concertante. Therefore an appropriate name for this role could be *Soloist Concertante*. It is important to notice that this switch occurred in the determination of the ecology, it is not a metaphor created in the design phase, rather it emerged in the actual use. Indeed, it emerged in relation with: the various artifacts present in the performance (Penguin and the accordion); in a dialogic relation and musical dialogue; and with the paper score as the tool used to study the form of the piece.

This elements points toward the fact that, despite the core elements of the piece (Studio I) are embedded in the system (Penguin), its actual form is influenced by all relationships among actors and artifacts in the ecology. This relationship between authorship and tools in the overall ecology will be further investigated in the case studies presented in the rest of this chapter.

6.1.2.2 Different Design Approaches and Authorship

Section 2.2 discussed how compositional processes often involve the development of interactive technology. When the composer and the designer are the same person, the authorship of the composer over the musical pieces is not affected. With *Studio I*, despite the fact the composer and the designer were the same actor, the composer is not the sole responsible for the final musical and choices. The overall idea of the piece and the interaction, along with the harmonic and rhythmic choices, maintained the original shape, but other elements changed. By incorporating idiographic elements from the performer in the final design of Penguin, not all the musical parameters remained under the control of the composer. To a certain extent, the authorship is shared between the composer and the performer, and the final performance is bound to the idiosyncrasies of the performer. Consequently, Penguin can be considered a co-created composed instrument and *Studio I* is a co-designed interactive performance, which relies on those specific actors to be performed. This represents an example of an Open Sonic Artifact, where the core musical ideas are incorporated in an interactive object, but there is space for musical exploration from the performer.

In the two case studies presented in the rest of this chapter, the combination of idiographic and autobiographical perspectives are further studied. In particular, it is investigated how different roles correspond to different activities and how the screen score mediates the various actions, and how the technology embeds musical ideas.

6.2 First Case Study: Two Instrumentalists

This first music case study analyses a performance ecology with Puffin V1, a new screen-score system, as the central technological component. The first version of Puffin transforms the notes that a first musician plays into notation for a second musician. The system was designed with the intent to expose the interconnections between two musicians in a performance ecology and the role of the interactive artifact and musical score in that ecology.

The study involves the author of this thesis as composer/designer and two instrumentalists, as participants/instrumental performers, who collaboratively created a piece. Daily interviews with the instrumentalists were conducted during the study to understand the different interconnections that emerged among the instruments, musicians, and the score. The resulting ecology was visually represented by using ARCAA. At the end of the four rehearsals, the piece was audiovisually recorded for submission to the music program of the Audio Moslty conference 2022; the piece has been accepted and included in the program of the conference [4] .

6.2.1 Puffin V1: a Screen-Score System for Two performers

Puffin V1 is an interactive screen-score system designed with a twofold purpose 1) expose how a digital interactive system can connect two human actors during a performance and 2) visualise how an interactive system can subsume the role of a score. Puffin V1 is meant for performances with two melodic instruments and is composed of two modules, a *Score Module* and an *Audio Module* (figure 6.3). The two modules exchange data and communicate via Open Sound Control (OSC). The Audio Module detects the notes that musician 1 plays and sends the related information to the Score Module.

The Score Module displays two staves (figure 6.4): the stave on the bottom represents in real time the notes being played by musician 1, while the stave on top visualises the same information with a delay, for musician 2 to follow. Additionally, the Audio Module manages two drone sounds, whose pitches are based on the notes from the respective stave.

6.2.1.1 Score Module

The Score Module is implemented using the Processing framework [5]. This module displays two staves (figure 6.4), corresponding to the two instrumentalists involved in the performance. Two types of note representations are used in the system for the notes

[4]Complete recordings of the pieces developed during the case studies are listed in the annexes of the thesis.
The piece Studio 2 created in this case study has been accepted at the music track of Audiomostly 2021 `https://audiomostly.com/2021/program/conference-program/` A recording of piece can be find at this link: `https://www.youtube.com/watch?v=xtCO5kduMjk`

[5]`https://processing.org`

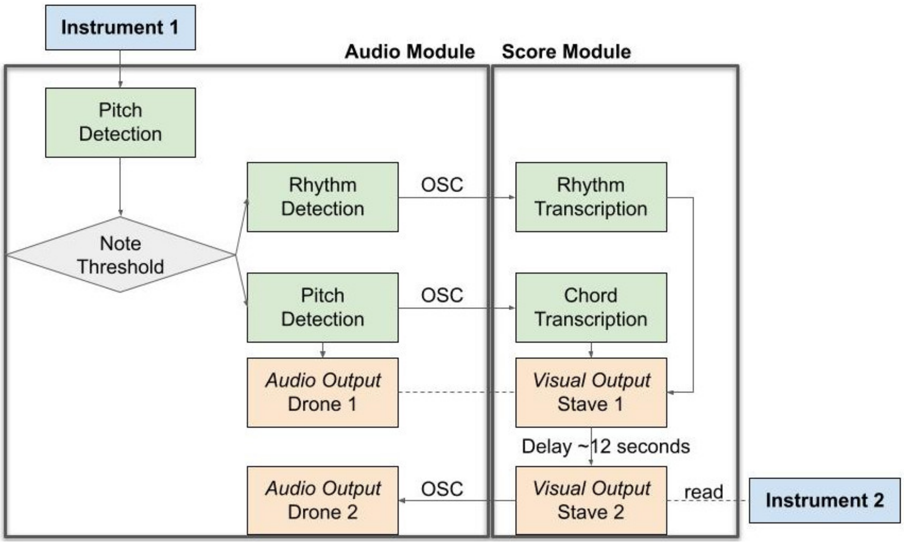

Figure 6.3: The architecture of Puffin

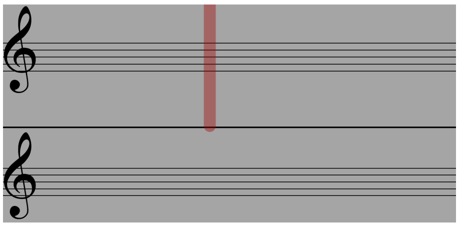

Figure 6.4: The two staves displayed in the Score Module

played by musician 1, one for the notes below a threshold and the other for notes above it. The ones below the threshold are transcribed rhythmically with square noteheads that do not indicate pitch (figure 6.5, left). The notes above the threshold correspond to different drones and harmonies, and are represented as chords with distinctive background colours (figure 6.5, right). The combination of the two types of notation aims at balancing freedom (of choosing the actual notes) for the second performer with constraints that ensure harmonic and rhythmic coherence in a resulting piece. The time is not notated using standard western signs, rather it is visualised using spatial distribution over the horizontal dimension of the staves. Indeed, both types of notes are spatially distributed over the horizontal axis of the staves. This choice allowed to represent time without the need to know in advance the length of the note as it would be required with traditional notation. The only information needed is the commencing of each note. After a predefined time span (by default twelve seconds), the notes on stave 1 at the bottom are copied to stave 2 on top; simultaneously, the transcription of musician 1 restarts from the beginning of stave 1. This mechanism is repeated in a loop, with stave 2 always having a fixed delay regarding what was notated on stave 1. As the loop is based on the length of the staves, the Score Module also manages the synchronisation of Drone 2.

Musician 2 reads from stave 2 (on top); she is required to improvise with the notes of the chord, imitating what musician 1 previously performed rhythmically, creating a sort of *canon* [6]. To facilitate the reading, a scrolling red line displayed over the staves visually represents the time (as in figure 6.4).

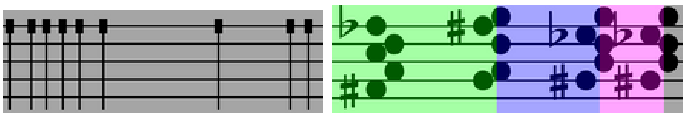

Figure 6.5: Left - rhythmic notation with square noteheads; Right - chords with distinctive background colors.

6.2.1.2 Audio Module

The Audio Module is implemented using Pure Data [7]. This module detects the notes by musician 1 and plays the two drones. The notes by musician 1 are detected by using the Pure Data object sigmund [8]. The output from sigmund is used to detect changes in the pitches, identifying new notes. Every time a new note is detected, an OSC message with the related pitch is sent to the Score Module.

This module also manages and plays two drones. Drone 1 is directly controlled by musician 1 with notes above a threshold (the same as new chords in stave 1). The pitch in drone 2 is changed by OSC messages received from the Score Module, corresponding to new chords in stave 2: each time that the red playbar crosses a chord representation in stave 2, an OSC message with the corresponding note is sent from the Score Module to the Audio Module. The drone sounds are implemented with an additive synthesis engine that combines eight sawtooth oscillators playing the corresponding notes at four different octaves, with a pair of oscillators per octave. The frequency of each individual component (sawtooth oscillator) is constantly changed randomly in a range of up to 6 Hz to obtain some beats [9]. Additionally, each component is modulated by a Low Frequency Oscillator (LFO) at a different frequency, with very minimal amplitude. Finally, reverb is added to the drones.

6.2.2 Case Study Description

In the case study, the author of this thesis, who designed the system, acted as the main composer[10] and developed, together with two instrumentalists, one musical piece using Puffin V1.The final piece was named *Study 2*. The two musicians were one violinist (Francesca Zanghellini, female 22 years old) and one guitarist (Ardan Dal Rì, male 30

[6] A canon is a contrapuntal compositional technique that develops a musical piece based on one melody with at least one imitation of the same melody played after a given duration.
[7] `https://puredata.info/`
[8] Sigmund analyses sinusoidal components of an input sound and can calculate a pitch estimate.
[9] The term beat is used in its acoustic meaning: a wave interference between two sounds of slightly different frequencies that produced rhythmic patterns
[10] The term 'composer' will be used for the sake of brevity in the rest of this section

years old). Both performers had higher education in music and work experience with their instruments and are used to contemporary repertoire and practices. Additionally, the guitar player graduated in electronic music. In the system, the guitarist assumed the role of musician 1 (controlling the notation) and the violinist assumed the role of musician 2 and read from staff 2.

Puffin V1 was primarily designed in advance of the study with an already clear vision of the main musical mechanism (repetition), without any real co-design process. However, the creation piece, that represented a creative adoption of the system, was collaboratively developed with the two performers.

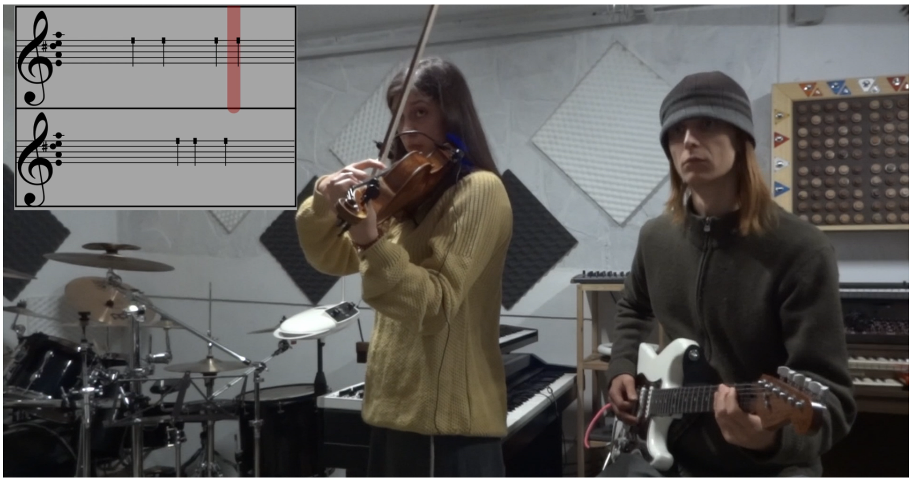

Figure 6.6: A rehearsal moment with a screenshot of the score.

The study was organised in four rehearsals. Due to Covid-19 restrictions, the collaboration between the two instrumentalists and the composer was held online. The violinist and the guitarist live together and have a small recording studio in their basement where they could rehearse the piece together. Each of the sessions followed a similar structure: 1) online (via a video conference platform), a moment in which the composer suggested some musical ideas that were afterward discussed (10-30 minutes); 2) in situ, the two instrumentalists rehearsed the ideas discussed in session 1 and audio recorded the musical result (figure 6.6); 3) online, collective discussion about the previous rehearsal; 4) online, individual interview with the two instrumentalists. Additionally, between the sessions, the composer listened to the recording outputs of the previous session to provide further feedback and develop new ideas for the upcoming rehearsal. Also, between sessions 2 and 3, the composer and the guitarist had an additional meeting to fine-tune some components of the system (details below). Despite being less interactive than an in situ collaboration, this workflow allowed for a collective development of a short piece (6 minutes) in four days.

6.2.3 Methods: Data Collection and Analysis

Methodologically, this study combines the autobiographical design perspective [243] of the composer with the idiographic experience [134] of other instrumentalists involved in the performance (two additional actors in the overall ecology). The autobiographical perspective is related to the fact that Puffin V1 is designed and developed by the composer, based on core research aims, and aesthetically is grounded in his background in western music and interest in imitative composition. These core components remained unchanged throughout the study. The idiographic perspective is related to the adjustments operated to the system according to some specific requests of the two performers. It also relates to the fact that the actual piece was created in collaboration with them, incorporating musical ideas,ergonomics and physical possibilities of the acoustic instruments.

At the end of each of the four sessions, the composer interviewed the two performers using semi-structured interviews. The questions focused on different elements related to the overall ecology, spanning from the collaboration with the rest of the team, the relationship with the technology, and the connection with their instruments. The two performers were independently interviewed. The interviews lasted between 13 and 35 minutes, and were analysed by the author of this thesis following thematic analysis [40] . Quotes from the interviews were translated to English as the original language was Italian. Additionally, the composer collected notes on his own perspectives and experience at the end of each session. These notes were taken to prepare the session of the following day incorporating the feedback, to keep track of each stage of the study and to better understand the ecology. The description of the four sessions is primarily based on these field notes.

6.2.4 The Four Sessions, an Overview

By reorganising the field notes, it emerged that overall the four rehearsals can be grouped into two main phases: co-creation/design phase (session one and two), in which the piece was defined, and a rehearsing phase (sessions three and four), primarily focused on fine-tuning details and preparing for the final recording.

6.2.4.1 Co-creation/Design Phase

In *the co-creation phase* - session one and two - the composer proposed some musical ideas or tasks to explore the musical possibilities of Puffin V1. We decided that Musician 2 could slightly modify the rhythms to create a variation in the repetition, as can happen in *fugues*. These elements also provide musician 2 with some freedom and more space to include her own expressivity. By listening to the musical material created during the first session, four exercises were created for the second session. These four exercises later became the core structure of the piece in four main parts:

1) *Without changing the drone, play with different rhythmic elements*, starting with sparse notes and progressively increasing the density. In the overall dramaturgy of the composition, this part of the piece aimed at onboarding the audience by exposing the rhythmic imitation using few elements that are clear to follow at the beginning.

2) *Play short melodies*, and change the drone at the end of each *short melodic sentence*. This part of the piece introduces a novelty: the fact that the guitarist can change the drones. By listening to the first session, it emerged that this part risked becoming very repetitive and it has been decided to limit it to only two short sentences with two changes in the drones.

3) *Play only the drone without any other note in the middle*, very slow to create a sort of *chorale* often with homorhythmic changes in the two drones (by aligning the new note with the previous one on stave 2). In this third part, the violinist played *al tasto*, or *flautando* to obtain noisy but soft components in the sound spectrum.

4) *Play only the drone*, progressively increasing the speed and obtain a chromatic *ostinato* with very *staccato* notes; the violin also plays with short notes, with various techniques from *jeté* to *pizzicato*.

Between sessions two and three, the composer and the guitarist had an additional meeting that lasted a few hours to fine-tune the code, to solve some minor problems that have emerged in relation with the tracking of the notes of the guitar and the musical expressivity. These modifications were performed after the second session because the structure of the piece was defined at that point; therefore, the guitarist's needs in the piece were clearly defined. The improvements included 1) moving the threshold to control the drone one octave above to allow the guitar player more space for the melodic lines; 2) adding two filters to better separate the signal of the guitar above and below the threshold; 3) fine-tuning the thresholds for the rhythmic transcription. These modifications were co-designed and both guitarist and the composer changed the code sharing the files with each other. Additionally, a function to facilitate the violinist to read has been implemented. The violinist asked to add the notation of the first chord at the beginning of the staff, even if it was continuing the previous chord. In this way, she could read the notes and did not need to remember the chord associated with the colour.

6.2.4.2 Rehearsing Phase

In the **rehearsing phase - sessions three and four**, the structure of the piece and of the system were not modified, while some details were improved. In session three, particular attention was paid to the violin gestures, refining the instrumental techniques for each of the four parts of the piece (*al ponte*, *flautando*, *al tasto*, *spalla*, *jetés*, *Bartock pizzicatos*). This exploration occurred in collaboration with the violinist by discussing specific techniques in relation to the system and the parts of the piece, for instance, *Bartock pizzicatos* and *staccatos al ponte* for the beginning of the piece, *al tasto* notes and *flautando* notes for the third part and *jetés* for the transition between the third and the fourth part. Additionally, during the initial discussion in the third session, the composer asked to reuse some specific musical elements that have emerged during the first session, using the same intervals and atmosphere in the second part of the piece. Session 4 simply focused on the rehearsal of the piece.

6.2.5 Results

Results of the thematic analysis from the interviews are presented here. Seven themes were identified with several subthemes (highlighted in bold in the text). Days of the session are specified for direct quotes (S1-S4).

6.2.5.1 Interaction with the Composer

Two types of interaction with the composer have been identified in the interviews. Both instrumentalists mainly **followed instructions from the composer**. This element primarily occurred in the explorative first sections (S1, S2). Additionally, the guitar player also expressed that he was happy about the possibility of **contributing to the piece**: "if our ideas can contribute to the piece, that is very good"(Guitarist - S2).

6.2.5.2 Relationship with the Piece

As the piece was progressively defined, the interviews revealed a more clear direct relation with the piece in its entirety and its musical form rather than with the instructions of the composer that initially were merely musical tasks.

Understanding the scope of the entire piece played an essential role in improving the feeling, the musicality and the confidence. Indeed, the musicians "were more convinced about what to do"(Guitarist - S3). Additionally, once the structure of the piece was defined and clarified, the violinist's relation with her own instrument improved: "My relation with my instrument was immediate, as I already knew what was going to happen"(Violinist - S4). Finally, once the piece was defined, the violinist "was also less bound to the screen"(Violinist - S4).

The piece represented a set of constraints in the performance. Once the structure was clarified, the piece itself imposed constraints that were different compared to the previous session, and changed independently from the system: "Although the system is the same, as there are more rules in the piece, it's as if there are more elements"(Violinist - S2). Such *constraints played became creative stimuli*, helping to structure the performance: "as there are more limitations, I had more ideas, [...] there are more elements that I can use."(Violinist - S2).

Finally, both musicians expressed **appreciation for the sonic features of the piece**. The violinist felt involved: "It all sounded very suggestive, and the system is quite captivating; I was very involved in the system"(S1). Additionally, the guitarist expressed aesthetic appreciation of the musical results and for the final piece.

6.2.5.3 Collaboration while not Playing

Discussing was a primary element of collaboration during the various rehearsals. As the two instrumentalists understood the piece and the system more, they increasingly discussed musical aspects of the performance and less the system itself. The instrumentalists also **commented on what just happened and redid parts.** Starting from the second session, they interrupted the rehearsal to discuss specific passages and improve them. In the last two sessions, they also **listened to the recording** from the previous rehearsal. Finally, the two instrumentalists decided to **rehearse specific moments only with their instruments without the system**.

6.2.5.4 Interaction with the Other Instrumentalist while Playing

The two instrumentalists performed a wide variety of activities complementing their playing and reading or controlling Puffin V1. **The two instrumentalists listened to each other.** The guitarist listened to the violinist mainly "in terms of densities"(Guitarist - S1), to get a general perspective of the direction of the piece. The violinist perceived that the guitarist was listening to her. The violinist also listened to the guitarist to better imitate him. Once the piece was structured, as in any normal musical performance, the two instrumentalists **"gave each other signals"** (Guitarist - S3). Finally, in some moments, the guitarist also waited for the violinist before performing new notes.

6.2.5.5 Relationship with the System

The two instrumentalists interacted differently with the system. The guitarist's interaction with the system was multifaceted, while the violinist one was more straightforward. The guitarist expressed the need to **understand the system**, stating that otherwise, it would have been difficult to create musically interesting results. Additionally, the guitar player was aware of his **role as an "orchestrator"** (S4) in the overall ecology. This mainly affected two performative elements: 1) the "harmonic perspective"(Guitarist - S1) as he had to think about the delay; 2) the control of the densities including "peaks, changing the speed, speeding up, slowing down"(Guitarist - S2). The screen provided visual feedback, facilitating the guitarist to control the density and the delay. "I look at where the notes appear and when she does them."(Guitarist - S3). Finally, the fixes to the system were briefly mentioned by the guitarist, who stated that he could interact better with the system afterward.

The violinist's interaction with the system, as expected, was primarily focused on **reading the screen-score.** In such a relation, however, different nuances emerged. The violist had to balance the reading with the listening. "50% I listened, and 50% watched the screen."(Violinist - S3). Additionally, the written notation on the score gave freedom and while also imposing clear constraints, it was perceived as a "guide"(Violinist - S1). The violinist also had to learn how to read the notation on Puffin in the context of the entire performance: "I metabolised the system better now, so it is more natural to follow it, and at the same time, I could listen to what Ardan [the guitarist] was playing. So now I feel that I can pay the right attention to the various components"(Violinist - S4).

6.2.5.6 Relationship with the Instrument

The two instrumentalists interacted differently with their instruments. The guitarist's relationship with the guitar was multifaceted. Due to the sensibility of transcription, in some cases, the system **limited the possibilities of the guitar**. To overcome this problem, the guitarist identified specific strategies: "play short notes, al tasto, with a sharp attack, trying to avoid resonances". Guitarist - S3. The guitarist also had to *balance the need to be expressive while playing the guitar with the need to control the system*, "I was not only controlling some triggers, but I was also playing"(Guitarist - S2). However, in the last two parts of the piece, the guitarist solely controlled the Puffin: "having the guitar or having a MIDI keyboard is *de facto* the same; from that part on, I stop thinking as a guitar player"(Guitarist - S3).

The violinist, identified some **limitations of some particular techniques**; for instance, some *pizzicatos* cannot be performed fast.

6.2.5.7 Possible Improvements

In the last interview, the guitarist also suggested some possible improvements to the system. In particular, to add a MIDI controller and more notes corresponding to drones (for this piece only 5 drones were used).

6.2.6 ARCAA Representation of the Study

This section presented how ARCAA (originally presented in chapter 4) was used to analyse and visualise this first case study and the corresponding performance ecology (figure 6.7).

The representation helped to visualise how all **the actors play different roles in different contexts** (see 'Role' and 'Context' layers in figure 6.7), **and those different roles correspond to different activities** ('Activity' layer in figure 6.7). In particular, it is interesting to observe how both the instrumentalists are part of the ecology in different contexts, not just when they *perform*, but also when they *discuss* musical ideas. The ARCAA representation can facilitate to go beyond the individual relationships between the different actors and the system; indeed it displays how **the screen-score system acts as a mediator between the two instrumentalists** who perform different activities (red rectangles '1' in figure 6.7): the guitarist *controls* or *plays* the system, while the violinist *reads* the resulting score. From the analysis, it also emerged that **the piece itself is an artifact** (with its four parts) – it emerged as an element important enough to be represented as an artifact distinct from Puffin (blue rectangle '2' in figure 6.7). Such an

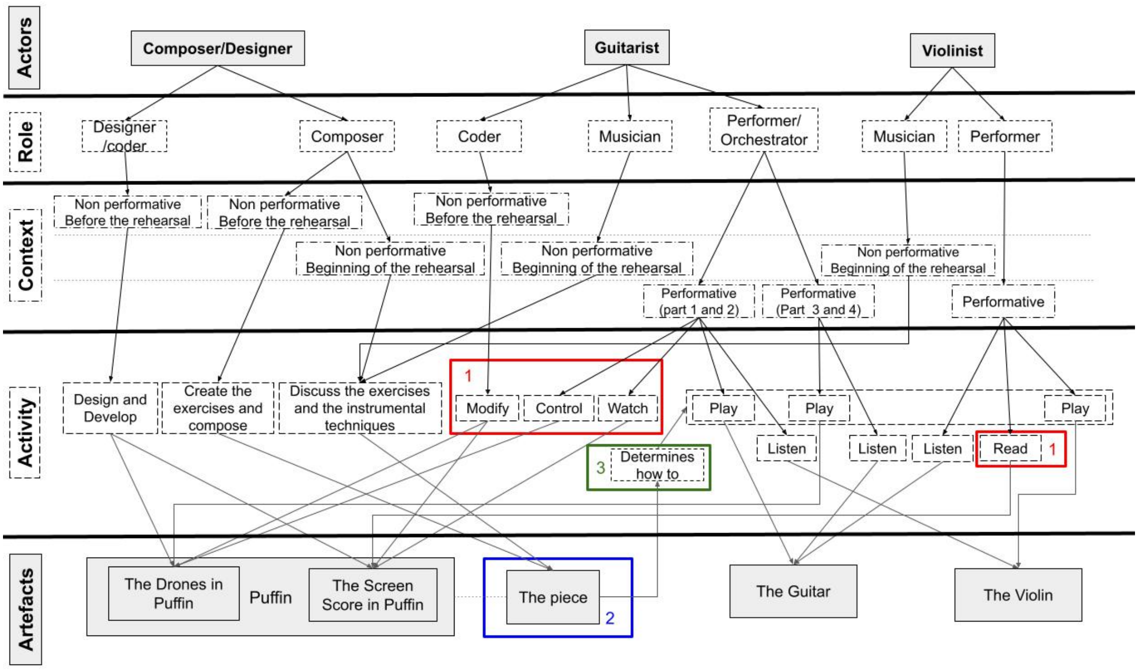

Figure 6.7: A representation of the overall performance ecology using ARCAA

artifact is deeply connected with the interactive system but also separated from it: as emerged from the interview, **the piece in itself has some specific constraints** (green rectangle '3' in figure 6.7).

6.2.6.1 Different Roles in Different Contexts

The two instrumentalists played different roles in the overall ecology. The guitarist identified himself as an "orchestrator", while the violinist did not identify any specific role for herself other than an instrumentalist who played the violin. Such a distinction is clearly primarily influenced by the system's design, which transforms the performance of musician 1 (the guitarist) into a score for musician 2 (the violinist), implicitly discriminating between two different roles. However, it is also possible to speculate that the personal background of the two musicians reinforced these discrepancies. For instance, the guitarist is also an electronic musician capable of operating changes in the system autonomously. This element probably facilitated him to acquire a more comprehensive understanding of the system, allowing him to obtain a better overview of the entire ecology, and possibly contributed to his feeling of being an orchestrator. On the contrary, the violinist's background is mainly in classic or contemporary score-based music.

"Orchestrator"is a term that derives from classical musical jargon. In interactive music technology debate, terms derived from classic music practice have been used; for instance, a musician can control algorithmic processes "analogous to conducting"[120]. However, researchers tended to use such metaphors primarily in a one-to-one interaction to describe mapping strategies. The finding of this study supports that these metaphors can be useful also to understand the relationships that an actor has with various elements of the entire ecology and its role within it. ARCAA can support the inclusion of such metaphors in the analysis of a performance ecology, as these metaphors can be used to identify the different roles that the various actors play.

6.2.6.2 Different Activities for Different Roles

Different roles correspond to different activities, in particular, the instrumentalists performed a variety of different actions without interacting with the system. These actions that might seem peripheral are actually necessary to effectively and musically interact with the system. For instance, the instrumentalists needed to discuss musical aspects of the performance to find a good equilibrium to perform together. The two musicians also needed to rehearse specific moments without the system and listen to the recordings. All these actions occurred outside the traditional framing of a performance or of interaction with a piece of technology. However, all these activities represent fundamental aspects of the ecology of musical creation. In the ARCAA representation, different contexts are also visible in all the activities represented in *non-performative contexts* and discriminated by those occurring in *performative contexts*.

6.2.6.3 Piece and System as Distinct Artifacts

Puffin (V1) was designed with an implicit but clear musical idea that determined the core musical mechanisms underlying the piece. From this perspective, this system followed Cook's guideline suggesting to create a piece, not just an instrument [59] – any piece that can be composed with Puffin (V1) is a contemporary form of *canon*. However, in its form, the actual piece *Studio 2* was developed and determined along with the instrumentalists in a second stage, and other pieces could be created with Puffin. Based on this, it is possible to speculate that in this study, the relation between a musical piece and a new music technology artifact is shaded – one is deeply bound to the other, but there is a distinction, as some constraints were determined by the piece rather than the technology itself. As the violinist reported: "Even though the system is the same, as there are more rules in the piece it is like if there are more elements"(S2). Furthermore, understanding the scope of the entire piece helped the instrumentalists to perform with their instruments. "My relation with my instrument was immediate, as I already knew what was going to happen"(Violinist - S4). This blurred distinction between Puffin and the piece provides a new nuance on the shaded boundaries between musical pieces and music technology. ARCAA facilitated us to reflect on this point by allowing us to identify the piece as an artifact in the bottom layer.

6.2.6.4 Specific Constraints of the Piece

The piece created a set of rules that impacted the activities of the performers. As the violinist declared, the piece created the most important constraints. It is interesting to see how, especially for the violinist, such constraints acted as a support "as there are more limitations, I had more ideas [...], there are more elements that I can use."(Violinist - S2). The fact that a set of constraints can stimulate musical creativity is aligned with other studies on music technology (e.g. [196, 121]). However, the distinction between constraints of a system and constraints imposed by a piece offers a new perspective on the role that constraints play in a digital music performance.

6.3 Second Case Study: Four Participants

This section extends the previous case study by presenting an updated version of Puffin, V2, which allows for a performance composed by four actors (one composer who manipulates Puffin and creates the score and three instrumentalists reading/performing it). As suggested by the guitarist in the previous study, a MIDI interface was added, as well as the possibility to control the drones with each of the twelve notes. This new version of Puffin was used in a case study with four music students, who alternated in the role of composer and instrumentalists: each of them composed one piece when playing the role of the composer. In the study, the different forms of interrelation that emerged in the performance ecology as well as the different forms of appropriation have been investigated [11].

6.3.1 Puffin V2: a Screen-Score System for Four Performers

Puffin V2 maintained the main purposes of the previous version to 1) expose how a digital interactive system can connect multiple human actors in the performance and 2) visualise how an interactive system can subsume the role of a score. The first version of the system (presented in the previous subsection) was designed for two musicians, where the system creates a score in real time based on what the first instrumentalists is playing and the second instrumentalist reads the score and imitates what the first instrumentalists did before. The second version of the system, was designed for an ecology of four musicians.

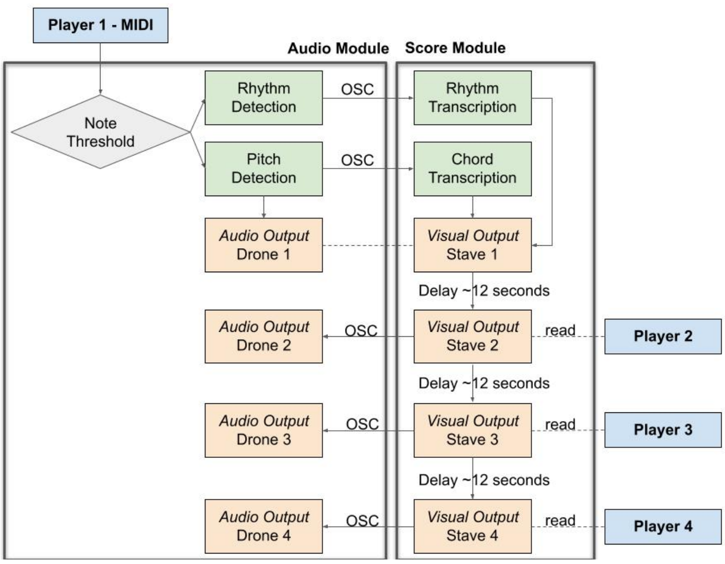

Figure 6.8: The overall structure of Puffin V2

[11]The piece Mútuas Colaborações created in the case study presented in this section, has been included in the project *As Nossas Árvores* by the collective of artists and ecologists Equilibrio https://uploads.knightlab.com/storymapjs/976eeb1b939c67f1696328f0192f950c/as-nossas-arvores/index.html
A recording of piece can be find at this link: https://youtu.be/WPMq0BCoN90

The new version maintains a two modules structure (figure 6.8): a Score Module and an Audio Module, that share data via OSC. Based on the feedback provided by the guitarist in the previous study, the Audio Module is controlled via MIDI through a keyboard, which is used to control a synthesiser. Additionally, the Audio Module processes the MIDI data and sends this information for transcription to the Score Module. The Score Module presents that information as four staves: stave 1 shows the information in real time from musician 1; stave 2 shows the same information with a delay (by default 12 second seconds), stave 3 shows the same information with a delay time doubled, finally stave 4 displays the same information after the triple of delay time (figure 6.9). Player 2, 3, and 4 should follow the staves 2, 3, and 4 respectively. In addition, the Audio Module plays four drone sounds, each based on the notes from the respective stave.

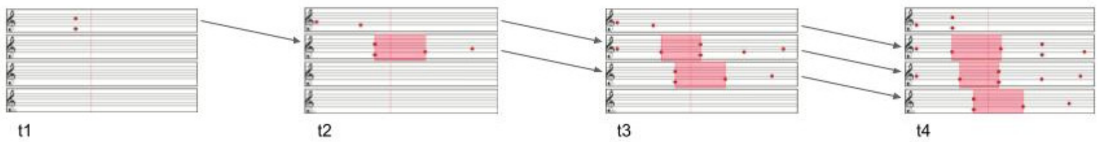

Figure 6.9: The score in four different moments with the various informations copied from left to right: t1, t2 (t1 + delay time), t3 (t1 + (delay time * 2), t4 + (t1+ delay time * 3). The arrow indicates the repetition.

6.3.1.1 Score Module

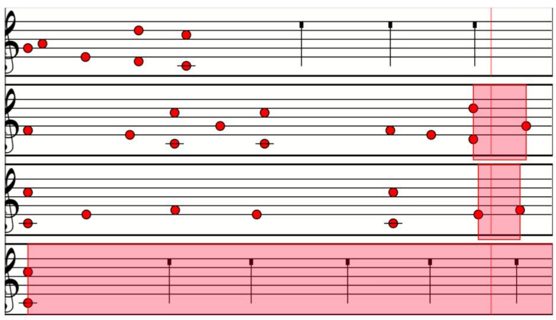

Figure 6.10: The four staves of the score. In this scenario, the first three staves are melodic staves, and the fourth has primarily rhythmic notes (with a more open interpretation).

The Score Module is implemented in Processing. This module displays four staves (figure 6.10). Stave 1 (on top) represents in real-time what musician 1 is playing. The ones below are transcribed as in figure 6.9. All the notes are spatially distributed over the horizontal axis of the stave representing the timing of the notes. After a predefined time span (by default 12 seconds), the entire stave 1 is copied to stave 2. Simultaneously, stave 2 is copied to stave 3, and stave 3 is copied to stave 4 (as in figure 6.9). At the same time, the transcription of musician 1 restarts from the beginning of stave 1. This mechanism is repeated in a loop, where stave 2 is always with a delay regarding stave 1, stave 3 with the same delay in respect to stave 2 and stave 4 in respect to stave 3. The Score Module also manages the clock of the system and the synchronisation of Drone 2, 3, and 4.

Musicians 2, 3, and 4 read from stave 2, 3, and 4 (second, third and fourth from top to bottom respectively). To facilitate the rhythmic and timing perception in the writing and reading processes, a scrolling red line representing the time (a read head) is displayed over the staves (as in figure 6.10). Additionally, a red rectangle highlights the current red notes for each staff independently (figure 6.11).

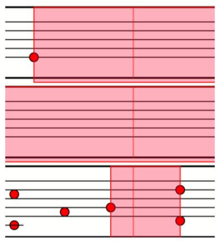

Figure 6.11: The red rectangles highlighting the notes according to the lengths.

There are two types of note representations, one for the notes below a threshold and the other for notes above it. The ones above the threshold are transcribed only rhythmically with square noteheads (figure 6.12), as in Puffin V1. The ones below are transcribed as notes. In the first version of the system there were harmonies related to each of these notes, in this second version only the note is transcribed.

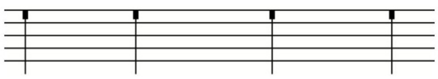

Figure 6.12: Rhythmic notation.

6.3.1.2 Audio Module

The Audio Module is implemented using Pure Data (PD). Musician 1 controls/plays the Audio Module by using a MIDI keyboard. The input notes from the MIDI keyboard are treated in two different ways based on a pitch threshold (the same that discriminates between rhythmic and standard notations, by default middle C: C4). The MIDI values are sent to the Score Module via OSC.

The notes below the threshold (that are transcribed as normal notes in red) control a drone; this drone is always active, and the notes simply change the pitch. The notes above the threshold (that are transcribed only rhythmically) control a monophonic (single voice) synthesiser. By default, the two synthesiser engines are implemented as follows. The drone uses additive synthesis using the same engine of the first version of the system. The notes above the threshold (that are transcribed only rhythmically) control an FM synthesiser – this sound has a sharp attack and can be used as a melodic instrument. The Audio Module also generates three further drones. Drone 2, 3, and 4 are changed via OSC messages received from the Score Module, corresponding to new red notes in stave 2, 3, or 4. When the red playbar crosses a red note in stave 2, 3, or 4 respectively, an OSC message is sent from the Score Module to the Audio Module. These drones use the same synthesiser as Drone 1.

6.3.2 Case Study Description

In the study, the aim was to analyse how the system shapes connections among different musicians in a performance ecology, expanding what was discussed in the first study. Puffin V2 was therefore used in a real world context in collaboration with the local Conservatory, to create a piece for a public concert.

6.3.2.1 Study Background

The system was used to create an artwork named *Mútuas Colaborações* (Portuguese for *Mutual Collaborations*). The piece was created within the scope of the project *As Nossas Árvores* (*Our trees*) in which five artists developed creative work in collaboration with local communities about specific trees. Each tree is presented in monthly public events, after which artistic documentation will become available online on an alternative touristic map, accessible to the public.

The piece *Mútuas Colaborações* in which Puffin was used was the first one presented in this project. The selected tree (a kapok tree) is located in Quinta Magnolia, a park in Funchal, Madeira, that is in front of the local conservatory. The tree lives in an ecosystem of 263 different neighbouring species in the park. The core idea of *Mútuas Colaborações* was to represent that a tree does not exist in isolation, it lives in a complex ecosystem of interrelations with the nearby environment. The piece aims at representing these multiple interrelations by creating a musical situation where the actions of one performer influences those of the others.

To develop the piece, a collaboration with the conservatory was established, to work with their students (S1, S2, S3, S4). Four students, two females and two males (age 16-17), of the conservatory were involved in the creation of the piece. The four instrumentalists play two violins, a viola, and a cello. The students were enrolled in the professional course for instrumental performers, and had basic training in harmony and theory but no previous formal experience in composition or improvisation. The work was included in the pedagogical curriculum of the students, and at the same time the final concert and the recording are included in the artistic project "As Nossas Árvores". Authorization to participate in the artistic project and to collect data about the use of the system was granted by the parents of the students beforehand. [12]

[12] As the students were underage, the ethical approval was obtained by the ethical committee of the Department of Informatics of the NOVA University of Lisbon.

Mútuas Colaborações was collaboratively created during the four rehearsals, with each of them leading the creation of an individual piece. Across the four pieces, all the members of the quartet alternate at the keyboard, with the other three playing their own instrument. Overall, *Mútuas Colaborações* can be considered a sort of meta-piece that comprises the four individual pieces. In addition to this metaphorical representation of ecology, the piece also incorporates some spoken reflections by the performers themselves on their own relationship with the tree: each piece had a short tape music introduction based on elaboration of the recordings of a short text that each student wrote about the tree. The focus of this section is on the use of Puffin, the creation of these acousmatic introductions will not be analysed in detail.

6.3.2.2 Study Setup

The study was organised as follows: four workshops/rehearsals in the classrooms of the conservatory, during which the designer and the four students collectively created the piece; one public concert at the end of the four rehearsals in the garden of the conservatory; and finally a recording session in a dedicated room provided by a local music association. The four rehearsals occurred one per week in a timespan of a month; the concert occurred the day after the last rehearsal; and the recording took place the following day. A 2-octave MIDI Keyboard was used (figure 6.13) with the threshold set in the middle C, with one octave for the drone (that is transcribed as notes) and one octave for the other synth (that is transcribed with the rhythmic notation). The instrumentalists read from an external monitor.

Figure 6.13: Puffin V2 (on the screen of the computer) with the MIDI keyboard.

6.3.2.3 Author's Role and Design Perspectives

In the case study, the author of this thesis, main author of *Mútuas Colaborações*, and designer of the system [13] developed one music work using Puffin V2, together with four instrumentalists, students of the conservatory. [14]

[13]The term 'designer' for the sake of brevity.

[14]As the scenario involved students, the author of this thesis needed to be particularly focused in facilitating the activity and supporting the participants. For this reason, a second researcher supported the data

The study therefore investigates and reflects upon the experiences of participants and researchers in relation to how the technology intervenes in crafting the final artwork. As pointed out, a "field study is necessarily influenced by the researchers' perspectives" [97]. This is true in any area within HCI, but it is even more relevant in the case of technology developed for artistic and musical purposes. Indeed, as Magnusson has recently discussed, any piece of music technology embeds a specific view of how music should be performed, composed and thought [200]. This is true regardless of the designer's involvement in the study.

In the case study presented in this section, the researcher acted as a facilitator, to allow the instrumentalists to creatively use the technology. This condition represents a real world context. Indeed, the final artwork was presented publicly, with the designer as the main author and coordinator. In our analysis, the various relations that characterised the collaboration between the designer and the participants will be considered and discussed. This approach is similar to other studies in technology for performance [92, 97].

6.3.3 Methods: Data Collection and Analysis

The study aims to investigate the use of the technology in a real use scenario (in the wild) collecting insights about it, moment-by-moment [82]. In the context of technology for performance, Benford speaks about performance-led research in the wild, tackling those cases in which the interactive system is designed for artistic performance [17]. In these cases practice and theory are deeply intertwined and reciprocally and mutually influencing each other.

The study combines the autobiographical perspective [243] of the first author, with an idiographic approach [134] looking at the four participants using the system. In the case presented here, the designer used the system to frame the overall process that identifies the artwork and the artistic concepts.

The following data were collected: the four rehearsals were audio-video recorded; throughout the four rehearsals ethnographic notes have been collected by a second researcher; at the end of each session these notes were double checked and integrated with the autobiographical experience of the author of this thesis; and at the end of the recording session, the four students have been interviewed individually (the length of the interviews spanned from 20 to 30 minutes). The questions for the interviews followed the same template as in the previous study regarding Puffin V1 (section 6.2).

The interviews were transcribed and translated to English, as the original language was Portuguese. These transcriptions were analysed following the procedure of thematic analysis [40]. The interviews were recursively coded and the coded were consequently clustered to create themes and subthemes. The thematic analysis of the interviews was integrated with the ethnographic notes, to better identify forms of appropriation and

collection during the rehearsals collecting field notes, and performed ethnographic observation throughout the entire study.

collaboration that emerged throughout the study. At the end of the analysis, the ARCAA framework was used to connect and visualise the data collected during the study.

6.3.4 The Four Sessions, an Overview

This section described a swift overview of the structure of the entire fieldwork. Figure 6.14 shows the setting of the rehearsals.

Figure 6.14: The setting of the rehearsals

Rehearsal 1 - Exploration. In the first rehearsal, the students were introduced to the system. After a first initial explanation on the main functioning of the system, they could individually explore it while the other three musicians read the generated score in staves 2-4. In this rehearsal, the designer showed all the possibilities of the system, but did not prescribe any particular rule on how to use or interpret the rhythmic notation. The four students started to decide how to use it (further details can be found in the Results section). At the end of this session, the designer asked the four students to prepare for the next rehearsal a short sentence about the tree (that served as inspiration for the piece).

Rehearsal 2 - Ideation. In this second rehearsal, the students started to build the structure for their own piece (in which each of them would control Puffin). Between this rehearsal and the next one, the designer asked them to create a paper score of the structure of their own piece. At the end of this rehearsal, the designer recorded the four students reading their sentence about the tree. This audio material was used by the designer to create short tape music intros to each piece.

Rehearsal 3 - Definition. In this third rehearsal, taking the paper scores as a starting point, each piece was finalised and the details were clarified. A fine-tuning on how to use the rhythmic notation occurred between rehearsals 2 and 3. In this rehearsal 3, it also appeared that it was necessary to add some controls to Puffin, to erase the score and restart, in order to perform the four pieces in a concert. These changes were implemented before the following rehearsal.

Rehearsal 4 - General rehearsal. In this last rehearsal, the students were introduced to the new controls to erase and restart the score. After that, a general rehearsal of

Table 6.1: The overall structure of “Mútuas Colaborações” with the alternation of the roles.

Piece	Controlling Puffin	Instruments
Intro tape 1	//	//
Puffin 1	S1	S2 - Cello S4 - Violin S3 - Viola
Intro tape 2	//	//
Puffin 2	S2	S4 - Violin S3 - Viola S1 - Violin
Intro tape 3	//	//
Puffin 3	S3	S4 - Violin S1 - Violin S2 - Cello
Intro tape 4	//	//
Puffin 4	S4	S1 - Violin S3 - Viola S2 - Cello

the entire concert was performed. Table 6.1 represents the overall structure of *Mútuas Colaborações* with the alternating roles.

Concert. The concert took place at night in the garden of the conservatory and was open to the public. The students read the score from an external monitor. The scores were also projected for the audience. To do so, the audio module was sending information about the notes, via OSC, to a second computer. A second instance of Puffin mirrored the screen scores.

Recording. The recording session occurred in a dedicated room of a local music association. Each piece was recorded individually and the score on the screen was also video-recorded . Figure 6.15 shows the setting of the recording.

Figure 6.15: The recording setting.

6.3.5 Results

The results of the thematic analysis are presented here. Six main themes with several subthemes were identified; the subthemes are highlighted in bold.

6.3.5.1 The Piece(s) is Partially Influenced by, but Independent from, the System

The musical artwork *Mutuas Collaborações* was composed of four short pieces. In each of these pieces a different student was using Puffin V2, while the other three were reading the screen score. The student that was using Puffin V2 (Puffin player) was in charge of the compositional process of that specific piece. All the students perceived that they composed an individual piece by using the system.

Ownership of each piece. Despite that the idea of composing intimidated the four participants at the beginning (S1 in particular), at the end, they all expressed happiness about it. When asked who the authors of the pieces are, all the four students replied that they were the authors. S1 has argued that "every piece has its own identity and represents the ideas of each of us". Additionally, S4 identifies herself as the author of her piece "Because I identify myself with, for example with the key, because I like the key of D major. And I believe also that the Melodies and the way I structure the piece is mine. It has a lot to do with my preferences." (S4). Despite recognising himself as the main author, S3 recognised that "without [the designer's] help and without the software also it would not be possible to create it. So I think it [the influence on the piece] is all equally divided."

Paper score to fix ideas. Throughout the compositional process, the paper score that was introduced in rehearsal 2 played an important role for creating the structures of the pieces independently from the use of the system. Indeed, despite the local notes being improvised during the performance, the overall structure of the pieces and some melodies were already decided by each student, and were defined with recursive improvements during the various rehearsals. Different forms of notation have been used (figure 6.16). Three students wrote their score on paper, while the fourth decided to use a tablet with a drawing program. These forms of scores proved to be useful to fix ideas and improve them: "There was a class, in which I liked what I did in that class, so not to forget, as I already had a basic idea, I went to the piano and I started to work out on the harmonies [...] So I was schematising what I did and I liked. I believe that it is also very important to do [...] a visual work and not only melodic, so that people who see that can understand the relationship among the notes." (S1). These forms of score were also used during the performance as reminders for the structure: it was a "'reminder' and not the entire thing, [. . .] the rest is in my mind, as I already know what to do" (S2).

The system constraining musical ideas. The system imposed some musical characteristics to the work. For instance, S2 found it limiting that he could not give instructions to all the instrumentalists at the same time but had to wait for the time of the repetition of the canon. Additionally, the system did not allow to create "elaborate stuff" (S4),

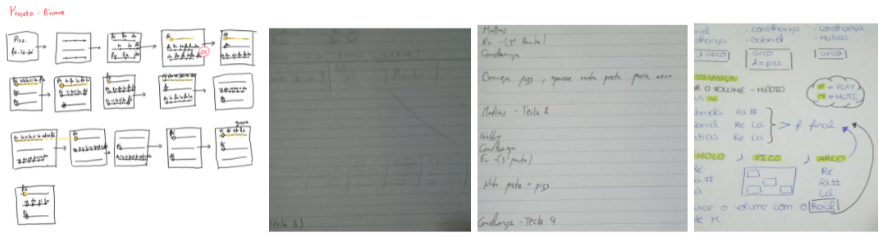

Figure 6.16: Examples of the paper scores of the students.

in particular precisely articulated rhythmic indications (S4 and S1). However, in some cases, this limitation was perceived as a stimulus, it “pushed our imagination to create the structure that was ours” and each of the students “could do its own interpretation” (S4).

Appropriation for composing. Throughout the creative process of using Puffin V2 for composing, three forms of appropriation have emerged. First, S3 decided *not to use the drones* in his piece and therefore turned off the volume of Puffin V2 for the entire duration of the work. This possibility was discovered by chance, as in the first time he simply forgot to turn on the volume, but he liked the musical result and decided not to use the drones in his piece.

Second, the students also *appropriated the rhythmic notations to communicate changes in the articulation of the notes*. This use of the system is different to its use as an indicator of rhythmic possibilities that was envisioned in the original design, and used in the first study with Puffin V1. In all the pieces, the string instrumentalists were asked to simply replay the notes in red, and the rhythmic notation was used for conveying information about specific timbric effects or techniques. In particular, two distinct uses of the rhythmic black square notation have emerged. Rhythmic notes have been used to communicate changes in the articulation of all the successive notes, therefore determining sections in the piece. For instance, in figure 6.17, all the notes after the black square note are supposed to be played with the bow, while all the notes before were *pizzicatos* (in other cases the changes are from tremolo to normal notes, or *pizzicato* to bow). In these cases, the rhythmic notation was used to create sections within the piece. Which type of technique to use in each section was decided during the rehearsals; therefore at performance time, all the musicians already knew the overall structure of the piece, and the sequence of the sections. Rhythmic notes have also been used to indicate to repeat the same note, but as pizzicato (figure 6.18). In this second case, how to interpret the rhythmic notation was also decided before. However, as it determines a local effect and non structural changes, it was not necessary to define the overall structure of the piece before the beginning.

Third, the *horizontal space of the staves have been used to create incremental subdivision* of the length of the notes increasing the rhythmic density (figure 6.19): “From a rhythm perspective I used the horizontal part, I started with 3 or 4 notes, and then I kept subdividing it , 4 became 8, or 2 to 6, and I tried to build up in this way” (S3).

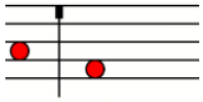

Figure 6.17: The black note indicates a change in the technique, the a would be a Pizzicato, while F (and all the successive notes) have to be played with the bow.

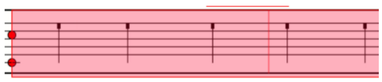

Figure 6.18: The five black notes have to be played as C pizzicatos.

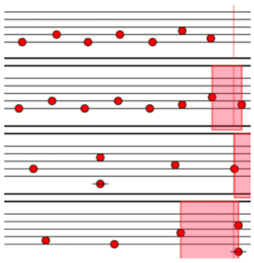

Figure 6.19: Incremental subdivision of the length of the notes increasing the rhythmic density, (the top notes are the more recent ones ones).

6.3.5.2 Using the System as a Way to Connect

A few patterns of specific actions that the Puffin players were performing in relation to the others have emerged. Overall, while using Puffin V2, all the students experienced forms of communication with the other three instrumentalists.

Real time composition is appreciated. Overall, the participants (S3, S2) appreciated the possibility to compose in real time as it helps create connections. "I would say that the more interesting aspects are: we can create something and at the same time we were giving indications about what we want for real. We are in contact with those who are playing, because they are playing at the same time. Therefore it is a connection between who is playing and who is composing." (S4).

The system as a mediator. Puffin was experienced as a tool to send information to the instrumentalists in real time: "I am passing the melodies and the music that I have in my mind to the keyboard, from the keyboard to the computer, and from the computer to the musicians" (S2). However, this information was not fully prescriptive, as the instrumentalists "had their freedom to choose the way to do it, like arpeggios. I was only controlling the notes and the rhythms [...] but inside the octave they could decide" (S3).

Focus on harmonies. The Puffin players focused on the overlapping of the different melodies that the string instrumentalists were playing, "in the verticality to try to do harmonies" (S3). This happened both to have chords "to make it so that everyone changes at the same time." (S2), but also in the overlapping of melodies: "when I was doing the melody I was looking at the other parts to check how it fit and if it fit well with the others" (S4). S4 also stated that she was singing the melodies in her mind to achieve that.

Need to pay attention. As the system creates a situation where the canon is always continuing, and there is a need to focus on three different melodies while creating a fourth one, a feeling of pressure emerged, such pressure that helped "being focused on what I was doing" (S4). It could be possible to observe that, when using Puffin, the students were always looking at the screen – except for specific moments in which they wanted to change dynamics of the other instrumentalists, or to ask for confirmation/help from the designer.

Listening while composing. Listening to the instrumentalists occurred both with the objective of directing the dynamics (conducting) but also for checking the musical results : "I was mainly hearing what came out" (S3); "I was also focused on what the people were playing to give some indication" (S1). In one case, the listening process was used as a support for the creative process "thinking about what happens next" (S2). However, S4 also acknowledged that when she was using Puffin it was difficult to listen to all the three instruments.

Conducting. The students performed conducting gestures to give indications about the dynamics of the other three instrumentalists. As they never did it, they learned to do so throughout the rehearsals, progressively gaining confidence. These gestures were used to obtain specific dynamics in some moments of the pieces. "My piece had a forte in the end and a crescendo, and it was this part with more interaction" (S4). Conducting was also used simply to balance the instruments. "With the hand I could control the others [...] for instance, imagine that I believe that the violin is too loud and the viola too low. I am able to lower the violin and increase the viola" (S2). S3 reported that on an occasion he failed to conduct: "there were many notes, therefore they needed to focus more on the visual component of the notes, to the trills [...] therefore many times they did not focus on [...] watching me conducting. Because of this sometimes they did not react to my indications." (S3).

Asking specific things during the breaks. Finally, the Puffin players verbally asked to play in specific manners right after or at the beginning of rehearsal. "[...] at the end [of a rehearsal] I told them that I want it more aggressive" (S3). S1 reported that it "is easy to give these indications when we have what we want in our mind."

6.3.5.3 Playing Together as in Chamber Music

While playing their own instrument, the students played as "a trio, that is chamber music" (S3). They all stated that they needed to pay attention to what the others were doing, and a few different patterns related to this need have emerged.

Paying attention to what the others played before to better imitate them. The students reported that listening to the others facilitated the process of imitating them, therefore supporting the reading of the score. "When there are fast melodies, it is difficult to read (at first sight), but by hearing the other before, or thinking about how the melody is, it is easier to read" (S2). It also helped to imitate the phrasing better resulting in a more cohesive musical performance: "I was always trying to focus on who was playing before, to know the order and therefore trying to recreate what the others did" (S3).

Non-verbal communication. In some passages, the notes on the different staves were aligned (figure 6.20) to create the effect of chords, with all the notes changing at the same time (homorhythmically), as in *chorales*. In these cases, the instrumentalists relied on signals to change at the same time: "We normally look at each other and make a gesture, and we even count 1 or 2, and we enter at the same time, and it goes well." (S2); or also they "breathe with the intention to raise a bit the instrument and the bow, and we all meet [fit] in the same spot" (S1). It is interesting to notice that S3 relied on previous common music practice for these particular moments. "I used to look at S1, as we already play in groups, and she is normally the first violin or the concertina, therefore she sometimes makes a signal and I use it as a guide, or else [I follow] her breathing" (S3). Over time these signals "turned out to be natural" (S4).

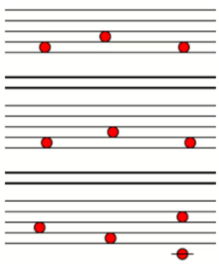

Figure 6.20: A passage like a Chorale, with all the instruments changing at the same time.

Peripheral view while playing. The fact that the instrumentalists paid attention to what the others were doing, resonates in the fact that they did not only read their own staff but also use "the peripheral view to see the rhythms above or below." (S3). In particular, S2 looked at the other staves when he had long notes.

Canon as an expression of musical relationship. Overall, the canon structure and the fact that they all played the same thing one after the other helped to create cohesion among them from a sonic perspective: "as everyone is going to play the same thing, sooner or later, we connected and created a sound in a nice way" (S2). "There was a connection with what the others were playing and it was interesting" (S4).

Relationship with the instrument. Overall, playing in the setting created by the use of Puffin did not affect the way the students normally play with their own instruments. The only difference in relation to how they normally play their instruments occurred for those instrumentalists that normally do not read in the G key, who "trained the reading (reading at first sight)" in this key (S3) during the rehearsals.

6.3.5.4 Supportive Collaboration with the Designer

Overall, the interaction with the designer was appreciated and perceived as supportive without imposing any specific direction of the work of the students while they were using Puffin V2.

Peer relationship between the students and the designer. Overall, during the rehearsals, the students deemed that "there was no pressure [. . .]. It was all quite peaceful but also productive" (S1). This was also facilitated by the fact that for the scope of the study we decided not to use formal language: "[The designer] let us address him by first name, it was not formal" (S3).

Supporting the improvement of the musical ideas of the students. The role of the designer was primarily perceived as an expert musician who supported the individual compositional processes. The designer was perceived as supportive in the development of the students' own ideas, but not prescriptive. For example, S3 felt total freedom in dismissing one suggestion by the designer, because he preferred another solution. Indeed, overall, the students felt supported rather than restricted by the suggestions: "[The designer] gave us a lot of instructions, and from these instructions we could adapt it in a way that it was our own creation, our piece." (S4). "I feel [...] that [the designer] helped me to realise the ideas that I wanted" (S3). In this case, the suggestions were mainly related to the development of musical ideas, such as "explaining techniques to improve our ideas" (S4) and help "to compose and to show us what we were doing bad and good, and how to improve." (S2).

The designer as a facilitator of the system. Finally, the designer was also perceived as an expert of the system facilitating and understanding the functionality of the system. "[The designer] knows how to use the program better than us" (S2). Therefore, the designer was helpful "to understand the system better" (S4).

6.3.5.5 General Consideration about the Experience

A few key elements were identified about the overall experience of playing with and alongside Puffin (V2).

Experiencing something new. The students appreciated doing something new, as they "never did anything like composing" (S4), the experience allowed them to explore aspects of musical creation that they are not accustomed to. "I think this experience was quite interesting, for us all, the four of us, we never did something like this, similar to this, playing music in such a free way, and more toward the contemporary, and based on our creativity, imagination, and intuition" (S1).

The improvements in the process. Overall, the students perceived an "evolution class after class, I believe it continued to improve and we managed to build our ideas, build our piece, our identity of the piece." (S1). Additionally, if there was more time the students perceived that they "could have ameliorated some aspects of the pieces" (S3).

Working together. The students liked the overall experience “it was also interesting to work with [the designer], with a different artist, to work the five of us together” (S1).

6.3.5.6 Possible Improvements in the System

Two suggestions for possible improvements were proposed. Firstly, it was suggested to add a possibility to change the key of the various staves S2. Secondly, S1 expressed that she would have liked to have at least two octaves of drones to have more space to create melodies. This would be easy to change by using a bigger keyboard or customising the setting of the threshold in the audio module.

6.3.6 ARCAA Representation of the Study

Figure 6.21 represents the overall ecology of “Mútuas Colaborações” . The scheme is valid for each of the four individual pieces of the students, and represents the shared commonalities among the four. Overall, the students did not play the same role, but the same configuration occurred 4 times. Therefore, it can be deduced that, despite being aesthetically independent, the four pieces share strong commonalities in terms of relationships among the various actors and artifacts. This ARCAA representation will inform an analysis of the different roles and respective actions of the student who is operating Puffin, and the different actions performed by the instrumentalists.

6.3.6.1 Composing with Puffin: the Systems and the Others

While composing the system (Puffin player in figure 6.21), the students performed three main sets of actions, respectively in relation with the designer, the system and the three instrumentalists. These three sets of actions (discuss, control, watching, listening) are roughly represented from left to right in figure 6.21, in the activity layer.

The designer was perceived as a friendly and non authoritative facilitator, who helped the students (when they were composing) to explore the system and develop their own musical ideas. The relationship between the system and the compositional process will be further discussed in the next subsection of the discussion. However, it is already important to highlight how the act of composing (even excluding the relationship with the instrumentalists) involved two actors orbiting around Puffin (the designer acting as a facilitator and the student who was actually composing). In this sense, this small piece of the overall ecology (the facilitator, the student and Puffin) can be intended as an artifact ecology composed of multiple people interacting with one single artifact (this type of ecology reflects the idea proposed in [31], with multiple actors relating to one artifact). It is also worth mentioning that the development of the musical ideas primarily occurred within this sub-ecology, not solely in the interaction between the students and Puffin. Indeed, the students reported that the human-human relation with the designer (as an expert) was pivotal in the development of the piece and musical exploration of the

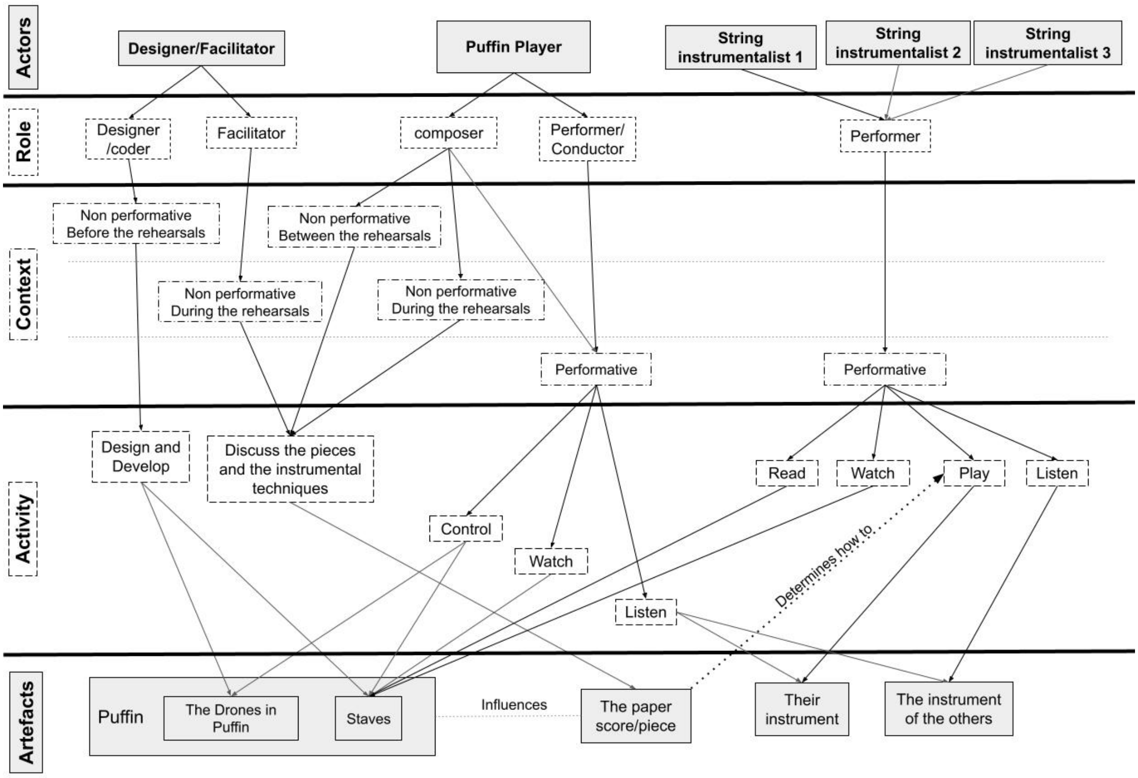

Figure 6.21: The overall ARCAA representation of the ecology of the performance with Puffin.

system. This element is aligned with what stated by Lucas and colleagues [187] about the importance of the ecology in music technology as assistive technology. Overall, all these interactions tended to occur not in real time but in discussions in preparation of performative moments.

While interacting with Puffin in real-time, the student (a performer playing with Puffin) constantly had to focus on the other instrumentalists. This happened both directly (listening to them or conducting) and indirectly (by checking the harmonies - the notes played by the others - on the score). Overall, Puffin acted as a mediator between the composer and the instrumentalists: an element that encodes and provides instructions. In this sense, it became the pivotal component of the entire performance ecology, and element that mediates the process of music making itself. Alongside the relation between the composer and the performers mediated by Puffin, a number of non mediated actions have emerged, such as listening and conducting, and even asking specific things during the breaks. These other actions should not be considered as secondary, rather are central and necessary to use Puffin in a meaningful way.

6.3.6.2 Composing with Puffin: a Distributed Cognitive Process

In the literature review of this thesis, and in particular in sections 2.2.2 (e.g. [59, 38, 293, 85]) we have seen how composing and creating new technology are often intertwined processes. In particular, Magnusson has underlined how DMIs are artifacts that carry a defined and specific vision on how a specific piece of music could be thought, expressed, and performed [200].

In this second study, despite the fact that a specific vision of music was embedded in Puffin itself, it emerged how the compositional process has actually been distributed among different components. Let us ignore for the moment the actual sound produced by the instrument of the instrumentalists (their perspective will be discussed in the next subsection), and focus on the process of the student operating Puffin. The system imposed a set of rules, which defined and framed the limits and possibilities of the musical discourse. This element embeds the vision from the designer, on the one hand his interest in studying how digital scores shape performance ecologies, on the other hand his compositional and musical preference on imitative counterpoint. However, it also clearly emerged that each of the students felt that she or he had been able to compose a personal piece that represented their own personal vision and aesthetic preferences. The pieces, therefore, *were influenced by, but independent from, the system*. Different forms of appropriations have emerged, for instance in the use of the different forms of graphic symbols, to communicate different things (the same symbol has been used for communicating end of sections, or pizzicatoes by different students). From this element it can be supported that, despite indicating one very clear musical imaginary that refers to the imitative counterpoint tradition, Puffin was open enough to allow multiple interpretation of its meaning and usage. Using Dix's worlds Puffin allowed for "improvisations and adaptations around technology" [77]. The students could rely on the non prescriptive spaces, the hidden affordances [108] of the system to explore and find personal ways of using it and infuse their own personal ideas in their pieces. The system actually helped the students to explore musical ideas and to start composing.

To define a personal way of using Puffin, the students also relied on paper scores to define the musical forms of their pieces. Magnusson has discussed how a piece of music technology acts as an epistemic tool, a physical element over which a musician offload part of his creative process [199], in the same way as the idea of extended mind works, humans can offload part of their cognitive process on tools [56]. In the case study presented here, the cognitive process was offloaded both on the tool (Puffin) and on paper scores that were used to both organise the musical form of the pieces and to remember it. From this, it can be observed how the compositional process itself relied on a small artifact ecology, composed by Puffin and the paper scores.

6.3.6.3 Instrumental Performers, not only Playing an Instrument

Many different actions correspond to different roles for the person operating Puffin. On the contrary, the instrumentalists performed the same set of actions. However, the instrumentalists, despite primarily playing only one role (the performer), performed a variety of different actions (listening, watching, playing) without directly manipulating the system. Such actions are necessary to effectively and musically interact with the system. It is worth noticing that some of these actions do not merely emerge as elements belonging to this specific performance, but rely on existing relationships and habits that the students previously developed. For instance, the students are used to playing together, and normally look at each other, or breath before notes that need to be played synchronously. In this sense, it can be argued that the ecology of a performance does not merely comprise the elements that actually composed that specific performance, rather it inherits habits and behaviors from previous practice. This element echoes Gurevich's conception of a performance ecology, that accounts for the relationships among the various persons involved also incorporating history and genre [122]. It can be speculated that a given performance ecology not only includes history, but also the various specific stories of the individuals involved.

Looking at the actions that the instrumentalists did (listening to each other and using the peripheral view to look at the staves of the others) from the affordance theory perspective, it is relevant to observe how their training, education and practice come into place. Heft has supported that affordances are learned in social context [128], and Costall argued that affordances should be accounted for as a social element [64]. In this second case study, this social element clearly emerged. There were no direct instructions to check the staves of the others, the instrumentalists simply did it. In some cases, the instrumentalists understood that the composer wanted some notes to be played as a chord, even if they were not completely aligned, therefore they gave each other signals to play those notes together. In these cases, their mutual knowledge even overcomes the actual indication of the score in a strict sense. Based on this, it can be supported that it is fundamental to account for the previous experience and the existing performance practice when designing new music technology. It is important to acknowledge that this compound of actions and affordances constitutes another layer in the way the piece is created which needs to be added to the distributed process described in the previous section.

6.4 Conclusion

In this chapter, after describing a preliminary study, two versions of a novel interactive screen-score system designed to expose connections in performance ecologies and two corresponding case studies on ARCAA, with two instrumentalists and four instrumentalists respectively, have been presented. In the studies, many relationships between the various actors and artifacts in a performance ecology have been analysed and discussed. Additionally, this chapter provides highly detailed examples of how the Puffin systems can be used "moment-to-moment"[82].

Both studies highlight how the instrumentalists are complex actors, not merely users of a system, rather musicians who can be happy to actively contribute to a piece as active actors and not just as users. This is in line with the original premises and aims of ARCAA.

In particular with the choice of the term Actor (see 4), and it resonates with Rodger and colleagues' statement [270] about the fact that music performers are not users "but rather agents in musical ecologies".

To conclude this chapter, some general trends emerged from the two studies presented, by combining what is discussed in sections 6.2.6 and 6.3.6.

6.4.1 Background of the Musicians

An important element that emerged in both studies is the relevance of the background of the musicians involved. For instance, in the first study, the guitarist's background as an electronic musician allowed him to operate changes in the system. In the second case study, the background of the participants played an even more relevant role in determining the set of activities performed. As the students are used to playing together in orchestra or chamber ensembles, they developed the habit to look at each other, or breathe for better synchronisation. Based on this it can be supported that a performance ecology inherits habits and behaviours from previous practice that shape the various interconnections in a performance ecology.

This observation resonated with the idea of the social component of affordances. Section 2.1.3 presented how affordances are relational properties that emerge in the relation between agent and objects. It has also been discussed how affordances have a strong social component, for instance, affordances should be accounted for as a social element [64], as they tend to be developed in social context [128]. Based on this vision of affordances, it is quite logical to expect that a given specific performance ecology inherits social affordances derived from the background of the actors involved.

6.4.2 Importance of Peripheral Actions (Indirect Interactions with the Technology)

In both studies, a wide number of actions unrelated or parallel to the use of the system have emerged as fundamental in order to meaningfully and musically use Puffin. For instance, in the first study, the two musicians discussed musical aspects of the performance or rehearsed specific moments without using Puffin. In the second study, participants discussed musical ideas, formal development, as well as defined the meaning of the graphic notation. Additionally, in both studies, activities performed in parallel to the actual use of the system have emerged, such as listening and giving each other signals. In the second study, these activities were more varied, also including conducting. It is possible to speculate that, in the second study, more of these parallel actions emerged, due to the need for coordination among a higher number of musicians. This element reinforces the initial proposition of ARCAA that supports expanding the scope of investigation on performance ecology, to include the interactions that occur in the preparation of the performance. It has been discussed that considering cultural aspects (see for instance [122]) should be accounted for to understand a given performance; these studies support adding another element, including all the non-performative interactions (e.g. discussing, listening, recording) as core constituents of a performance ecology.

6.4.3 Screen-Score Artifacts as Mediator

One of the core ideas of the Puffin (in both version 1 and 2) is to **expose how a digital interactive system can connect multiple human actors in the performance ecology** using a real-time created score. Indeed, Puffin transforms the actions of one performer into guidelines for other performers. Therefore, the score on the screen becomes the element that connects the two performers, creating a sort of *canon*, a delay of musical elements within the same performance ecology. Musically, Puffin is inspired by one of the most ancient compositional strategies of western music tradition: imitative counterpoint, canons, and fugues. The system is also inspired by more recent electroacoustic repertoire that employed delays in a structural way, creating imitative counterpoints, such as *Dorian Reed* by Terry Riley [15] and *Ricercare una melodia* by Jonathan Harvey [16].

Puffin offers a different perspective on such a compositional approach by combining the use of screen-score with structural use of delay and repetition. Electroacoustic pieces like *Dorian Reed* and *Ricercare una melodia* used manipulation of the sound of an instrument to create the delay. Puffin generates a score that asks other performer(s) to play with a delay of what the first performer just played. From an instrumental perspective, the technology mediates the relation among the various musicians and melodic components, determining the connections in the overall performance ecology. In both ARCAA representations, such connections are visible with the different actions that connect the instrumentalists with Puffin (i.e., controlling, reading, watching, listening).

Puffin also introduces a slightly new perspective over the traditional design and use of screen-score systems, as it is used to create connections between performers on a stage and not to give them instructions (e.g. [140]). It is true that in some cases, screen-scores can be affected by some performative actions (e.g. in [160], the performer can control the score with a pedal, and in [86], the score is affected by emotional biosignal measurements). However, the role of a score as an ecological delay that mediates the relation among the various performers represents a new approach to screen-scores design.

6.4.4 The Piece and the System

The second purpose of Puffin (both version 1 and 2) is to **explore how an interactive system can subsume the role of a score** (as suggested in [199, 277]). The tangible score project by Tomas and Kaltenbrunner exposed such a characteristic using tangible technology by transforming the "inherent score to the physical layer of the interface"[299]. In Puffin, the inherent score is exposed on a screen from two different perspectives: 1) the system produces the score for the instrumentalists; 2) the system visualises the core

[15] Example of one performance `https://www.youtube.com/watch?v=29U9Sk0g9is`.
[16] Example of one performance `https://www.youtube.com/watch?v=sxHZ_UN5BKE`.

musical idea of the piece – an imitative counterpoint that determines the core musical structure.

In both case studies, it emerged quite clearly how the musical ideas embedded in the system defined the set and possibilities and limits of the musical discourse. The technology indeed embeds the vision from the author of this thesis, derived not only from the research objective on scrutinising performance ecology, but also on musical interest in imitative counterpoint. However, it also clearly emerged that it was possible to compose different pieces. For instance, in both ARCAA representations, the pieces have been represented as individual artifacts. In the second study, the possibility of creating different pieces emerged more clearly, as each of the students created an individual piece, and each student identified that piece as his/her own.

6.4.5 Different Design Approaches Coexisting

In both case studies, two design perspectives coexisted. It is important to highlight here that both case studies' outcomes also included a musical artwork (included in a public performance), primarily authored by the author of this thesis, the developer of the system. Because of this involvement as composer of the author of this thesis, the autobiographical perspective (as described in [243]) was predominant in the creation of the system. Musically speaking, the relation with the western legacy of imitative counterpoint, canon and fugues, reflects one of the main musical interests of the author of this thesis. Repetition and imitation can be structural elements in non western musical tradition (e.g. the Javanese Gamelan), however the western perspective express the personal biographical experience of the composer (as presented in the introduction of this thesis, in section 1.1) [17]. At the same time, an idiographic perspective (as presented in [134]) was used to tailor the pieces, the activities and perform fine tuning to the system based on the needs of the participants.

6.4.6 Possible Improvements in the System and Future Works

Two suggestions for possible improvements to the system emerged in the second study. Firstly, it has been suggested to add a possibility to change the music key in the various staves. Secondly, it has been suggested to have more octaves in the keyboard to create melodies. Future works can also include further development of screen score systems as collaborative mediators in music ecologies also relying on network technology.

[17] Additionally, the author of this thesis had publicly performed the electronic part of the two aforementioned electroacoustic pieces that relies on delay to create canons–*Dorian Reed* by Terry Riley and *Ricercare una melodia* by Jonathan Harvey–

6.4.7 Final Remarks

In this chapter, two versions of Puffin have been presented. By discussing the respective case studies, it has been analysed *how different actors play different roles and perform different activities in different contexts, including actions that are related to the digital system only indirectly; how screen-scores can act as ecological mediators; how a piece and a system are interconnected but distinct*. Different conceptions of affordances (social and hidden) can be helpful in understanding these different actions and frame the relations in this ecology (in the case studies presented in this chapter, social affordances were useful for non verbal communication, and hidden affordance for appropriation). It is relevant to underline the importance of all the actions that do not directly involve a manipulation of the digital technologies for a good musical result. Finally, it was possible to observe *how autobiographical and idiographic design approaches can coexist*.

Based on the points emerged in the studies, it can be supported that this chapter can contribute to understanding ecological perspectives of music performances, and could support designers and composers working with interactive systems for music performance. It is also possible to speculate that similar situations can occur in other cases when there are many individuals involved, also with very different technologies.

7 Dance Technology and Co-creation Case Studies

A contemporary dance performance represents a complex scenario, requiring a multi-faceted approach from HCI and sonic interaction design, which needs to take into account the different roles of the technology in creating meaning in the overall dance performance. As observed in section 2.3 (in particulars in subsections 2.3.4 and 2.3.5), there is a growing interest in looking at relationships in dance ecology (i.e. [89, 141]). This chapter is inline with those existing works, and extends them in different directions, with two studies on dance technology. These two studies were developed in the scope of the Creative Europe project Moving Digits [1].

The first study is based on a focus group that aims to understand how dance artists (dancers and choreographers) wish to use and consider technology in the development of a dance piece that involves interactive tools (section 7.1) [2]. This first study produced a set of guidelines for designing interactive technology for dance performance.

The second study presented in this chapter follows the same approach used to investigate music ecologies (sections 6.2, and 6.3), and focuses on the creation of a dance piece (section 7.2) [3]. In this case study, the creation of different sonic interactive tools for a dance piece was analysed with a high level of granularity.

7.1 Study one - A Focus Group on the Role of Technology in Dance

In the study presented in this section, the goal is to understand how dancers relate to interactive technology by directly questioning dancers. Overall this focus group aimed at replying to the following question:

What is the role of technology in contemporary dance?

[1] `https://movingdigits.eu/`

[2] Parts of the text of the first study have appeared in the co-authored publication [220].

[3] Parts of the text of the second study have appeared in the co-authored publication [218].

To this end, a focus group with ten dancers was organised. The focus group was structured around the following topics: the role of technology in dance performance; in particular: the role of input and output technology, and how the technology supported the communication with the audience. Based on the analysis of the respective results, a set of guidelines is proposed[4].

7.1.1 Recruitment of Participants

The participants were selected using an open call that was disseminated through mailing lists related to contemporary dance. Ninety-two dancers applied to the call (73 female, 19 male). Each candidate was independently evaluated by six members of the Moving Digits team[5], according to i) their Curriculum Vitae as dancers and choreographers, ii) previous experience with usage of technology in their dance pieces and iii) motivation and expectations regarding the activity (and the overall Moving Digits project). Finally, the scores were discussed and moderated. Ten dancers were selected (nine female, one male, from eight countries) and all the selected dancers participated in the study. Travel expenses and a fee were paid to each dancer. Thanks to the competitive selection, all ten participants had considerable experience in contemporary dance as performers, some of them also as choreographers. All were knowledgeable about the use of technology in dance[6],

7.1.2 Setting

The objective of the focus group was to gather a better understanding concerning the role of technology in dance, with the goal to identify needs and preferences of dance artists. Therefore, the focus group was structured around the following main topics, which align with our research objectives: the role of technology in dance performance; the role of interactive technology; the role of media output; and communication to the audience in dance performance.

The focus group took place in the dance studio of Sõltumatu Tantsu Lava (STL) [7] and lasted for approximately two hours. The setting of the focus group can be seen in figure .

[4]The purpose of this focus group was to frame the initial requirements for a future prototyping process. The participants (in this case, the dance artists) were involved from an early stage to identify needs and preferences regarding interactive technology in dance, which was used as the basis for future co-design processes. In the scope of this thesis, only the case of sonic interaction design for dance will be presented and analysed from an ecological perspective, later in this chapter (section 7.2); however, this focus group represented a staring point for several studies of dance technology, including the use of glitch-based visuals [158], audience evaluation of live visuals [210, 63], and adaptation of dance pieces to VR[61] or browser-based installation [219].

[5]The author of this thesis was one of the six members of the Moving Digits team who participated in the selection process.

[6]The focus group presented in this chapter was part of a two-day co-design workshop. The workshop consisted of a series of design exercises. For the scope of this chapter, only the focus group component of the workshop will be presented and analysed.

[7]STL is a a theatre and a contemporary dance platform located in Telliskivi, a creative district in Tallinn, Estonia https://stl.ee/en/.

Figure 7.1: The setting of the focus group.

The activity was audio/video recorded.

7.1.3 Results

The recording of the focus group was transcribed, and analysed using thematic analysis [40]. The analysis produced six themes (in bold), each with multiple subthemes (in italic). Direct quotes from the participants are reported here anonymously (P1- P10).

7.1.3.1 Technology as Co-shaper of the Performance

Technology has specific characteristics, which fosters the dancers to reflect on them during the creative process. In this sense, technology becomes a co-shaper during the creation process of a dance piece: “the technology is always creating some [...] setting and then it actually becomes a dramaturgy” (P5).

The creative technology. The technology is itself creative: “it’s like creative dancers [...], there is also creative technology” (P3). Such a creative technology can "generate creative ideas"(P2). Therefore, technology may already embed a specific “dramaturgy” (P5).

Movements fostered by the technology. A technological artifact has an impact on the movement possibilities, therefore on any choreography: it imposes “physical limitations” (P3) and proposes new types of “technological gestures” (P2).

The problem of excessive focus on technology. According to the participants, technology should never be the focus of a performance (P9). It should be "subtle or invisible" (P9). Technology has the potential to "mesmerise", and "fascinate" (P6) the audience; however it should not be used in this manner: a shared need to "express something with it" (P3) emerged in the discussion.

Integration of the technology in the logic of the work. As a consequence of the problem of excessive technology, the technology should be "reflected" (P3) and "integrated" (P9) in the logic of the performance, not simply displayed.

Hacking. Our participants describe the process of using the technology as a "hacking" process (P3), indeed, dancers tend not to use "the technology the way that the technology designers meant" (P3).

7.1.3.2 The Problem of Redundancy of Information

One of the main problems that our participants identified is that technology, by repeating the same information already visible in a dancing body, often diminishes the layers of meaning in the performance.

Technology is illustrative. Technology risks to be "too illustrative, [...] and too connected to what you are doing with movement" (P6), for this reason it risks merely duplicating the body (P4).

Illustration and meaning. The visual output presented in performances is "too graphic, diminishing the multi-layered meaning" (P5) and risks simply replicating the information (P6).

7.1.3.3 Strategies for Interaction

From an interaction design perspective, some good practices emerged.

Complex mappings. Unclear, divergent, or "independent" mappings from input to output technologies could be used to create contrapositions or "counterpoints" (P9) between the dancers and the technology, thus avoiding more obvious or trivial mappings (P6).

Interaction Loop. Technology could create a complex mirror that challenges the movement of the body (P9), a sort of "feedback loop" (P3) that affects the choices or behaviour of the dancer.

7.1.3.4 Strategies for Output: Adding Layers

This last theme clusters suggestions related to the output of the digital artifact.

Various sensorial strategies. The participants suggested relying on other various channels, such as "kinetic illustration" (P5) and "sound" to "trigger sensation" (P10). Moreover, as sound is "multi-dimensional in space", it is more similar to movement as compared to visuals (P5).

Visualize the structure. Exposing a "score" before (P9) or during (P6) a performance might contribute to adding layers of meaning. Such a score can act as a "commentary on your own work and it's self-reflexive and it's interesting" (P6).

Play with time-related elements. This might include displaying "things that happened in the past and [...] resonate [...] in a performance" (P9), or "traces and the resonance of the movement" (P1).

Capture the intelligence. Several aspects of the intelligence of a body could be captured and revealed: e.g. "what's happening in the brain before the movement"(P6), "record the thinking process of someone doing something incredibly complex" (P2).

7.1.3.5 Audience Characteristics

The last two themes concern the audience. The participants generally consider the audience intelligent, but also unpredictable.

Audience is intelligent. The first characteristic of the audience that emerged is that it "is intelligent" (P8) – additionally, one participant aimed for creating "performance[s] for the most intelligent person in the audience" (P9).

Audience is unpredictable. A certain level of uncertainty concerning the audience has emerged: "you really never know who's sitting in this audience" (P2), also the audience members may have an unexpected response (P7).

Audience as a close human. Finally, a level of closeness with the audience members also emerged - "It's a little bit like creating this human moment of sharing something common, of human to human" (P8).

7.1.3.6 Communicate with the Audience

Some aspects concerning the communication with the audience were also present in the focus group.

Not impose one specific meaning to the audience. Relying on the fact that the audience is intelligent, the performance should not impose one specific and "didactic" (P2) or "prescriptive" (P3) perspectives, rather it should create "multi layers of meaning" (P5) and information (P9), and technology should support and contribute that. Even promoting provocative strategies such as deliberately causing confusion "un-focusing" (P6) could be effective. The participants also prefer to create situations in which it is possible to "articulate the performance" and "balance the clarity", without overexposing an idea (P3).

Shared experience with the audience. Relying also on the notion of closeness, the participants declared that in their performance practice they aim at creating a sense of "togetherness" (P9) with the audience. The moment of the performance was described as a shared "intimate" (P9) experience between artists and audience.

Create safe environments for the audience. Our participants declared that it is important to create "safe environments" (P5). In the performance, spaces of intellectual freedom where the audience "can come with their own knowledge and their own understanding." (P6).

7.1.4 Reflections on Interactive Technology for Dance

The results of the focus group contributed to understanding the role of interactive technology in dance. In addition, it helped to discuss how appropriation and ambiguity are relevant in interactive technology for dance. Based on this, some design guidelines are suggested. These guidelines are organised around three high-level aspects of interactive technology for dancers:

1. Use and role of the technology
    a) Technology should provide space for appropriation, enabling the dancer to give their own use and meaning (facilitate customization might be a possible strategy)
    b) Technology should be easily included in the dramaturgy of the performance – make it meaningful for the performance
2. Input and output strategies
    a) Technology should not repeat the information that the dancer is already giving with their movement (avoid overly clear mappings)
    b) Technology should have a complex input-output mapping, which might be used to create a loop between technology and dancers
    c) Technology should facilitate adding information contributing to the multiple meanings of the performance. For example: (i) showing non visible elements (either inner elements of the dancers or micro-movements), (ii) shifting the temporal dimension of the performance (e.g. showing, in time lapses, residuals aspects of movement), (iii) showing the structure (score) of the performance
3. Communication with the audience
    a) Technology should not impose one single perspective to the audience
    b) Technology should contribute to create multiple layers of meaning

7.1.4.1 Technology as a Co-creator

Technology plays a crucial role as co-creator of performances. A piece of technology already has its own pre-existing dramaturgy, using the world of the participants to the workshop. This element creates a parallel with what was discussed in the literature review of music technology, about the fact that a piece of technology shares elements of a composition (see section 2.2.2). A piece of technology imposes specific problems or limitations to a choreographer, which need to be addressed. It has been discussed that

DMIs, or pieces of music technology in general, are often artifacts that carry a defined and specific vision on how a piece of music could be expressed, and performed [200]. The same principle applies here, but it is important to make a distinction between the technology developed for general purposes and then used in a dance piece (e.g. a motion tracking system), with technology developed specifically for one performance. In both cases, the technology carries some notions of an implicit dramaturgy. In the case of existing technology, the implicit limitations of a piece of technology need to be incorporated in the ideas and meanings of the performance. The choreographic process, in its exploration of a piece of digital technology, determines specific affordances that combine the intrinsic possibilities and limitations of a specific tool with the needs, ideas, and aims of the dance artists involved. In order to use technology in a meaningful way that is harmonised with the overall performance, dance artists have the need to appropriate the technology and give it a new meaning that is aligned with the dance piece, therefore looking for hidden affordances [108]. This appropriation can also imply the modification or customization of the initial technology, or the creation of new features for a specific piece. In this second case, in the end a new technological artifact will be created, whose mappings strategies and aesthetic choices (ideally) mirror the dramaturgy of the performance.

In the focus group it emerged that a performance should be composed of multiple layers of meaning, and technology should contribute to this multifaceted structure. In the focus group, it emerged that the participants have had issues with technology when it adopts overly clear mappings. In this case it repeats the same information of the body, creating a redundancy issue regarding the information that it imposes on the performance. This repetition diminishes the layers of content of a performance, risking to reduce its overall meaning. Consequently, the participants in the focus group tended to agree in disliking this characteristic in interactive technology, as they generally aim to create rich and multi-layered performances. The need of structuring the meaning of a performance is also connected to the consideration of the audience that has emerged during the focus group. It also emerged that the participants consider the audience intelligent. Therefore, one clear meaning in the performance should be discouraged and avoided in favour of a multi-layered meaning. Interactive technology has the potential to support this approach, however it also risks being repetitive.

7.1.4.2 Appropriation and Ambiguity in Interaction Design for Dance

Our participants' need for reflecting and integrating technology in the performance reverberates with the design concept of *appropriation* as emerged in HCI [77] (for a wider overview of appropriation in HCI, see section 2.1.4). Similarly, the need for adding layers of meaning, and not imposing one single meaning in a performance, resonates in the design concept of ambiguity [278]. Additionally, the idea of layering the information ecoes elements from the proposal of designing for appropriation by Dourish: supporting multiple perspectives on information [80]. In this sense, two types of appropriation could be speculated: dancers *appropriate* technological artifacts to create multiple layers of meaning in a given performance; and these layers of meaning support the audience to *appropriate* the content of that performance.

Based on this it can be supported that an interactive digital artifact designed for dance performers should take into account this aspect, and not impose one restricted meaning or use. On the contrary, it should support dancers to appropriate it, to include it in the overall meaning of the performance. In an ideal scenario, during the creation of a dance piece, some level of redesign/development should be possible. For this reason, in the case study on dance technology presented in this thesis (section 7.2), the design of the interactive sonic systems for the performance occurred during a residency in close collaboration with the dance artists involved.

7.2 Study two - Designing Interactive Sonic Artifacts for Dance Performance: an Ecological Approach

As discussed in sections 2.3.4 and 2.3.5, contemporary dance performance scenarios tend to be characterised by complex ecologies, that usually comprise a choreographer and a number of dancers as main actors. In such an articulated scenario, the different actors need to relate to a technological artifact, including any interactive sonic systems, in a different manner, developing a personal relationship with it based on the specific needs of her role. Another important element of a dance context, as emerged in the results of the above focus group study (subsection 7.1.4.1), any piece of interactive technology needs to become an integrated aesthetic component. Interactive sonic artifacts need to follow the same logic: the possible interactions and selected sounds are aesthetically and dramaturgically part of the dance piece itself.

This section aims to investigate in practice how the different actors influence the design process of an interactive sonic artifact for contemporary dance. In particular, it presents a way of using the ARCAA framework (chapter 4) combined with the Didactic-Democratic model of collaboration between choreographers and dancers by Butterworth [43].

In this case study, the design of the system occurs in the physical space of the rehearsal (a black box theatre) in parallel with the creation of the choreography. For this reason, the idea of a design space and the various levels of appropriations proposed in the design-in-use model by Botero [37] emerge more clearly in the discussion of the ecology. The case study involves two dancers, one choreographer and one sound designer (author of this thesis). In the study, the different models are combined (ARCAA, Didactic-Democratic model, and design-in-use) [8] .

7.2.1 Case Study Overview

The case study was realised within the scope of an artistic residency developed in the frame of the project Moving Digits[9]). The residency consisted of five sessions (each lasting for approximately 6 hours) with a performance at the end, and took place at Sõltumatu Tantsu Lava (STL)[10] in Tallinn. During the residency, one choreographer had at her disposal: a team of two media designers, one for the development of an interactive sonic artifact (the sound designer, author of this thesis), another one for the development of interactive visual content; and two dancers. Given the focus of this and to restrain the complexity of the analysis on sound the visual component is not analysed here. The

[8]The dance piece Connection Retrieval described in this section has been included in the first public event of the Creative Europe co-funded project Moving Digits: https://movingdigits.eu/artistic-residency/

A recording of piece can be find at this link (a rehearsal with lights on): https://drive.google.com/file/d/1d8ujantwY-JzW_YoKZEt7SOhNm-jJHpX/view?usp=sharing

[9]https://movingdigits.eu

[10]urlhttps://stl.ee/

choreographer (Hanna Pajala-Assefa) has considerable experience in working with interactive technology and a portfolio of works in which she adopted interactive technology to generate sound from a dancing body. The two dancers (Madli Paves and Christin Taul) have international experience in contemporary dance, but no previous experience with interactive technology used to generate sound from the body. Figure 7.2 depicts the choreographer and the two dancers in the rehearsal space. The final piece was composed of three main scenes, each corresponding to a different interactive setting/instrument, plus an intro.

Figure 7.2: From the left: the chreographer Hanna Pajala-Assefa, and the two dancers (Christin Taul and Madli Paves), discussing the piece in the rehearsal space.

7.2.2 Technological Setting

The interactive sonic artifact relied on a RGB computer vision-based markerless motion capture system named Captury[11] as input to generate audio from the bodies of the dancers. As it relies on cameras, it offers a non-intrusive approach to track multiple persons' full-body movement. Our Captury set-up used 8 cameras to extract human skeleton data. The use of a non intrusive approach was based on requirements gathered from dancers and choreographers in a previous stage of the project 7.1. Captury output returns the coordinates of 12 skeleton points and the overall amount of movement of

[11] https://www.thecaptury.com/

the dancers. These points were then sent to a Unity [12] sketch for rendering of an avatar. Figure 7.4 shows the Captury and the rendering in Unity on the two different screens. The avatars have also been used to calculate an estimate of the average movement in two of the three scenes of the piece. The audio engine was developed using Pure Data Vanilla [13]. All the communication among the various components was routed via Open Sound Control (OSC). The final interactive sonic artifact for the performance consists of three different settings/instruments, each with a specific mapping strategy to generate different sounds from the movements of one or two dancers on-stage. The three settings correspond to the three main different scenes of the piece. The design of the interactive strategy and sonic component of these three instruments is further detailed in section 7.2.4.

7.2.3 Methods: Data Collection and Analysis

The two methodological approaches used in this thesis – autobiographical design [243] and idiographic design [134] – assume a different balance in this study compared to the studies presented on screen scores (chapter 6). Indeed, in this case study, idiographic design is used as the main approach, to design the system tailoring the artistic vision of the choreographer, who is the main author of the final artwork. At the same time, an autobiographical account is deployed to consider the personal experience of the author of this manuscript as a sound designer in the overall ecology. Figure 7.3 shows the team discussing in the space of the residency.

Following the technomethodology approach proposed by Dourish, the sound designer collected field notes and interviews during and at the end of each session, aiming to analyse how the different actors relate to the technology "moment by moment" [82].

At the end of each of the first four sessions, the sound designer interviewed the choreographer, and at the end of the residency, the two dancers. No interviews were conducted after the fifth session, as this session was only focused on rehearsing the piece, and no new elements emerged. Semi-structured interviews were used, using a set of questions similarly to the studies on screen scores (chapter 6). The questions to the choreographer focused on how she collaborated with the rest of the team and the relations between the development of the performance and the technology. These interviews lasted between 8 and 20 minutes. The two dancers were interviewed together, and the joint interview lasted 16 minutes, with questions focused on how they interacted with the technology, in each of the three different settings that we developed. The interview results are presented here independently for the various actors. The direct quotes are presented between quotation marks, the choreographer is abbreviated C while the two dancers are abbreviated D1 and D2. The interviews were coded to understand how the dancers relate to the

[12] https://unity.com/
[13] https://puredata.info/

Figure 7.3: All the team discussing toghether.

technology in the different screens of the performance and moments of the residency. Additionally, the author of this thesis collected field notes at the end of each session.

The interviews were analysed using thematic analysis [40] by the sound designer. In the final analysis with ARCAA, the sound designer also introduced his autobiographical perspective based on the field notes. The field notes were used to reconstruct the activities in the different sessions.

7.2.4 Residency Overview

A brief overview of the residency is presented, primarily based on the field notes. In the organisation of the field notes and of the analysis of the interview of the choreographer, a clear distinction emerged: between the first two sessions, as a more explorative and design focus moment; and the following two, focused on rehearsing. For this reason, the session descriptions presented were clustered in two phases: co-creation/design phase and fine-tuning/rehearsal phase. The design of the interactive sonic artifact was mostly concluded in the first phase. The structure of the activities was not predefined, rather it followed the needs emerging in each session.

7.2.4.1 Co-creation/Design Phase

In the *co-creation/design phase*, the three main instruments that corresponded to the three main scenes in the dance piece, and the dance piece itself were developed in parallel.

Figure 7.4: The Captury computer alongside the computer running Unity3D for avatar rendering (The screen is showing the avatar on OBS)

The first instrument was characterised by a *crackling sound* whose volume and density was mapped to the movement amount of the dancer. Such an amount was calculated using a computer vision approach. It was computed by subtracting two sequential frames of positional data of the avatars in Unity, based on the information coming from the motion capture system. The crackling sound was implemented using a set of variable time delays, reading in different points at variable speed a percussive sound stored in a buffer, resulting in a granulation of the original sound. This instrument was used in the first scene of the dance piece, in which the choreography consisted of an open task: D1 was required to improvise alternating movements with moments of stillness; the second dancer (D2) was required to imitate the first dancer's static pose. Only movements of D1 were used for the creation of sound, originating alternate moments of sound and silence. The two dancers are physically distant in this first scene, as they are in different parts of the stage.

The second instrument was a *percussive sound* that was triggered by dancers' hand movements in a gesture that imitates hand clapping. Initially the percussive sound was triggered when the dancers' hands were closer than 10 centimetres to the floor. However, the movement of this interaction highly impacted the physicality of the dancers and the dramaturgy of the choreography, imposing an action that interrupts the fluidity of other movements. To reach the floor, the majority of the body is involved. Therefore, their interaction was subsequently improved by changing it to a hand-clapping gesture that would act as a trigger. These changes were based on the observation that the choreographer made by seeing the dancers interacting with the system, and the new interaction modality emerged from discussion between the choreographer and the sound designer. Delays and reverberation have also been added to these sounds for aesthetic improvement. The sounds were similar for the two dancers, but the actual pitch and timbre of the two sounds were different, so each performer had her own sound. This was used in the second scene, where the choreographic task required the dancers to maintain a continuous movement, while sharing the same part of the stage. The two dancers are closer compared to the first scene.

The third instrument was a *cello drone*. The volume of the cello sound was linearly mapped to the average movement amount of the two dancers. The movement amount was calculated by using the same approach developed for the crackling sound. This instrument was used in the third scene. In this scene, the choreographic task was to explore the body of the other dancer, by grazing it with any body part while maintaining a continuous movement. As a consequence, the two dancers shared an intimate space, mutually influencing their movements.

In the first phase, the choreographer tried the hand-clapping interaction for the percussion herself. She also tested the choreographic tasks with the dancers, and modified them according to the feedback.

Overall, dramaturgically the piece progressively goes from physical distance of the two dancers to intimate connection in a close dance that shares the same space. The sound design accompanies this progression by transitioning from noisy spectra and irregular envelopes, to harmonic sounds with a smooth envelope. From this element we can already observe how the dramaturgy of the piece, which has specific choreographic tasks, was embedded in the sounds.

7.2.4.2 Fine-tuning/Rehearsing Phase

After session 2, the main design process was concluded and the features of the final artifact were defined, as well as the three instruments (*crackling sound*, *percussion*, and *cello*). In the remaining sessions, the sonic features were fine-tuned: the delay time in the percussion was calibrated and the timbre of the cello was improved (a second sound, one octave lower, was added to the original cello). In this phase, the calibration of the motion capture system was also fine tuned. This activity included a specific work and tasks involving the dancers. In order to test the threshold of the percussion and the crackling sound, the sound designer asked the dancers to perform the specific corresponding gestures and adapted the thresholds accordingly. Apart from these minor sound details and system calibration, the last sessions focused mainly on the development and rehearsal of the choreography.

The sound designer also explained to the dancers the functioning of both the motion capture system and the sound computing engine, showing where the motion capture was more efficient, and identifying movements that created issues with it. During this process, the dancers became more aware of the motion capture area and of how their movement influenced the various sounds. This process produced a very positive effect, the dancers started to dance with more confidence in the system.

7.2.5 Results

In the following sections, the main four themes resulting from the data analyses from the interviews are presented, with subthemes highlighted in bold. To better understand the relationship of the various actors in the overall ecology, including the evolving switch from a design moment to a rehearsing one, the two phases are specified.

7.2.5.1 Dance and Technology are Mutually Influenced.

Overall, the most important element that emerged is how the development of the technology and of the choreography were intertwined and mutually influenced each other, to the point that the entire work was a "negotiation between the dance and what the technology offers, and how do we use it artistically [... a] negotiation between all the elements." (C). Therefore the two processes proceeded in parallel: "Both changing the technology to adapt to the dancers and changing the [choreographic] task to adapt to the technology" (C). This element emerged in particular in the Co-Creation/Design Phase

Audio should not merely be doubling the dancers action. Avoiding repeating the same information already exposed with the body movement was the general design principle that was led by an artistic need: "audio not doubling" (C). In the Co-creation phase, the *choreographic task derived from technology.* The choreographic tasks are adapted to the technology: "the technology and the task is intertwined all times" (C). The objective was to "create a situation where the dancers can really do their job as a dancer, but also there is an additional awareness level [...]. It's really changing the choreographic task or the attitude of the dancer". This has also a practical implication: "It was easy to start with just one dancer in the Captury, just to define how it sounds, and how it moves" (C).

7.2.5.2 Team Collaboration

Sound designer as a collaborator. The sound designer was perceived as an artistic collaborator, not merely as a developer (despite the fact that at the beginning of the residency this was described as his role): "[this is] an artistic collaboration and [...] not only technical tasks."(C). However, the importance of supporting the process practically was also acknowledged: "because I can't do everything, pay attention to everything simultaneously" (C).

Open instructions to the dancers. Since the beginning of the residency, the choreographer gave tasks to the dancers that were quite precise in terms of defining the frame of possibilities, but also provided space for individual improvisation. "The [dance] situation is structured" (C), but also "*the tasks were* [...] open or improvisatory." (C).

Peer collaboration among everyone. In this final stage of the residency, the collaboration was "more a peer discussion" (C). Indeed, in the end of the residency the dancers were "able to give feedback because they know how it is supposed to go." It is worth noticing that in the previous phase, this element was not present.

7.2.5.3 Working with Sound Requires Time

According to the choreographer "working with the sound is more time-sensitive" (C), as it requires time to feel it, to explore the possibilities and learn how to move and dance in interaction with it. This element was present throughout the entire residency, but some specific elements particularly emerged in the fine-tuning phase.

Learn to play. In the final stage, there was a need to provide the dancers with the time necessary to acquire confidence with the interaction: "They have to get confident, learn to play" (C); "It's essential for the work [...] that the dancers understand [...] what [their actions] affects, and what to avoid" (C).

Technology Adaptation and Fine Tuning. Finally, in this stage, there was a need to adapt the specifications of the interaction modalities to the actual physicality of the dancers: "it's essential [...] to have these fine-tunings" (C).

7.2.5.4 Dancers Proprioception in Relation with the Instruments

In this interview with the dancers, some specific elements about how the dancers relate themselves with the technology in each specific scene have emerged. From the analysis of the interview, one different relationship to the technology became apparent for each scene. In the second and third scenes, the two dancers expressed to have the same relationship with the interaction and the sound.

First scene: the sound affects the dance indirectly. D1 reported that interacting with sound was indirectly changing her way of dancing: "it does [change] as a consequence of me thinking constantly of what my movement does because of the sound that I am creating" (D1). For this reason, she could not merely focus on the dance: "I have to divide my attention [...]. I am slowing down my movements [...], just to make sure that the sound is coming along with me." (D2), who was not controlling the sound, on the contrary did not pay specific attention to it.

Second scene: the interaction changes the dance. Both dancers were primarily affected by the fact that their hands were triggering the percussive sounds. "I know that my hands are the trigger, so I put a lot more attention there, even the posture of my body" (D1). "I can say that my movement starts from the hands, because I am super aware of them" (D2). The interaction with technology also produced a feedback loop as "the sound influences the movement back" (D2). Especially the delays and the reverberation added to the percussive sounds changed the way the dancers moved.

Third scene: Ignoring the sound and the interaction. In this last scene, the sound was not the main focus of the dancers, because the choreographic task (exploring the other dancer's body) was in itself overwhelming and required full cognitive attention: *"I think for me here the task is superior to the sound itself."* (D1), *"The task is over everything"* (D2).

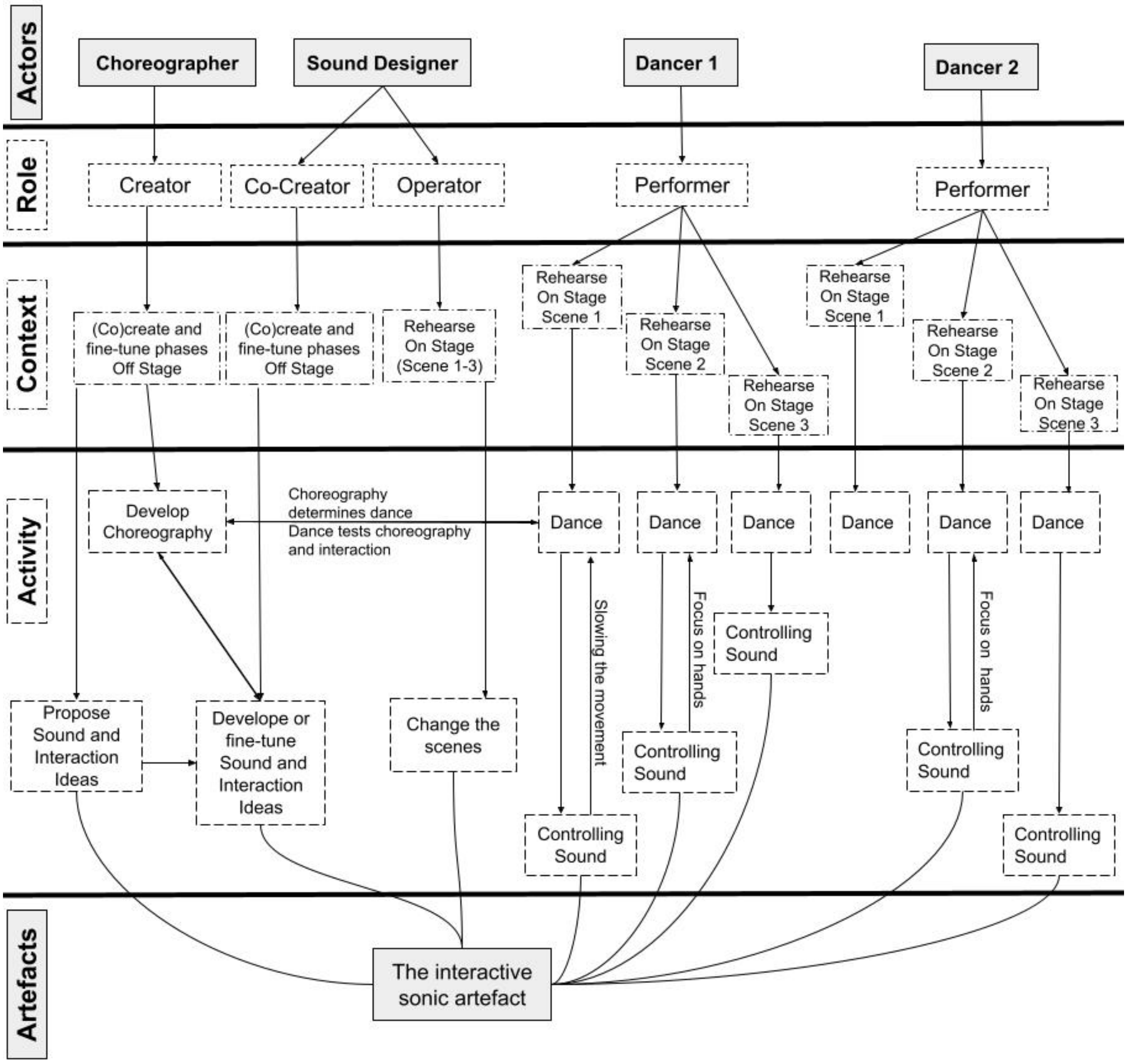

Figure 7.5: The overall ecology represented by using ARCAA

7.2.6 ARCAA Representation of the Study

From the observations during the residency and the results of the data analysis some main points emerged, in particular: 1) how the design of a system and the design of the choreography were mutually influenced, and 2) how the interaction design needed to be fine-tuned according to the actual movement and physicality of the dancers. The overall ecology in a graphical form using ARCAA is presented in figure 7.5.

ARCAA helps to visualise how the choreographer and the dancers mostly operate in two different contexts. From the graphic, it can be observed how the choreographer is involved in the off-stage context, during creation (design and implementation) process, while the dancers are involved On-Stage, therefore in the actual *interaction* in a traditional HCI sense. It is also worth noticing that both co-design and fine-tuning are activities that occur in an off-stage context and that the dancers are involved in both the testing (influencing the co-creation and the fine-tuning) and the actual interaction with the instruments (while rehearsing or performing). Based on this, the fine-tuning/rehearsing phase can be further separated using ARCAA according to the perspective of the different actors.

In the activity layer of the graphic, it can be seen that the design of the system and the creation of the choreography are interconnected, as highlighted by the loop between dancing and developing choreography activity. Using the words of the choreographer: the process implied “both changing the technology to adapt to the dancers and changing the task to adapt to the technology” (C). Concerning the main activity of the performance (dancing), we can see how many different elements have influenced it. Primarily, the dancers had a choreographic task to follow that was quite prescriptive, but also left space for their personal interpretation and provided them with enough flexibility to adapt it to the interaction with the technology. In the case study, the choreographer was instructive with the dancers, but also left space for improvisation. This type of relation corresponds to the third category in the Butterworth collaboration model: choreographer as pilot - dancer as a contributor [43]. Indeed, even though the dancers are mainly following a choreographic task (developed by the choreographer), the interaction with the artifact influences their dancing, and the dancers have space to explore the task according to the interaction (scene 1 and scene 2). In other cases (scene 3), the dancers adapted the interaction according to the task.

The graphic highlights how each scene represents a different specific context for the dancers. Indeed, in each scene, a different feedback loop between the sound and the dance has emerged. For instance, in scene one, D1 was “slowing down [her] movements”, in scene two their “movement starts from the hands” (D2), while in scene three the choreographic “task is superior to the sound itself” (D2). Based on this, it can be proposed that a sound designer should be particularly careful to address these interactions.

ARCAA also helps to visualise the autobiographical perspective [243] of the sound designer, and how he played two different roles. As emerged in the interview with the choreographer, the sound designer was a co-creator/designer in the design phase; he was also an operator during the performance.

7.3 Discussion

Here the results of the case study described in section 7.2 are discussed in light of existing literature, and informed by the main points that emerged in the initial focus group (section 7.1).

7.3.1 Co-creation and Composed Artifacts

In the case study, as well as in the focus group, it clearly emerged that technology needs to be incorporated in the choreographic thinking. In particular, in the case study, it could be observed how the creation of the choreography and the development of the artifacts unfolded in parallel, were intertwined and mutually influenced each other. Therefore, the final artifact embeds the aesthetics of the sonic components as well as the overall diametrical arch of the dance piece itself, and at the same time, the piece could not be performed without that specific artifact. The artifact is also an instrument, as it can be "played" by the dancers, and therefore can be considered a composed instrument [277]. From this perspective, the case study can be aligned with Cook's suggestion "make a piece, not an instrument" [59].

In the section 2.2, it can be seen how the creation of new musical instrument/interactive sonic artifact overlaps with the act of composing (i.e. [277, 199]). In most cases, the same person is the designer of the instrument, the author of the piece (composer), and the performer [236]. However, the case study in this chapter presents a situation where the three roles are played by different persons, but still the final technological artifact embeds the aesthetic of the piece. It can be supported that the interconnection between these three roles needs to be carefully considered during a design process. Mumma's sentence "building of circuits is really composing" [247], could be adapted to interactive systems for dance performance: co-developing the artifact is really co-composing the soundtrack of the dance piece, and (co-)creating the choreography. For this reason, based on the idea of composed instruments [277], it can be suggested that pieces of technology specifically developed for a dance piece are open sonic artifacts where the embedded aesthetics is co-created and derives from the complex ecology of a dance performance.

7.3.2 ARCAA and the Dance Design Space

In this section, it is proposed a practical way to combine ARCAA with the design-in-use framework by Botero and colleagues [37] to analyse the design space of an interactive sound technology for dance, based on the case study. The design-in-use framework helps to better frame the different levels of interconnections in the ecology in relation to different forms of appropriation. In the case study, it can be seen how the choreographer mainly operates in an off-stage context, and the dancers operate on-stage. Referring to the design-in-use model, the reinvention category (design) reflects mainly the activity of the choreographer, especially in the first phase (the co-creation/design phase). In this phase, when the system was actually invented, indeed, the choreographer led a process. It can be seen that the design was a process of reinvention of the use of the motion capture system that led to the design of the three instruments, as well as the choreographic tasks. In the second phase (fine-tuning/rehearsing phase), the activity of the choreographer is less strongly connected to the invention category, but rather it reflects an adaptation attitude, where both the system and the choreographic task are refined. The reinterpretation category by Botero reflects the perspective of the dancers, who are interpreting their choreographic task, according to the confidence that they gained with the system. Combining this observation with ARCAA, it can suggest that the off-stage context (where the choreographer is) mainly corresponds to the invention, and partially to the adaptation categories of the design-in-use model by Botero, while the on-stage context (where the dancers are) mainly reflects the interpretation category.

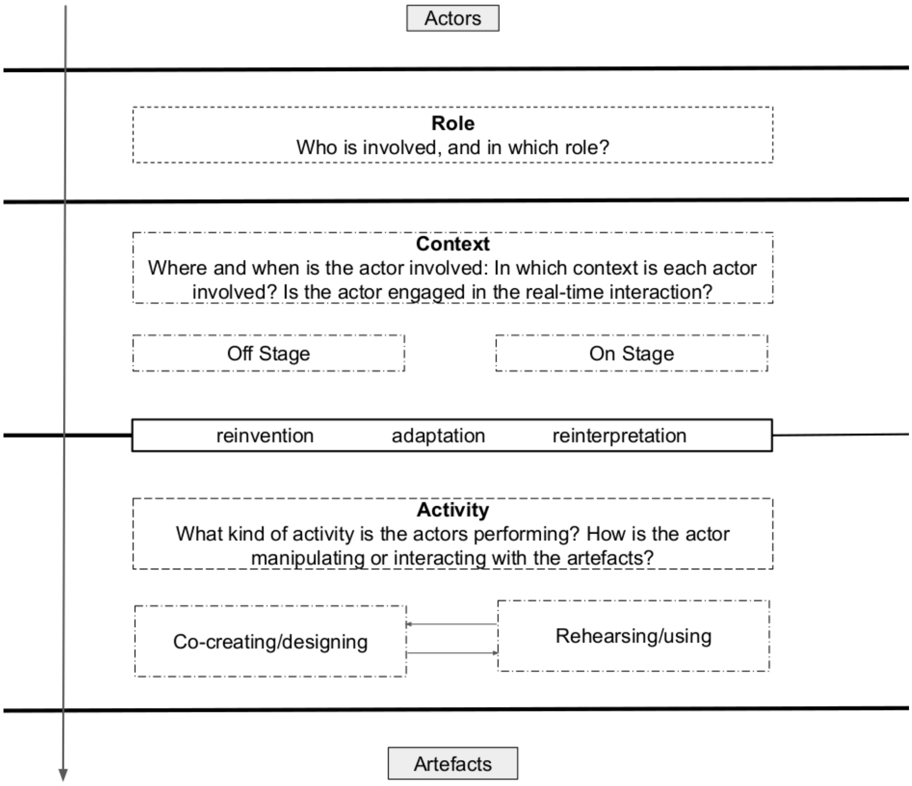

Figure 7.6: The ARCAA with the design-in-use model

Using ARCAA in the case study, it was possible to distinguish the co-creation/design phase (off-stage) from the use phase (on-stage) when dancers were actually interacting with the artifact, either in rehearsal or performance. These two phases correspond to the (re)invention and (re)interpretation categories of the design-in-use framework proposed by Botero [37], while the adaptation phase is in-between the two elements (figure 7.6). Compared to the original graphic of ARCAA, it further highlights the interconnection between co-creation and use, adding also horizontal connections.

7.3.3 Account for the Needs of the Different Actors (Insights for Sound Designers)

In the case study presented in this chapter, we can observe how the choreographer and the dancers have different needs. We suggest that both have the same level of importance that should be taken into account in the development of an interactive sonic artifact.

As a general principle, it can be suggested to consider the complexity of the ecology of a dance performance and how multiple people mainly play different roles (choreographer - dancer) and operate in distinct moments (such as co-creation/design phase, fine-tuning/rehearsing phase, performing). The choreographer has general needs related to the artistic ideas of the dance piece, the technology is a co-creator as also emerged in the focus group (section 7.1), while the dancers have needs related to the actual interaction, involving dancing, physicality and proprioception.

Based on the study some elements concerning interactive sound design related to the needs of the different actors can be highlighted:

1. The technology development and the choreography are mutually influenced, this affects the way of working and co-working procedures;

2. A choreographer might need extra time to work with sound to fit in the aesthetic of the piece;

3. The dancer would need to understand the functioning of the interactive system ;

4. There might be a need for the dancer to get confident and learn to play.

7.3.4 Conclusion

In this chapter, a new context (dance performance) was studied from an ecological perspective. In the case study, the distinction between the two main roles of a dance ecology (choreographer - dancer), and how they relate with an interactive sonic artifact in two distinct moments (design - use), were highlighted. Although the roles of choreographer and dancers could be blurred (the collaboration between them could assume different configurations, and they can even be complete peers, in some cases the choreographer is also a dancer) , this distinction is a truism that should be accounted for when designing interactive sonic artifacts for dance.

ARCAA can be integrated, in practice, with the design-in-use model [37] and the Didactic-Democratic model by Butterworth [43]. ARCAA helps to visualise the different roles, contexts and activities of the different actors, and facilitates the understanding of the entire context. Combining ARCAA with the design-in-use model [37] allows to develop a deeper understanding of the relation between design (inventing) and use (interpreting) that occurs during an artistic creation. This can be particularly relevant in those situations where the development of a piece of technology already occurs in the wild, in contact with various actors, and the complexity of a stage/theatre/rehearsing space. To study the design of interactive sonic artifacts for dance, a link between ARCAA and the model by Butterworth [43] can foster a better understanding of the relations among the various actors. Different types of collaboration can lead to different connections among the actors in the ARCAA framework. Nevertheless, using such a combination can help to frame the context in which the different actors interact with an artifact, and what the final impact on the aesthetic of the performance is.

8

Discussion

In this chapter, some final remarks and considerations are proposed based on the combination of the results of the various studies presented in the previous chapters of this thesis. In particular, two main blocks of discussion are proposed. Firstly, the various levels of ARCAA are discussed in light of the studies and in relation with existing literature. This discussion of the layers of ARCAA primarily answers RQ2 and RQ3, in particular it offers new perspectives on *how different actors influence the design of different artifacts*, and *how different actors interact and appropriate an interactive artifact*. Secondly, some general implications for design are proposed. These implications are an attempt to reply to the RQ1 on *how to support a joint expression across different actors in a given performance ecology*.

8.1 The ARCAA Framework: Final Reflections

In light of the studies, some final considerations about the ARCAA framework can be developed. In particular, it is possible to reflect upon the various levels of ARCAA in connection with existing literature. These connections are discussed in the next subsections.

8.1.1 Actors in ARCAA: Enlarging the Scope of Inquiry

The first layer of ARCAA can help researchers to widen the focus on the inquiry on the design and use of interactive sonic artifacts. In particular, this layer helps to visualise all the individuals involved in a complex scenario, including those involved only in preparative moments. This approach can also help to understand the various autobiographical and biographical design instances that unfold in parallel within a certain ecology.

The ARCAA framework can be particularly helpful to understand the **balance between autobiographical and idiographic** elements. Overall, the possibility to list the designer (author of this thesis) as an actor operating in an ecology helped to follow his active role in determining the final configuration of a performance. In the cases with screen scores (sections 6.2 and 6.3), a first person active role of the researcher in the final musical output were defined in advance, as the designer was also a composer/creator.

However, in the case of dance (section 7.2), this element emerged only during the study, as the designer was required to act as peer collaborator by the participants (in particular the choreographer). In the studies of music, the autobiographical approach was predominant in the aesthetic choice, and the idiographic element supported tailoring the system to the participants. On the contrary, in the case of dance, the importance of the two design approaches (autobiographical and idiographic) is reversed in comparison to the studies on music: the development of a system primarily followed an idiographic process targeting the artistic ideas of the choreographer and the physicalities of the dancers, the researcher/sound designer operated and influenced some choices that have an impact on the overall piece. Additionally it was possible to observe **two distinct ideographic processes** unfolding in parallel, one focused on an artistic vision (with the choreographer, supported by the embodied knowledge of the dancers), and one based on the physicality of the two dancers (also supported by the ability of the choreography to dance). In that case study, listing these three actors in the first layer as equally important in the overall ecology facilitated this reflection.

Including the actors who are primarily active in preparation moments as actively part of an ecology is helpful, as it can better highlight the various interconnections among design, the use, and artistic outcomes, and scrutinise autobiographical and idiographic process. Looking at the design phases of music technology is not a complete novelty. Indeed, in the last decades, studies that focused on the design processes of new technology for different purposes have emerged. For instance, some studies have focused on co-design processes, whose final design solutions and technological outcomes target a specific population (i.e. visually impared musicians [295], audiovisual performers [62], or percussive guitarists [208]). In other cases, the described design processes are part of a compositional process in practice based projects, for instance Magnusson recently described his design and creation of Threnoscope as the creation of a musical piece [197]. In other cases, many actors were involved (i.e., designer and one dancer [89], or a multitude of dancers, technicians collaborating with one choreographer [92]). Despite this trend of design research denoting growing interest in these aspects, there is still a general tendency to primarily focus on what happens during an interaction with the technology, overlooking the human-human interactions that occur in preparation of this technology, or at least not to consider them as central elements. For instance, in the literature review on scores at NIME (section 5), we have seen how most of the papers focus only on the individuals involved in the real-time interaction, not posing too much attention on the activity in preparation, and on the role of the designer as an artistic component of the ecology. In some cases the composer is mentioned (e.g. [139, 257]), but the focus is primarily on the performer.

ARCAA can contribute to considering the design moments as central aspects of an ecology, at least in those numerous cases in which a certain interactive artifact is designed for one specific piece/performance or with one specific aesthetic purpose. In particular the framework can offer a way to systematically scrutinise the various actors across the studies, and connect them within the same study. To conclude, it is important to acknowledge that in those systems where the target is a general population, the autobiographical perspective should probably not be adopted, as the tools are not designed with one specific piece or performance in mind. However, ARCAA could still be of use to help designers in thinking about scenarios in which their tools are used collaboratively by multiple actors.

8.1.2 Roles in ARCAA: Rejecting the Vision of "User"

In other part of this thesis (in particular sections 2.1.2 and 4.1), we have seen how the term *user* has been criticised as it echoes an implicit view that treats people as simply sets of elementary processes or isolated 'factors' diminishing their values as complex humans [11]. This is the main reason behind the choice of the term Actor for the first layer of the ARCAA framework (section 4.1). Rodger et al. have recently argued that musicians should not be considered users but rather agents in musical ecologies [270]. ARCAA, in its original conception, strongly supports this vision. Additionally, in its practical application, the framework helped us to add details on the profile of the individuals involved in a given ecology. In particular, the Role layer offers a dedicated space to reflect on the characteristics of the actors in terms of the position and purpose that they assume in that specific ecology. In the case studies, the Role layer proved to be particularly effective in adding dimensionalities and complexities to the profiles of the actors involved. In particular, this layer helps to visualise how the same actor can **play different and multiple roles**. For instance, in the case studies on music (sections 6.2 and 6.3), identifying the various roles that the participants play helps to understand in which way they contributed to the final musical result. Identifying their roles was also a fundamental initial step necessary to highlight the actions (discussing, rehearsing, modifying the system) that complemented the direct interaction with the artifacts.

In the systematic literature review (section 2.2.1), it has been discussed how the western traditional roles (composers, performers) taken as immutable categories do not represent the best approach to discuss and analyse contemporary technological mediated music practice. Indeed, music roles are fluid and the same person tends to play different roles (see for instance [171, 118]). For this reason, listing all of the various roles that actors play can be a way to investigate this fluidity. In particular, by looking at the other layers, it is possible to observe when and where the same person plays different roles.

Additionally, **observing the various roles together can help to understand the relationships among the various actors**. For instance, in the case study on dance (section 7.2), the role of the sound designer as the co-creator determined a visual parallel with the role of the choreographer as a creator(figure 7.5). In the case of dance, the roles proposed by Butterworth in her model that categorises the forms of collaboration between choreographers and dancers [42], can further help a reflection about the relations among the roles and the actors.

8.1.3 Context in ARCAA: Time Phases in the Ecology and Design-in-Use

The Context layer in ARCAA can **facilitate understanding the spatio-temporal dynamics occurring in a given ecology**. The two questions *where* and *when* proposed in this level, with the two general answers *off-stage - on-stage* and *in real-time - in non real-time* proposed in section 4 act as a general compass to consider a performance ecology from a broader perspective. In particular the off-stage, non real-time context is useful for including those design instances discussed in the previous subsections.

By using the model in different case studies, it was possible to identify some patterns that are useful to refine the use of this layer. First of all, it clearly emerged that there is a continuous alternation of real-time and non real-time moments in preparation of a performance. This alternation in a rehearsing phase provides space for trial and errors, discussion, and fine tuning of ideas, and is necessary for the musical ideas to be developed for the final piece. It also emerged that across all the studies overall some phases emeged, that can be clustered in two main categories:

> *Creation phase* - in this first phase, musical and artistic ideas are explored at the end of this phase, the piece tends to be defined but for details;
>
> *Rehearsal phase* - in this phase, the piece is rehearsed, and details are perfected.

In both phases, the real-time and non real-time contexts alternate. Therefore, it is important to remark that real-time and non real-time contexts do not define temporal sequences across a residency, but only define contexts in which activities are performed. Overall, the technology can be modified across the various phases (Creation, Rehearsal). For instance, in the first study on Puffin (section 6.2), modifications to the system occurred in between the creation and the rehearsal phase to adapt the system to specific needs that emerged during the creation phase. In the second study on Puffin (section 6.3), some modifications were made just before the final general rehearsal, to facilitate the technical passage between the various individual pieces of the participants. Finally, in the study on technology for dance, the technology has been created in the first phase, and fine-tuned in the latter (section 7.2).

In the case studies on music performance, there is another distinction that discriminates between during and before/in between the rehearsals. Indeed in these cases, individual or subsets of actors decided to operate in autonomy outside the spatiotemporal space of collective work. This distinction did not emerge in the case of dance technology. We argue that this difference derives from an overall setting, and not from a distinction between dance and music. Indeed, all the activities related to the case study on dance technology occurred in the black box theatre, and the technology was entirely created in an ideographic process with the choreographer. Additionally, in the dance residency all the actors involved worked on a full time basis for approximately the entire length of the residency. On the contrary, the music case studies were less demanding in terms of time commitment and distributed over a longer time span. This allowed, for instance, the designer and the guitarist to meet and fine-tune the system in between the rehearsals in the study with Puffin V1, or to the instrumentalists to reflect on their piece and work on their own score in the study with Puffin V2.

As already pointed out in the original presentation of ARCAA, some parallelisms exist between the framework and design-in-use model by Botero and colleagues [37] (section 4.6). As detailed in section 2.1.4.3 in the literature review, Botero lists three main categories that identify different levels of appropriation: *Reinvention* on the design end of the spectrum, *Adaptation*, and *Reinterpretation* on the use end of the spectrum. Based on the case study, it is possible to push the parallelisms a bit further. The initial parallelisms proposed that the reinvention category (design) reflects mainly the activities that happen in non real-time, while the reinterpretation category reflects the perspective of the on-stage setting, where the technology is actually used. A real reinvention (in the meaning intended by Botero) of the existing technologies (such as music programming, or coding), for instance, occurred in the creation phase during the residency on dance. In that study, the existing technologies were combined together and reinvented toward the creation of the instruments.

As it has been widely discussed, the creation of new music technology is a process deeply intertwined with music technology design (see subsection 2.2.2, and in particular the work by Lucier [188], Cook [59], Schnell [277], Tanaka [293] , Dudas [85] and Magnusson [199]). The Context layer of ARCAA can be useful to study these relationships. Indeed, it helps to visualise the pre-performative/design activities as part of a given ecology, and connect them to the performative aspects.

8.1.4 Activities in ARCAA: Multiple Affordances

The Activity layer in ARCAA finally connects the Actors with the Artifacts. In this level it is possible to actually see what people do in relation to the technology, but also in relation to other artifacts.

One major advantage of this layer is the opportunity to list and visualise all those activities that occur **non real-time** and **do not directly involve a digital artifact**, for instance discussing, these actions can be considered as peripheral. These activities include: *develop*, *propose ideas* (case study on dance); *design and develop*, *create and discuss exercises or the pieces* (case study on Puffin V1 and V2); as well as *writing on the paper scores* (case study on Puffin V2). All these activities are part of that compositional process that is embedded or goes in parallel with the design of interactive music tools. Indeed, these activities have a direct impact on music and artistic outcomes. In 2001 Cook suggested to "make a piece, not an instrument or controller"[59, p. 1]; we argue that it is fundamental to look at these peripheral activities to work toward the creation of musical pieces. In some cases, some of these activities imply a certain level of **appropriation**. For instance, the actors can use the system in a way that was not intended or imagined in the initial design. In other words, they perform "improvisations and adaptations around technology" [77, p. 1]. Among the various case studies, this element emerged particularly clearly with Puffin V2, especially with the different manner in which the instrumentalists used the rhythmic notation. In this case, the notion of *hidden affordance* by Gaver [108] proved to be relevant, as this possibility emerged between the artifact and the instrumentalists, but was not conceived (was hidden) in the initial design.

These layers of ARCAA can also help to understand the complexity of *actions performed while using the system in real-time*. Some of these activities are evident (controlling and reading with Puffin V1 and V2, or dancing). However, some other activities are not obvious, and to a certain extent appear to be peripheral, but are actually central and necessary for the musical interaction. For instance, in the case study on dance, the fact that the dancing activity was actually controlling the sound created some feedback loops and affected the speed or the focus of movement (on hands). It is also important to notice here an interference between the choreographic task and the controlling sound that created a cognitive overload in the third scene. Indeed, in that case, due to the difficulty of the task the dancers could not focus on the sound. Similarly, in the case study on Puffin V2, on one occasion the instrumentalists were so focused on reading the scores that they were not able to follow the instructions by the conductor.

Additionally, **a set of activities is related to non verbal communication while interacting with the artifact in real-time**. This set of activities emerged clearly in the studies with Puffin, as the musicians gave each other signals to play in a more musical way. With Puffin V2, these forms of non verbal communication relied on a previous mutual knowledge among the participants who are used to playing chamber music together. In this case, it can be supported that these actions build upon a shared social background. In this case, a social view of affordance [128, 64] can be particularly useful to understand these activities, as these are supported by the social background of the musicians, and not determined merely by the situation. This consideration of social affordances is in line with Gurevich view that social and cultural contexts are part of a music ecology or ecosystem [122].

By using ARCAA in different studies, we could observe how **different conceptions of affordance can be useful to analyse different aspects of an ecology**. In particular, hidden affordances [108] are useful to observe appropriation fenomenal, while a social conception of affordances [128, 64] are useful to reflect upon those actions that build upon a shared background among the musicians.

8.1.5 Artifacts in ARCAA Pieces and Technologies: Embedded and Distributed Cognition

The final layer of ARCAA lists all the artifacts of a given ecology. In the case study on dance, this can actually be only one artifact. This case mirrors the conception of artifact ecologies that focuses on a multitude of people operating around one single artifact (as in [31]). In the case studies with Puffin (both V1 and V2), however, a multitude of artifacts is present, echoing the original conception of artifact ecology [157]. In this case, is important to consider both digital and non digital artifacts following the examples of recent studies on artifact ecologies (e.g. [31, 268, 6, 22]).

In the two case studies with Puffin, it was possible to observe that **the piece became an element so important to be represented as an artifact**. This was different from the case on dance, where the three scenes that structured the choreography were embedded in the artifact itself. In the case of dance, indeed, the creation of the choreography and the development of instruments proceeded in parallel simultaneously. Part of the artistic process of the final piece was therefore offloaded in the technology itself. The idea of offloading is based on Clark's proposal of an extended mind, which supports that humans extend the cognitive process outside their head, offloading the part of it on tools [56]). On the contrary, Puffin was not designed with one specific piece in mind, but rather with one approach of composition in mind. Echoing the reasoning by Magnusson, Puffin (as every musical tool or instrument) implies a specific way in which music can be thought, expressed, and performed [200]. Indeed, the idea of repetition and imitation are embedded in the system. However, multiple pieces can be created with it. In particular in the second case study, the participants relied on notation on paper for structuring four different pieces. In this case, therefore, the cognitive process of composing is both offloaded on the paper and supported by the technology.

The case of Puffin V2 introduces a new shade on the blurred relations among composing, performing, improvising, and designing. In this case, **the score is not entirely embedded in the system** as it was in other cases (e.g. [277, 293, 299], but also the case study on dance presented in this thesis), nor does it determine a musical space and a set of possibilities that is then explored in a free improvisation as in the proposal of comprovisation [85]. Puffin determines a set of musical possibilities, but a second compositional process in which the piece is structured and developed during the study. This process occurred in trials and errors in collaboration with all the actors in the ecology.

It is possible to speculate that in this process of developing a musical form, some cues, and some other musical ideas which are derived but independent from a specific technology design, can occur in other cases when there are multiple electronic musicians playing together. ARCAA offers a tool to analyse this process.

8.2 Design Recommendations

Based on the conducted studies, some final considerations can be proposed to design interactive sonic artifacts that support or facilitate a *joint expression across different actors operating in a performance ecology* (replying to RQ1, How can the design of interactive sonic artifacts support a joint expression across different actors (composers, choreographers, and performers, musicians, and dancers) in a given performance ecology?). Such recommendations are presented here.

8.2.1 Borrow Tools from Third-Wave HCI

Music technology design has now a long tradition of systematic use of research tools related to mapping strategies and evaluation methods, an early pivotal research paper in this area being [313]. These tools were derived from a traditional first and second wave HCI approach. It can be supported that today many other tools from HCI, in particular from the third wave, could be borrowed, such as considering ecologies of artifacts values, appropriation, and sociocultural aspect of interaction design [28]. Actually, some of these concepts have already infiltrated the music technology debate (e.g. [118, 314, 200]). These concepts are particularly relevant to support a joint expression across different actors, as they propose a conception of HCI which is more situated and helps to understand the specificity of a given ecology. Understanding the specificity of the ecology can support each individual actor to operate at best.

8.2.2 Design and Appropriate

Among the concepts borrowed from HCI, ambiguity [109] and appropriation [77] stand out to be relevant for creative practices. The different forms of appropriation proposed in the design-in-use model [37] can be particularly useful to look at the design of music technology. As discussed, different forms of appropriation could occur in a design phase when combining and changing existing technologies, but also in the use when new ways of using a specific artistic artifact are discovered by the musicians. Considering the design and appropriation as a continuum of different artistic and creative practice is relevant to provide each actor with a creative space, favouring a collaborative effort toward the achievement of a shared objective.

8.2.3 Rely on Multiple Design Approaches

Music technology has a long tradition of practice-based research and in recent years also on User Centred Design. More recently, studies using autobiographical [302] and idiographic [134] approaches were proposed. Based on the studies developed for this thesis, it can be supported that a combination of autobiographical [243] and idiographic [134] design offers a nuanced representation that can be useful when designing music technologies for performances. In the case studies proposed in this thesis, the combination of these two approaches helped to balance the artistic needs with the practical and operational needs of the various actors involved.

8.2.4 Do not only Create Pieces, Suggest and Explore Music Possibilities

It has been pointed out how important it is to have a specific music idea when designing a new interactive artifact (e.g. [59]). This principle remains valid, however it can be expanded to favour collective music expression. When designing a new interactive system for collective music practice, it can be useful to create musical possibilities and think about how this can be explored and appropriated collectively during rehearsal; consider the various peripheral actions that would be necessary to obtain good musical results; and how it can affect the overall cognitive processes. We support that multiple conceptions of affordances can be useful to reflect on these varieties of actions.

8.2.5 ARCAA and the Design Suggestions

The ARCAA framework can be useful to apply three of these design suggestions. The framework embeds the idea of *artifact ecology*. We have also seen how the framework facilitates to look at *autobiographical idiographic approaches* within the same study. Finally, we have seen how the *design-in-use* model by Botero can be integrated in the use of ARCAA.

9

Conclusion

The importance of ecologies in performance that involve digital technology has been discussed by various authors (e.g. Waters [314], Keller [163], Gurevich and Treviño [122]). This thesis expands this discourse by connecting it to the recent discourse on artifact ecology in HCI bridging some concepts from the third way HCI to music technology design. This thesis proposed ARCAA (chapter 4), a new framework for studying performance ecologies, and than used it in one systematic literature review (chapter 5), two studies on music performance with a new screen score system (Puffin) (chapter 6), and one study on sonic interaction design for dance (chapter 7).

9.1 Thesis Contributions

Overall, this thesis produced four main theoretical contributions to the field of music technology design, in the scope of performance ecologies.

9.1.1 ARCAA

ARCAA is the primary and core contribution of this thesis. It is a framework to analyse the set of interconnected relationships in interactive (music) performances. After the initial proposal in chapter 4, the framework has been validated through 2 music studies (chapter 6), 1 dance study (chapter 7) and 1 systematic literature analysis (chapter 5). Finally, ARCAA has been discussed in light of all the case studies (chapter 8). This discussion of the various levels of ARCAA in light of the various studies provides an answer to RQ2 (How does each different actor influence the design of different artifacts, and what impact does this have on the overall artwork?) and RQ3 (How do the different actors in the same ecology interact, and appropriate an interactive artifact?). Indeed, in this analysis the various interconnections among actors and artefacts in design (RQ2) and use (RQ3) moments are discussed. Additionally, ARCAA can be used as a tool to support a joint expression across different actors, in particular in combination with the design recommendations which are the second contribution of this thesis.

9.1.2 Design Recommendations

Based on the various studies and supported by the ARCAA analysis, four recommendations for designing interactive music systems for performance (music or dance) have been proposed (section 8.2). These recommendations can help accounting for the needs of the various actors and for the overlapping of music composition and design of interactive technology. These recommendations represent the main proposed answer to RQ1: How can the design of interactive sonic artifacts support a joint expression across different actors (composers, choreographers, and performers, musicians, and dancers) in a given performance ecology?

9.1.3 Taxonomy of Score-Based Performance Ecologies in NIME

A taxonomy of how scores have shaped performance ecologies in NIME, based on a systematic analysis of the literature on scores in the NIME proceedings is presented in chapter 5. This taxonomy, in addition to being a case to test ARCAA as a tool for systematic literature review, is in itself a contribution that extends the knowledge on performance ecologies, scores, and DMIs.

9.1.4 Methodological Approach

Finally, this thesis advances of a methodological approach that combines autobiographical and idiographical design for designing interactive systems for performance. This approach is not a complete novelty per se, rather it offers a new way of combining existing methodological approaches. This approach is initially exposed in chapter 3 and tested in the case studies in chapters 6 and 7. This approach can balance the artistic needs with the practical and operational needs of the various actors involved. Additionally, this approach was revealed to be valuable to investigate the different perspectives of the various actors involved including the researcher/designer.

9.1.5 Practical contributions

Additionally to the four main contributions, this thesis presented two following practical contributions: 3 case studies on performance ecologies and Puffin V1 and V2 as a new form of a screen score system.

9.2 Limitations

Three main limitations can be identified in this thesis, which are presented and discussed below.

9.2.1 First Limitation: Overlooking the Audience

One first limitation of this thesis is the scope of inquiry. This thesis has focused on the actors involved in the creative and performative aspects of a performance ecology, but has overlooked the audience. The audience is a very important component in a performance ecology, as pointed out, for instance, by Gurevich [122]. In case of an audience actively participating in a performance, it can be speculated that their integration in ARCAA could be relatively easy. Indeed, in this case the audience becomes an actor and can be analysed as such. In the case of a more standard audience, its integration is arguably more complex. On the one hand, the audience is never just a passive spectator, as there is always a feedback loop in any live performance; on the other hand, it is not actively interacting. In this case, representing the audience in ARCAA as an actor who simply listens or watches would probably not add a lot to the overall picture of the performance ecology.

9.2.2 Second Limitation: Area of Inquiry

The second limitation is related to the types of studies. Chapter 5 presents ARCAA as a tool to study one specific aspect of music technology in a systematic way, while chapters 6 and 7 present studies in which the author of this thesis is involved as a composer or a designer. However, up to this point the framework has not been used to analyse in depth one existing piece or performance with a musicological purpose. The reason for that is that this thesis contribution is primarily in the area of interaction design and music technology, therefore a systematic literature review or studies on design of new technology have been considered to be appropriate for this field of study. However, it is possible to speculate that ARCAA can be a useful tool for musicological inquiry and analysis of new music.

9.2.3 Third Limitation: Western Centric Approach

Finally, this thesis primarily positions itself in the western/european music history. Both the discussion on composition and performance, and the focus on score are elements that inherited a western legacy in music practice. A certain level of linkage between contemporary music technology discourse and western legacy is probably implicit in the practice itself (as many early experiences of electronic music emerged from western composers). Recently, it has been discussed how neocolonialism can be a problem within NIME (for instance, this point is central in the theme of the NIME 2022[1]). I come from a western music background, and, therefore, a western perspective on music technology reflects my own personal biographic history and perspective. Therefore, the angle of the research developed in this thesis is aligned with my own cultural identity. But I want to highlight that this is not the only possible way to look at performance ecologies.

[1] https://nime2022.org/

9.3 Future Work

The identified limitations can lead to future research. First, more studies can be conducted to integrate the audience perspective in ARCAA. This work can include both theoretical works to combine the model with existing literature, for instance with existing models such as [322], and more case studies looking at the audience. Such studies would probably create other layers of ARCAA to better integrate a representation of the audience. Second, ARCAA can be applied to study other people's work in detail, this can be a useful tool for musicological inquiry and analysis of new music or help practitioners to self-reflect. The workshop that we will hold at NIME 2022 aims at starting work in this direction (see annex III). Future research, possibly in joint efforts between academics whose expertise is in interaction design and musicology, could investigate the usage of ARCAA for musicological aims. Finally, future research is needed to develop a discussion on performance ecology from a non-western perspective. I hope that other researchers coming from different backgrounds will develop further the research on performance ecology, either using ARCAA and showing the limits of this model when the cultural background changes, or creating new models. I will soon move to Thailand and I hope that teaching music technology in an Asian context will help me to develop other non western perspectives.

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I

Annex 1 - Publications not connected to the main research goal

The following contributions were accomplished during the research period but are not connected to the main research theme. Since these explore alternative research threads, they are not described in this document.

1. Masu, R., Dal Ri, F. A. (2021) Structures Remediation: Applying Serial Techniques to Audiovisual Composition. In Sonic Scope: New Approaches to Audiovisual Culture. 2021. [215]

2. Masu, R., Melbye, A. P., Sullivan, J., Jensenius, A. R. (2021). NIME and the environment: toward a more sustainable NIME practice. In Proceedings of the International Conference on New Interfaces for Musical Expression. The International Conference on New Interfaces for Musical Expression. [221]

3. Masu, R., Pajala-Assefa, H., Correia, N. N., Romão, T. (2021). Full-Body Interaction in a Remote Context: Adapting a Dance Piece to a Browser-Based Installation. In the10th International Conference on Digital and Interactive Arts (pp. 1-4). [219]

4. Masu, R., Correia, N. N. (2020). Pathways to live visuals in dance performances: a quantitative audience study. EAI Endorsed Transactions on Creative Technologies, 7(23). [210]

5. Correia, N. N., Masu, R., Pham, A. H. D., Feitsch, J. (2021). Connected layers: evaluating visualizations of embodiment in contemporary dance performances. In Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction (pp. 1-12).[63]

6. Correia, N. N., Jürgens, S., Masu, R., Feitsch, J., Druzetic, I. (2021). Performative Virtual Scenes: A Dynamic VR Environment Design Approach. In the International Conference on Entertainment Computing (pp. 100-114). Springer, Cham. [61]

7. Jürgens, S., Correia, N. N., Masu, R. (2020). Designing glitch procedures and visualisation workflows for markerless live motion capture of contemporary dance.

In Proceedings of the 7th International Conference on Movement and Computing (pp. 1-8). [158]

8. Jürgens, S., Correia, N. N., Masu, R. (2021). The body beyond movement:(missed) opportunities to engage with contemporary dance in HCI. In Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction (pp. 1-9). [159]

9. Dal Rì, F., Masu, R. (2022). Exploring Musical Form: Digital Scores to Support Live Coding Practice. In Proceedings of the International Conference on New Interfaces for Musical Expression.[65]

10. Dal Rì, F., Masu, R. (2021). Zugzwang: Chess Representation Combining Sonification and Interactive Performance. In Audio Mostly 2021 (pp. 89-92). [66]

11. Dal Rì, F., Masu, R., Graziani, M., Roncador, M. (2020). From the Body with the Body: Performing with a Genome-Based Musical Instrument. EAI Endorsed Transactions on Creative Technologies, 7(23). [67]

12. Bettega, M., Masu, R., Brodersen Hansen, N. Teli, M. (2022). Off-the-shelf digital tools as a resource to nurture the commons. Accepted for publication in PDC 2022: The Participatory Design Conference, August 19th 2022. [23]

13. Bettega, M., Masu, R., Teli, M. (2021). "It's like a GPS community tool": Tactics to foster Digital Commons through Artifact Ecology. In Designing Interactive Systems Conference 2021 (pp. 1710-1725). [21]

14. Bettega, M., Masu, R., Alves Pereira Diogo, V. L. (2021). Collaborative Economy in Portugal: the Recent Evolution. In The Collaborative Economy in Action: European Perspectives, edited by Andrzej Klimczuk, Vida Česnuitytė, and Gabriela Avram,250–262. Limerick, Ireland: University of Limerick. [20]

15. Dorigatti, E., Masu, R. (2022). Circuit Bending and Environmental Sustainability: Current Situation and Steps Forward. In Proceedings of the International Conference on New Interfaces for Musical Expression. [79]

16. Morreale, F., Masu, R., De Angeli, A. (2019). The influence of coauthorship in the interpretation of multimodal interfaces. Wireless Communications and Mobile Computing, 2019. [234]

17. Bala, P., Masu, R., Nisi, V., Nunes, N. (2019). "When the Elephant Trumps"A Comparative Study on Spatial Audio for Orientation in 360º Videos. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (pp. 1-13). [8]

18. Bala, P., Masu, R., Nisi, V., Nunes, N. (2018). Cue Control: Interactive Sound Spatialization for 360º Videos. In International Conference on Interactive Digital Storytelling (pp. 333-337). Springer, Cham. [9]

19. Gold, N, Masu, R., Chevalier, C., and Morreale, F. 2022 (in press)."Share Your Values! Community-Driven Embedding of Ethics in Research."In CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI'22 alt.chi). ACM. [115]

II

Annex 2 - Media

The pieces related to the case studies presented in chapters 6 and 7 have been included in public events.

II.1 Studio 2

The piece Studio 2 created in the case study presented in section 6.2, has been accepted at the music track of Audiomostly 2021 conference: https://audiomostly.com/2021/program/conference-program/

A recording of piece can be find at this link: https://www.youtube.com/watch?v=xtC05kduMjk

II.2 Mútuas Colaborações

The piece Mútuas Colaborações created in the case study presented in section 6.3, has been included in the project *As Nossas Árvores* by the collective of artists and ecologists Equilibrio:

https://uploads.knightlab.com/storymapjs/976eeb1b939c67f1696328f0192f950c/as-nossas-arvores/index.html

A recording of piece can be find at this link: https://youtu.be/WPMq0BCoN90

II.3 Connection Retrieval

The dance piece Connection Retrieval developed during the residency described in section 7.2 has been included in the first public event of the Creative Europe co-funded project Moving Digits: https://movingdigits.eu/artistic-residency/

A recording of piece can be find at this link (a rehearsal with lights on): https://drive.google.com/file/d/1d8ujantwY-JzW_YoKZEt7SOhNm-jJHpX/view?usp=sharing

III

Annex 3 - ARCAA Workshop at NIME 2022

In addition to the studies presented in this thesis, a workshop base on ARCAA has been accepted in the NIME 2022 conference (https://nime2022.org/).

III.1 Short Workshop Description

In this workshop, we aim at fostering a conversation on performance ecologies. At first, part of the workshop will be a self-reflective activity. The participants will analyse one of their recent performances, or pieces of music technology they developed. This activity will be facilitated by the use of ARCAA—a framework to study performance ecologies. Then, a collective discussion will characterise the second part of the workshop.

III.2 Organizers

Raul Masu, raul@rualmasu.org FCT/NOVA University of Libon, and ITI/LARSyS.

Adam Pultz Melbye, Sonic Arts Research Centre Belfast, Northern Ireland.

III.3 Description

In the last two decades, the idea of a performance ecology indicates a complex set of elements that compose a performance, including makers, performers, composers, instruments, and the environment. While discussing the ecology of music creation, Gurevich and Trevino proposed to focus on the "relationships between composers, performers, and listeners as a part of a system", also considering history, genre, and context . Similarly, Waters argues that performance ecosystems encompass the interactions among performers, instruments, and environments .

In this workshop, we aim at promoting a discussion on performance ecosystems with our participants, with the intent to reflect on commonalities, differences, issues and advantages when a given piece of interactive music tech is designed, by considering the entire performance ecology.

To this end we will organize two activities, an initial self-reflection followed by a collective discussion. To facilitate the self-reflective process we will ask the participants to use ARCAA to represent the ecology of a recent performance in which they took part (as performers, composers, designers, builders, technicians or any other possible role).

ARCAA is a recently proposed framework to analyze performance ecologies. It is based on the structure of MINUET , a previous framework presented at NIME in 2014. The idea of ARCAA is to help understand the relations between the various human actors and artefacts by visualizing them. The framework (Figure 1) suggests to connect all the actors (top in the image) to all the artefacts (bottom in the image) using three levels: Role, Context, and Activities. Each level proposes a different question: 1) "Who is involved, and in which role?". 2) "In which context is each actor involved?".3) "What kind of activities are the actors performing?"

The self-reflective process will be done individually. We will prepare an online document where the various participants can upload their ARCAA representation of the ecology. In this way, it will be possible for all the participants to observe the various ecologies.

After this, we plan to set up a collective discussion about the produced schemes. First, each participant will briefly present their ecology. Then, we will collectively discuss all levels (Role, Context, Activities), looking for similarities and differences. In the end, we will discuss advantages and issues of considering the overall ecologies in reflections on interactive music technology.

III.4 Timeline overview

Introduction and ARCAA presentation: 10 minutes

Individual self-reflective activity: 20 minutes

Individual presentation: 20 minutes

Discussion similarities and differences: 30 minutes

- Role: 10 minutes
- Context: 10 minutes
- Activity 10 minutes

Discussing advantages and disadvantages: 10 minutes

Final remarks and conclusion: 5 minutes