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3D [Embodied]

Projection Mapping and Sensing Bodies:

A Study in Interactive Dance Performance

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A Study in Interactive Dance Performance

by

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3D [Embodied]

Projection Mapping and Sensing Bodies: A Study in Interactive Dance Performance

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The University of Texas at Austin, 2016

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This dissertation identifies the synergies between physical and virtual environments when designing for immersive experiences in interactive dance performances. The integration of virtual information in physical space is transforming our interactions and experiences with the world. By using the body and creative expression as the interface between real and virtual worlds, dance performance creates a privileged framework to research and design interactive mixed reality environments and immersive augmented architectures. The research is primarily situated in the fields of visual art and interaction design. It combines performance with transdisciplinary fields and intertwines practice with theory.

The theoretical and conceptual implications involved in designing and experiencing immersive hybrid environments are analyzed using the reality–virtuality

continuum. These theories helped frame the ways augmented reality architectures are achieved through the integration of dance performance with digital software and reception displays. They also helped identify the main artistic affordances and restrictions in the design of augmented reality and augmented virtuality environments for live performance.

These pervasive media architectures were materialized in three field experiments, the live dance performances. Each performance was created in three different stages of conception, design and production. The first stage was to “digitize” the performer’s movement and brain activity to the virtual environment and our system. This was accomplished through the use of depth sensor cameras, 3D motion capture, and brain computer interfaces. The second stage was the creation of the computational architecture and software that aggregates the connections and mapping between the physical body and the spatial dynamics of the virtual environment. This process created real-time interactions between the performer’s behavior and motion and the real-time generative computer 3D graphics. Finally, the third stage consisted of the output modality: 3D projector based augmentation techniques were adopted in order to overlay the virtual environment onto physical space.

This thesis proposes and lays out theoretical, technical, and artistic frameworks between 3D digital environments and moving bodies in dance performance. By sensing the body and the brain with the 3D virtual environments, new layers of augmentation and interactions are established, and ultimately this generates mixed reality environments for embodied improvisational self-expression.

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Introduction

> The combination of sensing with projection is to live digital visuals what a technique like perspective was to painting centuries ago. It's a calculated illusion, but it could be the basis for an entire body of work, both a marvel in itself and a springboard to new art.
>
> —Peter Kirn, 2011

The overlapping fields of technology and art blur the boundaries between disciplines. This study is the result of collaborative work from different fields, namely computer science, the humanities, media studies, design, and visual art. The interdisciplinary work presented involves interactive visual media designers and computer science researchers working with dance practitioners and choreographers in order to create interactive dance performances.

Computing has become more ubiquitous and pervasive in an increasingly digital world. The merging of real and virtual worlds is creating new environments in which physical and digital objects coexist and interact in real time. These hybrid spaces and architectures have unique qualities and forces at play. Mixed reality environments are manifestations of computer applications and digital environments that move beyond the desktop into our physical surroundings. They create hybrid realities, merging the digital and physical in interdependent environments. Expressions such as "virtual," "augmented" and "mixed reality" environments are used to refer to computer-generated environments that involve some form of interactivity and visual immersion. Chan (2014, p. 1) sets the stage for the terminology of “interactivity” and “immersion” by quoting Sohn: “interactivity is a form of reciprocal engagement with a virtual environment, whilst the term ‘immersion’ refers to the feeling of being encompassed by computer-generated imagery” (2011, p. 1323). Interactivity and immersion thus provide the foundation for feedback architecture design within computer-generated environments. Such networks of communication in the context of live performance are described as “mixed reality performances,” “a term that is intended to express both their mixing of the real and virtual as well as their combination of live performance and interactivity” (Benford, 2011, p. 1). Mixed reality performance is a new field of practice and artistic experimentation, constituted by the combination of diverse computing technologies and performance genres that juxtapose and overlay the real and the virtual.

An emerging generation of artists is using digital interactive technologies to transform live performance. Using practice as research, this dissertation explores the ways humans can reshape interactions between physical spaces and virtual spaces.

Dance performance provides an essential infrastructure to develop and test experimental research by interconnecting the perception of space, movement and artistic expression. Digital dance performance, as an interactive art form, is a participatory experience that connects bodies with space through movement in immersive and responsive augmented architectures. The intersection between dance and interactive images coexists in a mixed reality environment, one that is neither solely “real” nor solely virtual. The relationships generated between the dancing body and these augmented architectures of projected light are investigated through field experiments. This study focuses on the creative process of media design, starting from the assumption that digital technologies are integral, fundamental, and essential components of contemporary live performance. These technologies are reshaping mediated dance practices in the 21st century and can, ultimately, expand the ways we interact with digital information. By connecting digital information and space to our bodies and minds, we can augment our capabilities to interact with our surroundings and environments and make the invisible visible.

The world is experienced and perceived through the use of human senses and cognition. The interaction with virtual environments relies heavily on the stimulation of the multisensory perceptions of human environments. To address the need to classify and analyze the level of reality-virtuality overlap, Milgram and Kishino introduced the reality-virtuality (RV) continuum in 1994. This spectrum provides a fundamental theoretical framework to analyze and investigate the unique qualities of different augmented environments. It was used in this study as a road map to analyze the creative mapping in mixed reality performance.

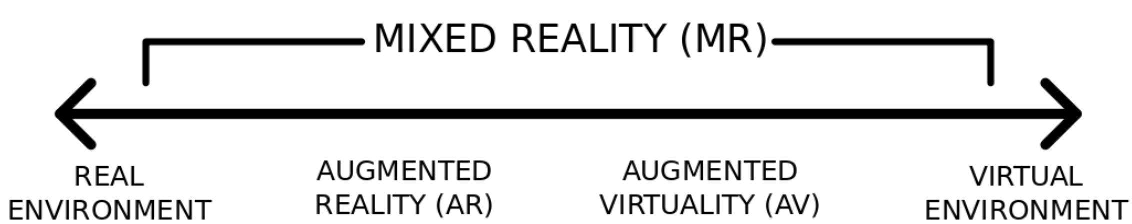

Figure 1: Simplified representation of the reality-virtuality (RV) continuum by Milgram & Kishino (1994)

Embodied interactions between the live performer and projection mapping are described in this study as "mixed reality performance." To perform in mixed reality is to explore creatively the visual dimensions of communication and the metaphoric places of transition between the virtual and the real. In this study, I integrate depth sensors and brain-computer interface (BCI) sensing technologies with 3D projection mapping to investigate augmented environments for live performance.

MOTIVATION AND BACKGROUND

Investigating the intersection of immersive mixed reality spaces with performance forms the core of my research. By exploring these spaces, I can intertwine theory and practice, allowing the two to build off one another. More specifically, I try to understand how these mixed reality environments are fundamentally connected to the physical world and thus not simply a "virtual" reality.

The intersection of visual art with technology has been the main focus of both my artistic and academic bodies of work in the last decade. This dissertation draws on my experience as a student of media theory and a practitioner of projection design and new media art. As a student of fine arts and multimedia, and later as a professor, I am highly inspired by electronic music arenas. More precisely, I have focused on the immersive and improvisational aspect of the collaborative integration of lighting and visual design in performance.

Around the year 2000, I started to manipulate digital video for electronic music events. The collaborative and experimental process of designing these events influenced my artistic and personal development. My main interest as a visual artist has always been light. Cubitt described light as the condition of all vision: “Control over light, and its mediation through visual technologies, matters because it alters the constitutive grounds of sensing, knowing, and relating to another and to the world” (2014, p. 3). My master’s thesis, an extension of the design work I did in electronic music arenas, focused on the theory of real-time visual performance, also described as VJing (from “video jockey”). VJing is an extension of the DJ practice, which is based on live audio manipulation of records and audio signals. Also described as video jamming or live cinema, VJing is a “common term referring to a form of presentation, how visual content is combined and performed live. The origin of the content may be any combination of graphics, video, 3D animation, photography, film . . .” (Engström, Esbjörnsson, & Juhlin, 2008, p.2006).

To do a comprehensive study on the components of VJ performance was an opportunity to add a more defined layer of theory and research to my artistic practice with live visualizations and exploration of hybrid media forms and technologies. Following a practice-based approach, I identified the principles and elements in such practices. Further, I directly manipulated these parameters in response to energy transferred between music and visual representation. More precisely, I focused on the dynamic vocabulary used by new media performers, strongly related to the intrinsic characteristics of experimentation and improvisation in real time.

In August 2010, I moved to Austin to pursue my doctoral degree at The University of Texas at Austin. I began to design for a new collaborative environment and framework: dance performance. Dance is a natural extension of my previous work based in the synesthetic experience of vision and sound. Even though my particular approach and output was based in the perception of light, video, and space, dance performance added unique characteristics towards media integration, such as presence and rhythm. Birringer defines dance as a fundamentally multimedia system due to the association with visual forms and rhythms and the integration with other media and art forms, similar to VJing principles, in which programming interfaces between live music and visuals imply the creation of an "unstable" and unpredictable system (Birringer, 2002, p. 87).

The dancer's ability to express emotions through movement generates valuable and unique sources of data to be captured and incorporated in digital environments. Therefore, working with dance performance provides visual artists unique qualities and frameworks to design for real-time events and audiences. Those qualities are then applied in augmented environments generated by video projections. Projector-based augmentations are created by the use of video projections and visual programming. They allow us to change the immediate relationship of space and body, essential in the nature of dance practice. Digital dance performance extends the alphabet of dance practice, creating and programming new sets of media that react to the dancer. This particular framework gave us the ability to generate a laboratory-based environment and, along with the dancers, co-create a digitally-enhanced space that continuously moves between physical space and the projected spaces of light and sound. Working with dance performers and using sensing technologies to digitize their physical and brain activity allows media designers to have an organic ecosystem of patterns and creative expressions generated in real time. Our creative and technical process involves the mapping of these three-dimensional numeric patterns in augmented and responsive spatial three-dimensional environments, all in real time. The multidisciplinary body of work created in this study is fundamentally structured by a triangle of three main fields: human computer interactions (HCI), visual art and design, and media and art theory. All these fields intersect and come together through performance art, more precisely, through digital dance performance (Figure 2). This becomes necessarily a collaborative process, mediated mostly through design and experimental use of sensing technologies with digital video projection techniques.

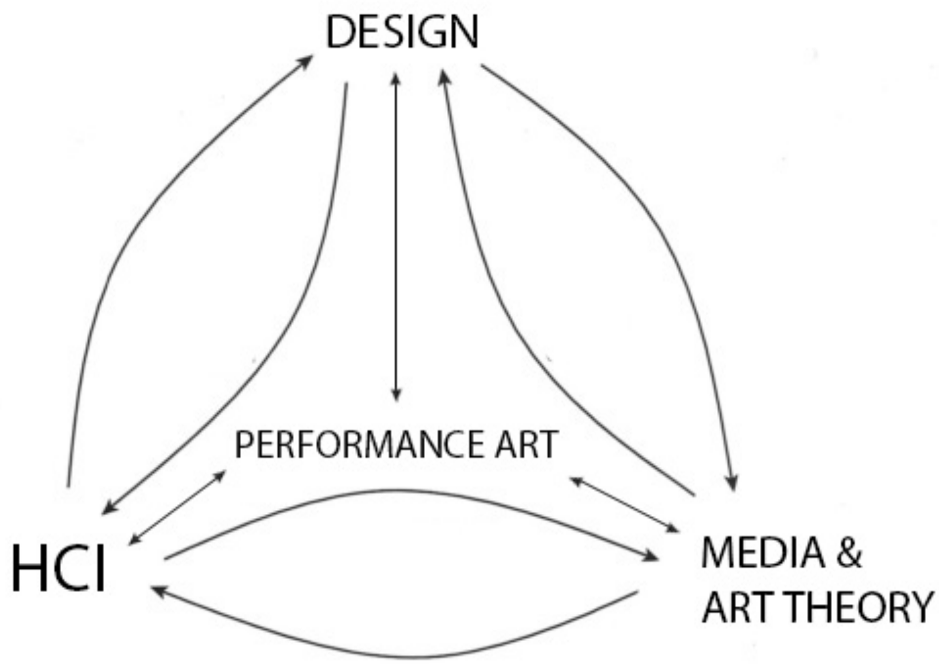

Figure 2: Multidisciplinary areas of research in this study that intersect in visual and performance art

RESEARCH QUESTIONS

The title of this dissertation, *3D [Embodied] Projection Mapping and Sensing Bodies: A Study in Interactive Dance Performance*, reflects the experimental and conceptual approach of my work. It focuses on the understanding of the connection between the key concepts of immersion and interactivity in mixed reality environments. This study attempts to formalize practical guidelines for projection design and embodied interaction, more precisely, to pinpoint strategies for generating projection-based augmentations with motion-sensing technologies and interfaces. My primary research question is related to the direct integration of sensing technologies with live visual projection design or, more precisely, to the intersection between interactive technologies and immersive environments: What are the creative opportunities that are open to us when we consider the use of augmented reality (AR) for live performance derived from digital video technologies combined with sensing technologies?

The spectrum between reality and virtuality becomes more complex as it is supplemented by computer-generated sensory inputs and situated in immersive environments beyond synthetic virtual reality headsets. I focus on creating collective visual augmentations for the audience through spatial augmented reality, also referred to as 3D video mapping, which allows me to overlay virtual environments directly over the physical space and the performers' bodies. By combining sensing technologies as the input signal, and projected imagery as the output, we focus on identifying and creating communication channels and images for mediated creative expression in live dance performance. Using mixed reality performance as the context, my second research question is: Considering the full spectrum of the reality-virtuality continuum, what are the main attributes and limitations in designing embodied mixed reality environments using projector-based augmentations?

The architecture design in mixed reality environments has been expanding as new technologies and modalities are created to overlay and juxtapose real and virtual worlds.

Environments such as augmented reality and augmented virtuality have unique sets of attributes and qualities for live dance performance. By analyzing the input, processing, and output of these theoretical frameworks in the live dance performances created in this research, I identify the key issues to consider when designing immersive AR and AV-embodied environments. Finally, based on the interdisciplinary nature of dance performance, we also focus on the collaborative process between the agents (the choreographer, the media designer, and the dance performer) and, borrowing Downie's expression, the "extended agent" (the software) (2005). What are the key guiding principles for designing software that function as a "choreography partner" in augmented dance performance? How can these interactions generate improvisational and dynamic mapping between the physical space and the virtual world?

The last research question in this study introduces a new layer of sensing technologies by tapping directly into the performer's brain activity. We incorporate new sets of data and behavior into our framework by connecting BCIs with depth visualizations. Exploring the role of emotional response tracking to digitally augmented human movement as an art form to conceptually explore dance expression beyond physical movement: How can brain computer interfaces (BCIs) be integrated into mixed reality performance?

The integration of motion capture technologies with BCIs expands the design of mixed reality environments and expands the relationship between the performer and media. This particular framework is implemented and analyzed in the last chapter and performance of this study, *Biomediation*, to add a new layer in 3D embodied environments.

METHODOLOGY

A doctorate in design and visual composition stems from a blend of theory and practice. It includes an understanding of ongoing innovation in practice-predicated environments and cognizance of insight acquired throughout the process. The research presented in this thesis follows a practice-based approach. Conducting research through practice has been widely used in the last decade by artists and researchers. This framework for research gives us the structure to engage with issues by writing from within practice, generating an intimate and auto-ethnographic analysis of the experience of creating new artistic projects. Practice-based research has given rise to new concepts and methods in the generation of original knowledge (Candy, Amitani & Bilda, 2006). Media and cultural theorists look at artists to be among the first to explore and make sense of new media. Critical thinkers and creative minds operate in tandem as they both seek to understand new interactions with new technology. Media designers and transmedia artists generate a privileged framework to provide and generate media theory, grounded in applied art. Lialina asks, “Who if not them are to be nurtured with media theory’s ideas, and give back in form of art works, artistic research and designs?” (2015).

PERFORMANCE AS RESEARCH

On practice and performance as research, Shannon writes:

> While performance practices have always contributed to knowledge, the idea that performance can be more than the creative production, that it can constitute intellectual inquiry and contribute new understanding and insight is a concept that challenges many institutional structures and calls into question what gets valued as knowledge. Perhaps the most singular contribution of the developing areas of practice as research (PAR) and performance as research (PAR) is the claim that creative production can constitute intellectual inquiry. (2009, xv)

This research project emerged from practice, creating mixed reality environments beyond the virtual reality and embodying the physical world. We follow an interdisciplinary approach that draws on design, visual arts, computer sciences, human computer interaction (HCI), performance and media studies, and art theory.

By using a mixed-methods approach within these different disciplines, the projects employ digital technologies to create distinctive forms of interactive and experimental dance performances. Our methodology also includes qualitative interviews and questionnaires. The interdisciplinary success of longitudinal technology and temporal art projects depends directly on the articulation between creative and technical agents. Our methods and strategies are based on what Donald Schon described as “the situations of practice—the complexity, uncertainty, instability, uniqueness and value conflicts, which are increasingly perceived as central to the world of professional practice" (Schon, 1983, p. 14).

Our methods enable intuitive and expressive navigation through gestural and mind interactions with our system and sensor reactive systems. Sensing design and stage mapping processes are fundamental for the practice generated in this work, and to connect the physical, the cognitive and the virtual. Our method began by collecting data from dancers. Then, we projected interactive imagery on the performers' space. This system creates two-way communication between the dancer and the interactive projected imagery, generating the coexistence and convergence of interfaces in augmented performance.

The methodology arises primarily from reflections on practice, but also by incorporating theories and related written research. The synergy between practice and theory is executed with a performative approach to research (Haseman, 2006). The early practical experiments were motivated by artistic and technical motivation, being guided by passion and my artistic instinct. The theoretical and research agenda is a direct consequence from this practice and framework. The *3D [Embodied]* performance solidified the theoretical framework and the main terms of the research agenda.

Benford and Giannachi (2011) formalized the methodology of "research in the wild" as a result of a decade of collaborative work and research at the Nottingham University's Mixed Reality Labs. The work is focused on the evolution of interdisciplinary approaches that combine the goals of artists and new experiments with researchers who want to develop new technologies, such as physical interfaces and/or software tools. The authors identify three main elements in this method: 1) It is led by practice; 2) The data collected is gathered from ethnographic studies on the technologies in use; 3) Theory is generated directly from these findings and analysis (Benford & Giannachi, 2011, p. 8).

The relationship between theory, practice, and creativity is described as a feedback loop process in the following diagram from the doctoral research of Rowe (2015) (Figure 3), which has many similarities to the methodology and structure used for our study.

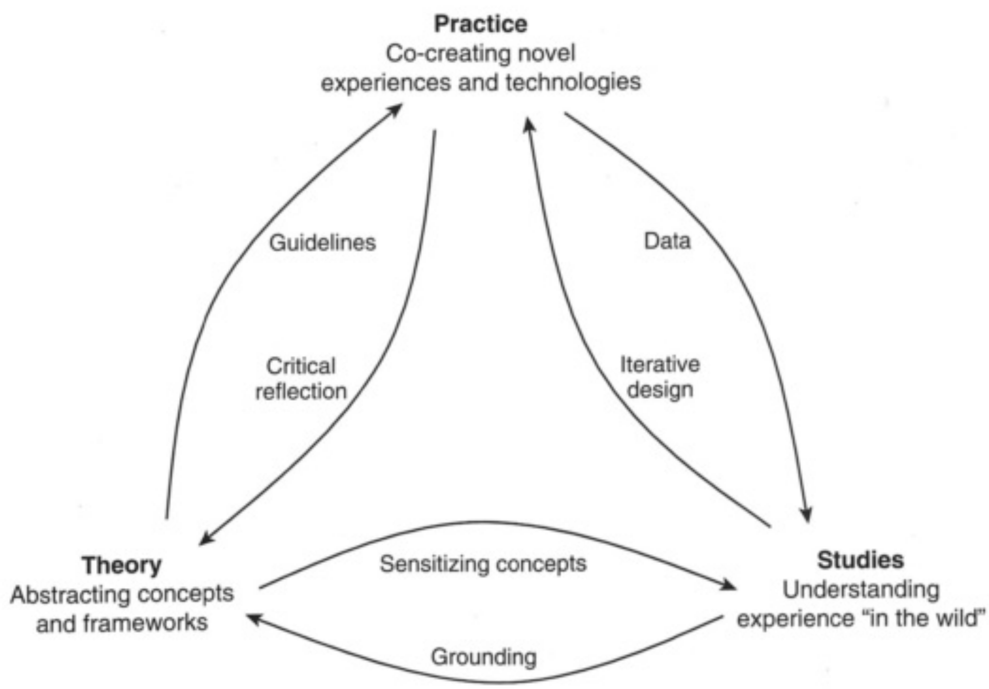

Figure 3: "Research in the wild" diagram, relating practice, studies, and theory (Rowe, 2015).

ZERO POINT METHODOLOGY

In his doctoral dissertation, *Beyond the Electronic Connection*, Yacov Sharir proposes a collaborative multidisciplinary methodology that he named the "Zero Point Methodology" (2012). Sharir uses this phrase to describe the necessary working relationships that best facilitate a multidimensional, multidisciplinary, genuinely collaborative new project. The basis of this methodology lies in creating non-hierarchical roles in order to enhance the creative process. Communication is the key active agent between the collective and the creators; it is the fundamental premise that sparks the creative process and collaborative exchange between the media. The foundation for this collaborative method relies on communication. Applying effective listening skills and conceptualizing, proposing and respecting ideas in the space creates group commitment and non-hierarchical relationships.

Sharir writes, "The most precious asset related to this methodology is its ability to engage in careful listening, which leads to analysis, and ultimately the understanding of all the components that are necessary to engage in such an interaction" (2012, pp. 40-41). Sharir's methodology was naturally suitable to my study. As a supervisor and mentor, Sharir guided the collective on mutually agreed upon "thematic ideas, content, and the meaning that will serve as the driving force that eventually brings about a successful iteration to be shared with an audience" (2012, pp. 40-41).

Working with interactive media and experimental visual arts in performance implies the need and ability to listen in a way that helps researchers understand the subtle relationships between and among performers and technology. It requires technical proficiency with a strong understanding of projection, video, animation, light, and design and the skills necessary to produce original artistic work. In academia, my research falls in the category of projection design programs. Similar programs are by nature geared towards the entertainment industry and, as an approach, are similar to media designs driven by technical applications. The work reported in this document was generated primarily from an artistic and conceptual augmented environment. The role of each collaborator was distributed equally between choreographer and media designers. The goal is to co-create an interactive media form in which the body in movement is an equal and integral partner.

Digital artist Klaus Obermaier argues that there are fundamental differences between interactive performances conducted by choreographers and directors and those conducted by media artists. When directors and choreographers think of a new piece, they create work primarily rooted in their main medium of expertise. For example, in theater, text will be the starting point for the creative process and thus, as Obermaier says, "Only very late do other media get involved and can thus only have an ornamental relevance instead of attaining essential parts in form and content" (2008, p. 259).

Media artists working with interactive performances start this creative process directly from their artistic medium and incorporate them in a multidisciplinary framework. For example, light has been widely used as decoration and as an auxiliary tool for stage performance instead of becoming a fundamental creative partner and medium for artistic production and performance. In fact, even today, there is a conservative and traditional approach to media design in live performance. The role of media design is not a creative equal with performance partners such as dancers, but the implementation of new technologies in live performance “have changed and renewed them” and they have become “integral parts” of performance (Obermaier, 2008, p. 259).

Our methodology gives equal value to the different roles played by various creators in the creative process. All the elements involved in this body of work and research incorporate dance and expression in an augmented space that is designed as a living digital organism and environment. Under this framework, media designers working with choreographers and dancers need the interdisciplinary team and nonhierarchical order to enhance the creative process as an integral part in performing arts.

On Collaboration and Practice

Combining practice with theory is difficult to present in a linear document. Theories were developed and processed during practice. The collaborative projects were also opportunities to test the theories, and performances embodied the research and knowledge acquired. To present both theory and practice simultaneously is a difficult and challenging task. This document is organized to present the research process in a organized and structured publication, but does not reflect or mimic the timeline and temporal execution of the research.

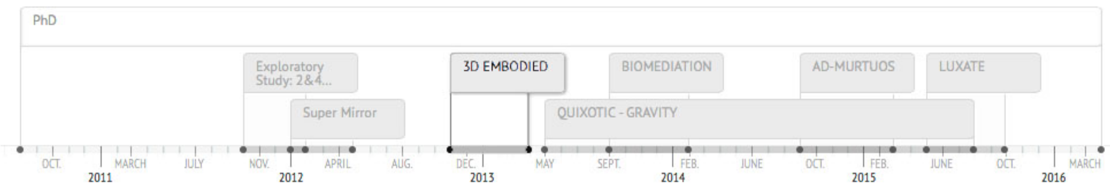

Figure 4: Timeline of research projects and performances developed in the framework of *3D [Embodied]* research and dissertation

The group of agents involved in interdisciplinary work in performing arts is vast, and it is very difficult to effectively describe the role and relevance of every agent that contributed to the pre-production and production of the show. The practice-based approach of my committee towards live dance and media performance made it possible to collaborate directly with them and take my work beyond the theoretical. Dr. Sharir choreographed three of the performances and Dr. Pennycook designed the interactive sound design from 2011 to 2015. Throughout the process, we worked with undergraduate and graduate students from the department of theater and dance at the University of Texas, Austin. I also worked with professional dancers from Quixotic, a performance art collective that fuses dance with new media art. The collaboration with professionals outside of academia can be argued to constitute a fundamental component of transdisciplinary research, bringing a broader range of knowledge and different set of skills and expectations (Cutler, 2010).

CONTRIBUTIONS

> The contributions of visual and performance artists to VE's continued development is key to how we will know and comprehend ourselves in the near and far future as creatures existing in both the physical and the digital domains. (Ford, 2007, p. 123)

Our focus in this interdisciplinary research project is using technology and creating responsive visual environments for dance performers and choreographers in order to expand the current set of expressive methods for digital dance performance. We avoid the gadget effect of displaying technology for its own sake and instead focus on using technology to drive interactivity and expand the ways we think of reality and virtuality. We appreciate the value of direct articulation of the expressive relation and network between the physical body, virtual environments, and artistic expression. We aim to create a practical guide for artistic, conceptual and technical implementation for mixed reality performance, outlining visual programming and media design between the sensing technologies (input) and projection based augmentations (output). We also provide a theoretical and critical analysis of the performances, specifically by reporting and analyzing creative applications and mapping strategies of motion tracking systems and projector-based augmentations.

We seek to explore the potential of using augmented reality (AR) in the context of contemporary dance performance through projector-based augmentations. The interaction between the software and the dancers is designed to better convey the choreographer's vision and act as an extended agent for the dancer. By incorporating brain computer activity in our workflow and interface, we extend the field of research beyond the physical dimension. We strive to streamline the theoretical understandings and analysis between real-time interaction of the body and mind with designed augmented spaces. These augmented architectures and custom-made algorithms and software are available for further research and experimentation through my website, an extension of the dissertation.

This study contributes to the HCI field by producing user-centered design development in software production with sensing hardware technologies. It adds to the field of performing arts by analyzing the interdisciplinary collaborative design process. Our study contributes to the media studies field by identifying practices and generating new architectures and interactions of virtual embodiment and mixed reality performance. Finally, the interactive systems created provide original contributions to knowledge focused on the improvement of the interdisciplinary practice of mixed reality performances.

OVERVIEW OF THE STUDY

This study is focused on dance performance and its intersection with and mediation by digital light and visual art. It aims to create sensorial and experiential visual feedback through media design. It aims to co-create an interdisciplinary exchange and link between projected light and bodies in movement.

The Introduction describes the contextualization and methods used in the study, combining theory and observation in design and media with practice. It also introduces the previous work that led to the interdisciplinary group of students, professors, dancers, engineers, and artists that contributed to this study. It also highlights the problems and research questions this study explores.

Chapter 1 presents the context and theoretical framework used to analyze mixed reality environments as architectures for live performance. It focuses on the immersive and interactive qualities of augmented environments and the overall principles and main concepts developed in digitally augmented environments for mixed reality performance. The intersection between sensing technologies and projection augmentation is presented in this study as the input (sensing and digitizing the moving body), processing of data sets (interactive design), and output (3D projection mapping). This organization also reflects the architecture of digitally augmented environments.

Chapter 2 describes *Too&For*, an exploratory study and our first performance. *Too&For* was created with choreographer Yacov Sharir at the University of Texas in the Theater and Dance department in August 2012. Its focus is on the immediacy and expressive role of multi-touch and drawing techniques in the mediation of live dance performance with computer-generated 3D graphics. This was an exercise to investigate the principles of motion tracking and computer-generated imagery without the use of automation in mixed reality environments.

Chapter 3 describes Super Mirror, an attempt to provide a motion capture interface for ballet dancers. Through software development and integration with a low-cost depth sensor, Super Mirror expands the role of the traditional mirror used in rehearsal spaces, providing automated corrective feedback to the dancer. Through comprehensive, evaluative research with dance students and practitioners we evaluated usability to understand the impact of our framework in assessing and assisting the practice of specific ballet movement.

Chapter 4 describes *3D [Embodied]*, the first dance performance we created incorporating the Super Mirror system and real-time generative computer graphics. It is an experimental mixed reality performance that investigates the real-time dialogue between the moving body and 3D geometry perspective calculations. Through a continuous stream of full body tracking, the dance performer is able to control and transform the geometric transformations of computer-generated imagery in real time. This mixed reality architectural design represents a practical application of spatial augmented reality environments.

Chapter 5 describes *Luxate*, which explores the qualities of digitally projected light beyond the screen and a different approach to projector based augmentations in the performance. The goal is to encourage the perception of an augmented holographic interface, creating a reactive environment between the dance performer and the perception of a light field generated by smoke. Ultimately, this project seeks to explore the digital interactive qualities of light beam architecture in the physical space.

Chapter 6 describes *Biomediation*, which goes beyond the physical dimension of sensing the movements of the dancers and taps the performer's brain directly. Through the use of Brain Computer Interfaces (BCIs), we establish a communication process between the depth sensor and the brain computer interface, creating a new and different form embodied in the mixed reality environment. Ultimately, *Biomediation* analyzes the potential of brain computer interfaces for dance performance.

Chapter 7**,** the conclusion, summarizes the main findings and contextualizes the study. It also discusses the study's location in a broader landscape and suggests future work and research in mixed reality interaction design and performance.

Chapter 1: Context

OVERVIEW

This chapter presents the theoretical and conceptual implications involved in designing and experiencing immersive digital environments, specifically, in the creation of computer-generated environments that involve spatial interactivity and immersion. I start by defining virtual reality (VR) simulated environments and then transition to more hybrid augmented environments. Physical space and digital environments have rapidly converged in the last decade into a technological state known as “mixed reality.” Mixed reality pushed the boundaries of our contemporary theoretical relationship with digital technology, and, in turn, new conceptual models were created to describe and analyze this technical, cultural, and artistic shift.

Within mixed reality lies augmented reality (AR). Augmented reality enhances the user’s perception and interaction with the real world by supplementing 3D interactive virtual objects in the user’s field of view (Azuma, 2001, p. 34). AR is usually thought of in terms of a specific technology that recognizes computer-generated sensory input in the physical world and triggers audiovisual feedback in mobile displays, but AR is not restricted to mobile or screen-based display technologies. Projection-based visualizations for AR have unique qualities because the interface elements are projected directly into the real world. I move to discuss spatial immersion in performance by using projector-based augmentations. In my work, I situate projection mapping, otherwise known as "spatial augmented reality," within this framework.

To theoretically situate projection mapping as augmented reality, I start by explaining the current literature on immersive environments. I argue for the advantages of augmented environments over the purely virtual. To me, augmented reality created by projector-based augmentations maintains a connection with the tangible world, which can be considered a different approach from purely synthetic virtual spaces. Because the mediating technology is non-invasive, unlike the clunky equipment of virtual reality, the user can engage the experience in a more natural way. Furthermore, it avoids the one-way communication stream of virtual reality in favor of real-time interactions with the sensory world, and can even encourage people to build social connections.

From a full discussion of the media involved in spatial augmented reality, I move to explore the theoretical underpinnings and uses of spatial augmented reality and explain the theoretical concept of augmented virtuality. These theories help me explain how augmented virtuality is achieved through the integration of dance performance with digital software and projection.

This chapter serves to lay the groundwork for understanding the embodied projection-based augmentations created in this research and provides a fundamental map to understand and analyze the complex connections between virtuality and reality in live performance. The mixed reality continuum and theoretical framework will serve as a reference in order to map the whole spectrum established by different technologies and modalities for the input and output between real and virtual, as this study presents four dance performances that explore those intersections and characteristics of media design in different areas of the continuum.

IMMERSIVE DIGITAL ENVIRONMENTS

Audiovisual magical environments have been imagined, explored, and created by artists, scientists, designers, engineers, writers, and others to generate unique sets of autonomous spaces and environments throughout history. More specifically, the use of projected light in performative settings and experimental live settings to invoke illusions, fantasy, and unnatural phenomena can be traced back several centuries. The introduction of digital media in the creation of immersive environments has created the possibility to be physically present in reality and a virtual world at the same time.

Virtual Reality

The first artificial environment created in computation was virtual reality. There is no common definition for virtual reality, but it is possible to identify common characteristics. The main goal is to mimic the real world by creating a simulated 3D environment. Virtual reality visionary and theorist Ivan Sutherland explains the importance of replicating the “real” to practitioners of virtual reality: “The screen is a window through which one sees a virtual world. The challenge is to make that world look real, act real, sound real, feel real” (1965, p. 506).

Virtual environments are by design systems to enhance communication between humans and computers. The synthetic qualities of virtual environments, commonly referred to as virtual reality, consist of numeric and programmed data sets in a synthetic and digital world. The visualization is generated by head-mounted displays and sensor tracking interfaces such as gloves or head tracking. With advances in technology, the ability to recreate a simulation of reality or new realities was expanded to new levels of engagement and immersion for virtual reality, but it excluded the physical space and environment of the user from the experience.

Virtual reality has evolved in both our minds and in our attempts to achieve it. The first reference to the concept of virtual reality came from science fiction literature, in the 1935 short story "Pygmalion's Spectacles" by Stanley G. Weinbaum. In the story, the "spectacles" are goggles that allow the user to interact with and engage in the sensory world of a movie. In the mid 1950s, cinematographer Morton Heilig created the Sensorama, an installation featuring stereo speakers, 3D display, fans, and vibrating chairs—a well-known attempt to engage all the senses in an immersive, virtual environment. Helig also patented the first VR head-mounted display, known as the Telesphere Mask, in 1960. This provided stereoscopic 3D, wide vision, and true stereo sound; importantly, it also freed virtual reality from cumbersome stationary equipment. In 1965, Ivan Sutherland created the Ultimate Display, a virtual reality head-mounted display in a room that allowed users to control and transform the virtual environment. Sutherland saw the potential to go beyond mimicking the real world. He described the possibility of accessing places with "concepts not realizable in the physical world," places with "forces in non-uniform fields, non projective geometric transformations, and high-inertia, low friction motion . . . . It is a looking glass into a mathematical wonderland" (1965, p. 506). Sutherland's vision marks a clear evolution in how virtual reality could be conceptualized.

At base, virtual reality is a computer technology that uses software to replicate real 3D environments and enables the user to interact with artificial and digital environments through the use of head-mounted displays (HMD, the iconic head-mounted goggles with a screen in front of the eyes) and tracking systems. Sutherland constructed the first HMD VR system in 1968, which he nicknamed "Sword of Damocles" and which included head tracking and three-dimensional display (Sutherland, 1968). The introduction of sensory devices incorporated different senses and transformed the medium's ability to respond to the user's movements in the artificial world. Since then, new technologies have powered high-fidelity experiences to the point of not just mimicking reality, but creating a space that feels so real that it is indistinguishable from reality. Full immersion into virtual reality relies on the idea of transcending reality and is often described as the "willing suspension of disbelief" (Coleridge, 1817).

Beyond Virtual Reality

The extension of immersive environments beyond virtual reality address creative and artistic exploration of the experimental qualities of the digital medium. Immersive digital environments do not seek to replicate reality just as it is. Instead, creating immersive digital environments provides an opportunity for artists and designers to generate environments in which the user feels an experience that transcends ordinary reality. It allows for the creation of "places that work as alternative, parallel worlds" (Beira, Carvalho & Kox, 2013, p. 45). These places don't need to fulfill the same roles and functions as the real world, and perceptions of the laws of physics, logic, and sensory input can be manipulated and augmented. These spaces work as the "metaphoric places of transition between real and virtual worlds in which virtual and real elements are interwoven" (Beira et al, 2013, p. 45). The goal is not just to simulate the real world but instead to transform it by creating new perceptions and to "define arbitrary, abstract and otherwise impossible relationships between action and result" (Krueger, 1997, p. 119). Designers are now able to create unique digital environments that challenge the fundamental rules of reality.

IMMERSION AND INTERACTIVITY

When designing digital environments, it is important to consider the fundamental principles of constructing an immersive space. The definition of immersion has a wide range of meanings, but in the context of digital media, it refers to the spectrum of mediated experiences within media arts and interaction design and the overall engagement of the viewer. Immersion in virtual environments is enhanced by the active participation of the user, known in the field as interactivity. Because of interactivity, immersion stands in opposition to being a passive observer of pre-recorded media such as video or film. Key elements that can increase immersion include considering sensory modalities and spatial fidelity, including kinesthetic learning, and making the medium invisible. Despite the medium's ability to bend reality, orienting the senses can contribute to a more immersive experience, as the viewer's ability to suspend their disbelief increases. Brenda Laurel explains, "Tight linkage between visual, kinesthetic, and auditory modalities is the key to the sense of immersion that is created by many computer games, simulations, and virtual-reality systems" (1993, p. 161). Considering sensory modalities and spatial fidelity in real time are fundamental to creating immersion in a virtual environment.

The role of spatial involvement and engagement in immersion is reflected in the relationships between image and body space, which is central in Calleja's analysis of immersion (2011). In virtual environments, the relationship between the body and the mechanics of movement, also known as kinesthetic learning, is created by the interface. The adoption of non-invasive sensing technologies and interfaces is a fundamental process in the creation of virtual immersive environments. The ability of the media to disappear and to make the mediated content indistinguishable from reality is required for the creation of an immersive virtual medium (Ryan, 2001). In achieving this in an immersive environment, concept and technology are interdependent.

Grau also links optical illusion and transparency of the media with immersion:

> Immersion arises when the artwork and technical apparatus, the message and medium of perception, converge into an inseparable whole. At this point of calculated "totalisation," the artwork, which is perceived as an autonomous

> aesthetic object, can disappear as such for a limited time. This is the point where being conscious of the illusion turns into unconsciousness of it. As a general rule, one can say that the principle of immersion is used to withdraw the apparatus of the medium of illusion from the perception of the observers to maximise the intensity of the message being transported. The medium becomes invisible. (2003, p. 348)

The transparency of the medium generates more natural interactions between the user and the environment, which consequently increases user engagement in the environment.

The principles and qualities of immersion and interactivity are fundamental for the generation of immersive digital environments, where the user is able to interact in a natural and intuitive manner with the technology interface. The ultimate goal is to achieve what virtual reality researchers refer to as a “state of presence” in the mediated environment.

MIXED REALITY PERFORMANCE THEORETICAL FRAMEWORK

In recent decades, computer imagery and content have conquered the challenge of physical space, transcending the limitations of screen-based and head-mounted displays, thus leading to more possibilities for an immersive experience. Our concept of mixed reality is born out of the age of pervasive and ubiquitous computing and its ability to merge the real and the virtual in a unified environment. The space between reality and virtual reality, and the different varying levels between them, is called mixed reality. Milgram and Kishino defined a mixed reality as a mediated experience located "anywhere between the extrema of the virtuality continuum" (1994, p. 1324). Such environments intertwine spatial and temporal components into cohesive, hybrid experiences between the viewer, the physical space, and the virtual space. The authors also created the "reality-virtuality continuum," a taxonomy of mixed reality displays (Figure 5). This theoretical framework provides a fundamental roadmap to understand the complex connections between reality and virtuality. The continuum defines four fundamental modes and areas of relationship between the viewer and the digital media in this mixed reality: the real environment, augmented reality (AR), augmented virtuality (AV), and virtual reality or virtual environment (VR/VE).

Figure 5: Adapted from Milgram & Kishino's "reality-virtuality continuum"

In one extreme of the continuum lies virtual reality. Virtual reality describes computer-generated environments where the user experiences only virtual stimuli, experienced through head-mounted displays or stereo back-projection environments such as the CAVE (Cruz, 1992). Augmented reality lies between reality and virtual environments. It can be described as physical environments overlaid with digital information. Augmented virtuality, on the contrary, signifies virtual environments overlaid with physical information (Milgram & Kishino 1994).

The term "mixed reality" incorporates a spectrum of theoretical models for framing reality and virtuality by presenting them in one display and frame. Unlike virtual reality, Benford argues that the mixed reality environment "offers the possibility of creating such hybrid performative and participatory environments in which real and physical data appear" (2011, p. 5). Instead of being integrated into one another, they are juxtaposed on top of or next to one another.

The goal of mixed and augmented art forms is to challenge and explore different approaches to the relationship between the viewer, the experience, and the media. Through performance and installation, artists have attempted to aggregate computer-generated content and the physical environments in order to create higher levels of immersion. These theoretical models framing the relationship between real and virtual as a superimposition of the two were originally proposed by Sutherland: "The user of one of today's visual displays can easily make solid objects transparent—he can 'see through matter!'" (1968, p. 507).

In a first attempt to realize this theoretical model, Myron Kruger created *Videoplace* in 1974. This installation combined human interaction with computer-generated graphics in real time. Through the use of a video camera and software development, Krueger overlaid the graphical representation of the silhouette of the participant's body (1991). Krueger is considered to be one of the first augmented reality artists and researchers, and instead of using virtual reality head-mounted displays, Krueger investigated the output qualities of juxtaposing virtual projections onto physical walls. Krueger's work pioneered augmented reality as an interactive art form.

Augmented reality became an independent field of research as the technological advances of the 1980s and early 1990s were used to advance the field's conceptual output. Boeing researcher Caudell coined the term "augmented reality" to emphasize the need to focus beyond the virtual experience, but also in the augmentation of the real through digital information (Caudell & Mizell, 1992).

Augmented reality can be defined as an extension of virtual reality. The difference between virtual reality and augmented reality is the fact that augmented reality integrates the real world and the physical environment in the mediated experience, in opposition to virtual reality, which positions the user's senses always in the purely simulated virtual environment, ignoring any physical reference in the real environment. Examples of AR applications have been explored in products like Google Glass, and multiple camera-based applications in smart phones, such as QR and AR codes. Contrasted with virtual reality, Milgram defined AR "as any case in which an otherwise real environment is 'augmented' by means of virtual (computer graphic) objects" (1994, p. 1323). Litchy extended this notion to include "a welding of a form of real-time video and virtual reality, or an optically registered simulation overlaid upon an actual spatial environment" (2014, p. 99). Thus we have both the virtual and the real sharing a mixed reality.

Augmented reality simulates virtual objects and displays digital information, juxtaposed with the physical environment. In augmented reality, sensors and algorithms are introduced to determine information such as the spatial position and orientation of the user in the real world. Litchy proposes five modalities in AR: Fiducial, Planar, Locative, Environmental, and Embodied (2014, p.100). Each one creates different relationships and interfaces with the user, the physical, and the virtual in order to create specific gestures of media delivery. Rowe identifies the transition from static media to augmented virtual environments, as one of three different stages of evolution in media art: first, by expanding the image space, from a post-cinematic/video art tradition; second, by entering the image space, such as in virtual reality and, finally, by exploding the image space, which includes various forms of augmented spaces (2015, p. 58).

Augmented reality as a technology renders 3D graphics to be displayed exactly as they are perceived from the user's position and location and the camera's point of view in the virtual world. Such technology has created a fundamental transition in how users experience mediated experiences, and the practical outcome of virtual environments.

PROJECTION MAPPING AS SPATIAL AUGMENTED REALITY [OUTPUT]

Projection based augmentation, or projection mapping, is also referred to in academia as Spatial Augmented Reality (SAR) (Bimber, 2007). In such environments users can move freely without having to wear "oppressively heavy head mounted displays," which generates a natural interface for artistic expression for the performers (Grau, 2003, p. 245).

The most common form of augmented reality visualization is known as *See-Through Augmented Reality* (STAR). The digital elements are seen through a screen, generally a mobile/portable screen, or a head-mounted display. STAR has limitations on the number of users who can experience the augmentation and also brings a physical obstacle to the process, the screen, which makes it difficult to use in a creative social and performative environment such as live dance. In this research we focus on another form of augmented reality visualization technology based on the projection of light directly to the physical space: projection mapping.

My focus goes more precisely towards the use of projected light as a form of augmented reality (AR). Projection based AR applications have unique and different characteristics from other AR applications:

> With projection AR, interface elements can be projected directly onto the real world in registration with it. While it is also possible to create the appearance of interface elements in registrations with the real world in other AR paradigms, there is a more immediate sensation that the interface element is actually a part of the real world in projected environments. (Craig, 2013, p. 202)

The development of augmented reality interfaces led to the overlay of the real world and physical space with the virtual image space in three dimensions, and this has become a fundamental area of development and research of virtual environments and augmented reality.

Projection mapping, also referred to 3D video mapping, is a recent term that gained more popular acceptance and usage than the academic name “spatial augmented reality” (SAR) or “projection-based augmentation,” coined by Raskar in 1998. It is a mixed reality environment where the virtual elements are displayed in the space and mapped within the architecture of the space. Contrary to virtual reality, the observer does not use headsets or any other technical gear for viewing. The visualizations are integrated into the physical environment through the use of digital video projectors or by using built-in flat panel displays (Raskar, Welch, & Fuchs, 1998, p. 1).

For the purpose of this study, we focus on the use of digital projectors that integrate computer-generated graphics directly into the user’s environment. 3D projection mapping, or projector-based augmentation, can be described as the manipulation of three-dimensional digital animation perspective transformed with projection design to match exactly the 3D canvas of objects and buildings in the real world and physical space. It is a technique that uses perspective 3D transformation in projected light in order to turn any surface into a dynamic visual display. It is an extension of virtual reality systems, consisting of physical three-dimensional models that co-exist in the physical and virtual space and which have the same geometric shape and structure/architecture.

This technique has created a new artistic medium in the last decade. One key advantage between 3D video mapping and other displays such as head-mounted displays is the capacity to generate multiple-user experiences in the same environment. In previous years, the access and cost of digital video projectors and motion capture technologies made it possible for a community of engineers, artists, and designers to create software and projection algorithms to experiment with and create interactive and augmented techniques in SAR. The design of immersive spaces with projection-based surround-screen displays, semi-immersive wall-like, cylindrical, or spherical spatial displays helps generate a more immersive experience due to the fact that "spatial displays detach the display technology from the user and integrate it into the environment" (Bimber, 2005, p. 7).

Bimber and Raskar created a comprehensive overview of the general principles and techniques of 3D projection mapping in their book, *Spatial Augmented Reality: Merging Real and Virtual Worlds* (2005). They were two of the pioneers in applying the basic principle of 3D projection mapping by starting with a physical object and then creating a 3D virtual model of the same object. This was achieved by manipulating the object in the 3D software, and by transforming either the lightning, the position, movement, and texture of the surfaces in the virtual space, and then projecting it back to the physical object. This projection and display technique allows for collective experiences of optical illusions and virtual augmentations, taking advantage "from its geometrical features and viewers' perspectives to insert objects, create new spaces or manipulate the real physical one" (Bimber, 2005, p. 214). 3D video mapping has unique qualities to explore and design immersive and interactive virtual environments beyond virtual reality. It allows us to create collective mediated experiences for dance performance art, as it overlays virtual information onto physical environments through projected light.

The Psychology of 3D Projection Mapping as a Visualization Display

Studies have demonstrated that embedded augmented reality information in physical surfaces and spaces produces superior performance in users (Tang, Owen, Biocca, & Mou, 2003). Jung's research compares 3D projection mapping versus 2D projection (similar to the projection used in cinema, video, and television) to understand if projection mapping enhances user experience and cognition. More precisely, the researcher investigates the impact of 3D projection mapping displays versus 2D and examines if the sense of presence and immersion is enhanced, making the experience more memorable and accessible to viewers. The viewer's transformation and perception of space is increased by 25% (Figure 6). Furthermore, the author argues the movement of images into the physical 3D environment increases the accuracy of the viewer's recognition memory by over 230% for pattern location (Jung, Biocca & Leee, 2015, p. 213).

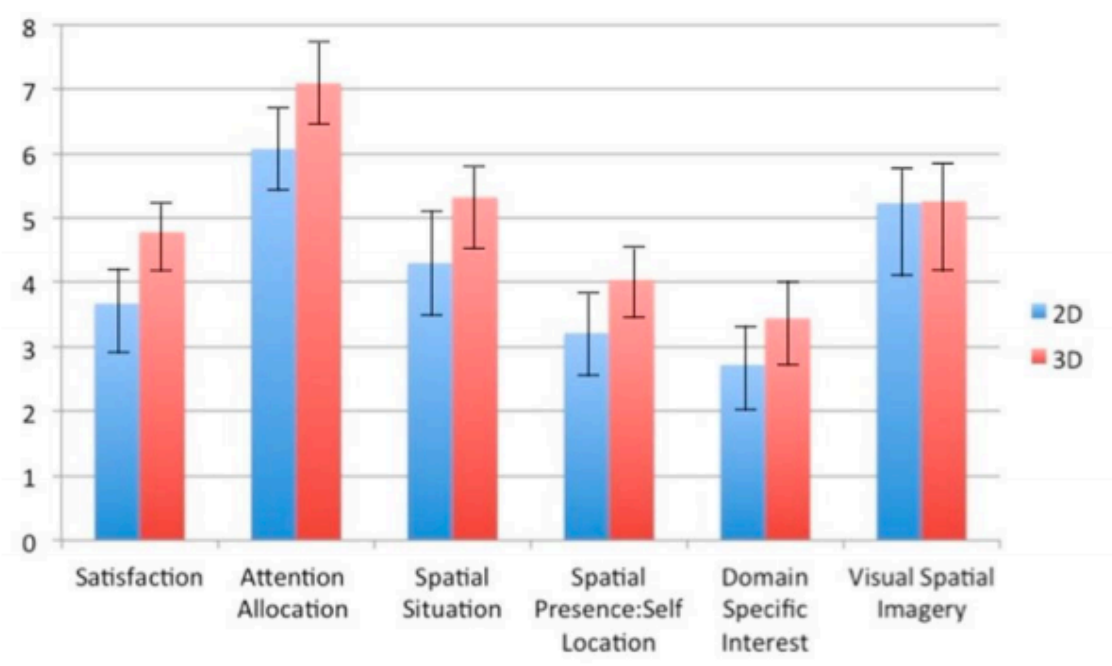

Figure 6: Comparison of the effects of 3D projection mapping (versus 2D projection) on user satisfaction and various sub-dimensions of spatial presence (Jung, 2015).

Jung argues that 3D video mapping provides spatial presence to the viewer "and stronger than that created by the ghostly overlays of some head-mounted augmented reality and hologram technology" (2015, p. 216). Therefore, 3D video mapping is an effective SAR display technique to create an immersive environment beyond headsets and mobile display devices. By superimposing the projected image directly on a physical canvas and on the environment of the users and observers provides an effective solution to generate collective spatial augmentations visualizations.

Projection Mapping and Performative Arts

From a creative and artistic approach, the perception and visualization of 3D projection mapping illusions create a suspension of disbelief effect on the observers. In our case, the dancers and the virtual environments must be simultaneously perceived as part of a conceptual whole for the observers, the audience members. The capacity to make the audience perceive the displayed imagery as real is essential to the appreciation of the art form. The more real and genuine the illusion is, the more immersed the viewers are.

Immersion in augmented reality performance is experienced in digital performance in two different and complementary ways—first, by the active participation of the live performer: the physical interaction between the live performer and the 3D projected environment. Secondly, the audience passively views these interactions between the performer and the 3D environment.

In short, creating spatial augmented strategies for live performance demands the creation of a scenic environment where physical performers and digital information must be simultaneously perceived by the audience as a singular, integrated experience. Vincs et al describes this process in relation to digital dance performance:

> Digital dance performance evokes a kind of hallucination that is predominantly visual to the audience, but invisible to the biological body (the dancer) who is inhabiting that shared space. Without perspective and glasses, the dancer is present physically, temporally and geographically—but she is fundamentally

disengaged from the primary entry point of the "hallucination"—what can be seen (2014, p. 171).

Vincs is highlighting the limitations of using 3D projection mapping for the performers on stage. They are too close from the projection display area and their perception of the illusion is limited. Porter emphasizes the same idea: "the stage and theatrical environment are not primarily user-led environments, in opposition to most computer science applications and research in spatial augmented reality for interactive rapid prototyping" (2010). This visualization hierarchy, in which audiences have the optimal reading, and full experience, is essential to perform SAR in the context of intermedia dance performance as a performative art form. Immersion for the viewers arises from this inseparable whole between the dancers and the virtual elements in one augmented and hybrid environment.

Sensing Bodies and Projection Mapping

The theoretical framework for embodied cognition in SAR in this study is centered on sensing bodies and projector-based augmentations. We separate the tracking process as the input and projection mapping as the output, and view the interface and visual feedback as mediators.

Sensors (input devices) are critical components of augmented reality. They feed real-time information, a process known as "tracking." Spatial augmented reality systems use tracking techniques carried on the user and the environment. Most commonly, the tracking is established through the use of cameras, in particular, depth sensor cameras and infrared sensors such as the Xbox Kinect by Microsoft. Other sensing technologies are, for example, Electroencephalography (EEG), a monitoring method to record electrical activity of the brain introduced in the last project of this study (Chapter 6: *Biomediation*), or galvanic skin response (GSR), also referred to as skin conductance (SC) or electrodermal activity (EDA). In our research we use primarily spatial scanning with a Kinect depth sensor and use brain computer interface (Emotiv) with dance performers.

3D projection mapping (output), as a display, is usually referred to as a form of augmented reality, as it overlays digital information over the physical space (Dalsgaard & Halskov, 2011; Jung et al, 2015).

The performance dance pieces created throughout this research are positioned in three different areas of the mixed reality continuum. Each performance establishes different architectures in input and output signals, virtual and real worlds, and media from the perspective of the audience. In my analysis, mixed reality performance is based in the visualization of the stage by the audience members, as the conceptual “frame” and display to experience and analyze mixed reality performances. To position 3D projection mapping with live performers on the virtual continuum, it is necessary to focus on the correlation of physical space and virtual information in the visual spectrum as an essential condition.

Augmented Virtuality Live Performance

It is not completely clear where projection mapping should be placed in the virtual reality continuum when combined with dance performance. In general, stage interactive performances are referred to as augmented reality performance. I propose that the combination of sensing technologies with 3D projection mapping affects the nature of the augmentation process, as proposed by Milgram (1994), and that it should be defined as augmented virtuality.

Milgram explains this terminology problem:

> That which is being augmented is not some direct representation of a real scene, but rather a virtual world, one that is generated primarily by computer. In keeping with the logic used above in support of the term Augmented Reality, we therefore proffer the straightforward suggestion that such displays be termed “Augmented Virtuality (AV).” (1994, p. 1325)

Simply by applying this logic, I situate *3D [Embodied]* (Chapter 4) and *Luxate [Komorebi]* (Chapter 5) performances as embodied interactions in spatial augmented virtuality (Figure 7). I create augmented virtuality by positioning our primary environment as virtual, similar to a computer game experience, and by juxtaposing it in the real world, through projection mapping, which by itself would be defined as spatial augmented reality. The visual media is primarily designed and programmed to interact with the dancer in the digital space. Only after, it is projected directly onto the performer's environment. By doing this, we are adding human interactions to virtual environments for the audience to experience.

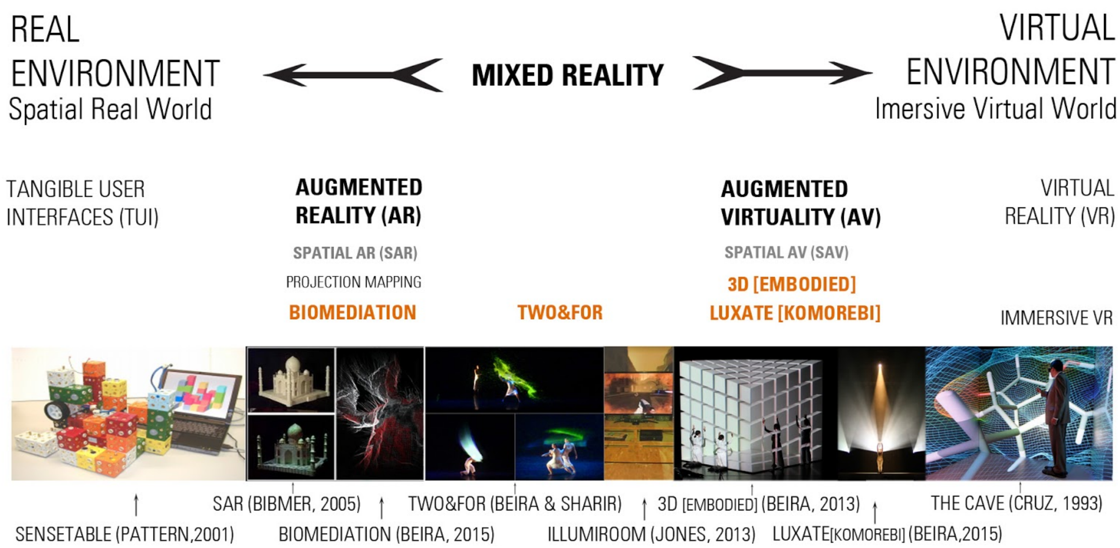

Figure 7: Mixed reality performance within Milgram's "continuum of display" (1994)

Another argument and approach in considering interactive dance performance and projection mapping AV, in opposition to AR, is based on the amount of the projected surface area displayed over the physical space. In projection mapping environments and displays, most of the visible spectrum is covered by projected imagery in order to create an effective illusion. As previously described, virtual reality visualizations generated by HMD or in environments such as CAVE (Cruz-Neira, Sandin, DeFanti, Kenyon & Hart, 1992) cover 100% of the visible spectrum for the user. Augmented reality only adds a small portion of digital information to an observer's field of view, usually ranging from 0 to 20% of digital enhancement. Augmented virtuality creates from 20% digital enhancement right up to 99% ("The Face Race: Virtual Augmented & Mixed Reality Competitor Matrix", n.d.)

Augmented Reality Live Performance

As previously discussed, augmented performance usually refers to interactive systems in live performance, covering to the whole spectrum of mixed reality continuum. For example, Sparacino defined augmented reality performance by addressing the multiple modalities and dimensions of the interactive design as one phenomena, the augmentation: "the augmented performance allows us to operate a semantic transformation of story fragments acted by the mime, through the use of the added computer graphics objects" (1999, p. 42). I propose a more defined description and definition of augmented reality live performance. The description provided by Sparacino, in the context of this study, would be positioned as augmented virtuality performance, because the software digital agent is the primary source of augmentation. Vincs also defines this particular role of augmented reality in dance as a form to transcend the physical limitations of the performer and to expressly add real-time visualizations. He writes, "Augmented reality in the context of digital dance performance is generated from technologies that enable the sharing of embodied experience beyond the limits of the physical presence of a performer" (2014, p. 173).

Augmented reality performance's primary source of augmentation lies in the enhancement of the physical and biological phenomena. The goal is the amplification of reality through sensing technologies. The capacity of the system to digitize the performer and the physical environment expands the qualities of creative association and virtual extension design. The expression modalities are mainly driven from the body as the primary source of communication. The collection of datasets in live performance have been explored in motion capture and by the use of biosensors. *Biomediation* (Chapter 6) is an exercise to make visible to the audience the 3D volumetric scan of the body, which is processed and transformed in real time by the performer using a brain computer interface. The physical body and the stage are digitized in real time by a depth sensor camera, and then are manipulated by tapping directly to the performer's brain activity. The mapping between the mental states and the command sets always uses the input of the depth sensor technology. The design qualities are then based in the intimate and complex relation between the biological body input and the extended virtual environment dynamics. I then classify *Biomediation* as augmented reality performance in our theoretical framework of augmented live performance (Figure 7).

Mixed Reality Live Performance

Mixed reality performance is a network between biological and digital bodies that expresses the interconnectedness of the real and virtual, as well the integration of interactivity and live performance. Benford highlights the relation between the medium and the art: "The nature of mixed reality and of performance is complex and hybrid, involving multiple spaces, shifting roles, and extended time scales, all of which are connected in multiple ways through diverse forms of interfaces" (Benford, 2011, p. 7).

The nature of mixed reality performances covers the center of the virtuality continuum by using both sources of augmentation, virtual and physical.

Chapter 2 of this study, *Two&For*, is an exploratory dance performance in the nature of mixed reality performance, and explores the intersection described by Benford. *Two&For* is an interactive mediated performance without the use of sensing technologies. I process the input and output as a media performer in real time using a touchscreen interface as well as computer generated imagery using generative particle systems. I then situate *Two&For* as mixed reality performance (Figure 7), as the primary input and output changes according my focus of augmentation. At some points, I was augmenting the movements of the dance performers (augmented reality). At some other points, I was creating virtual landscapes environments (augmented virtuality). By acting and performing as an autonomous media system, I investigate the need to design mixed reality performance, and engage in a higher form of interaction and immersion.

CONCLUSION

In the theoretical framework for this dissertation, I define the tracking process as the input and projection mapping as the output. The tracking is created through the use of sensing technologies and the output through projector based augmentations. Together, they provide the structural elements to creatively explore digital dance performance or, as we described it, mixed reality live performance.

By following this more deterministic approach of visualization design for mixed reality performance, the separation between AR and AV is not based on how the world is experienced from the audience's perspective, but rather in how information architecture foundations are created and designed in mixed reality performance. Milgram concludes that this debate "may ultimately weaken the case for use of both *AR* and *AV* terms, but should not affect the validity of the more general *MR* term to cover the 'grey area' in the centre of the virtuality continuum" (1998, p. 1324).

Regardless the hierarchical relationship between virtual and physical worlds, the conceptual affordances of augmented artworks rely on the integration and communication between the multiple sources of the experience. The relation between virtual and real in live performance is often juxtaposed and overlaid, instead of just being opposed to one another, as Benford argues (2011, p. 3). Though, this relation provides a reference point to define in the nature of the performative work within the mixed reality continuum. I believe this contributes to understand the exponential growth of technologies and augmentation architectures in mixed reality performance. It provides a better defined road map to investigate and analyze the nature and artistic expression of augmented and mediated performance art.

Chapter 2: *Too&For*:

An Exploration in Augmenting the Perception of Space and Movement

Too&For is the first multimedia dance performance created in the context of this study. It was featured in the *Catalyst* show, which ran from March 23-25, 2012, at the University of Texas at Austin's B. Iden Payne Theater. It was a collaboration with choreographer Yacov Sharir, musician Tom Lopez, and costume designer Kaitlyn Aylward. The project had six dancers, and I managed projection design and live visuals. The dance performance was organized in four main acts: two solo dance performances, one duet, and one quartet.

This chapter presents a first approach and investigation towards interactive, embodied, projector-based augmentations. *Two&For* is an exploration in augmenting the perception of space and movement using generative visuals with a multi-touch interface. This exploratory research is a hands-on approach in the investigation of improvisational real-time systems to generate augmented 3D visualization of bodies in motion. It combines improvisation for both media and dance performers using a live performance setup.

Figure 8: ***Too & For*** **performance by the author and Yacov Sharir, at the University of Texas at Austin in 2012**

CONCEPT

Two&For explores real-time, generative visualizations between the physical and the virtual agent. More precisely, it focuses on the exercise of augmenting dancers' movements by overlaying digital video and imagery directly on live performers. This creates a hybrid environment that is generated primarily by "digitizing" the dancers' movements into datasets. This is usually referred to in computer sciences and new media art as motion capture (mo-cap), motion tracking, or motion sensing. Mo-cap refers to "the electronic hardware and computer software that makes possible the digital 3-D representation of recorded moving bodies" (DeLahunta, 2001, p. 55).

Two&For investigates the qualities of interactive systems without the use of any motion tracking camera, software or sensing technologies. In this performance, I rely only on my vision to digitize the dancers' motion into datasets in real time. The ability to digitize human movement, especially through wireless and non-invasive interfaces, creates extensions of the human body through sensors, and provides the ability to recognize and track the surrounding environments. Such systems applied to performance art maximize the interactions between the performer and the system. The digitization process that transforms the dancer's body into programmable units reflects the essence of the body as an interface on its own. The capacity to establish dynamic architecture between the body and the media creates the foundations of digital dance performance. It creates new directions in dance performance involving technology, rather than restricting or leading to a disembodied spectacle.

However, it can be argued that such systems should go beyond the linearity of automated movement capture. Some authors and artists have a critical opinion of capturing movement data with sensing technologies in the context of performance, arguing that detailed interpretation of movement of the human body should include information that is less quantifiable than automated data. Povall explains this method of using emotion to produce interactive art:

> I have rejected the more common methodologies of moving further and further towards a literal, accurate, detailed interpretation of the physical body, and instead use speed, direction, acceleration, and size of moving objects to gain an approximation of the kind of movement that is occurring in the performance space. Although I am able to sense an object's position in space, I rarely use this data, usually considering it irrelevant or unnecessary. Instead, I am looking instead (*sic*) for information from the movement that tells me how, and therefore possibly why the performer is moving. I am searching as much for the emotional intentionality of the movement as I am attempting to map the actual, literal physical movement. (2000, p. 64)

In other words, Povall believes that tracking physical bodies with sensors can be too "literal" and misses the larger picture of emotionality. However, this is exactly the concept we are grasping by performing with this system and setup: to experience artistic forms of expression beyond the physical movement and the linearity of time. In fact, motion capture has been described as an "unfortunate" term by several authors (Kozel, 2008; deGraf & Emre, 1999) because it implies that the motion is contained once it is captured. Kozel describes this medium as "a sophisticated and poetic slice of human-computer-interaction" and says that this is about "flow, patterns, and shapes of movement, about the way life can be breathed into that which seemed inanimate" (2008, p. 220).

Two&For investigates these patterns and flow by executing real-time feedback directly from the dancer's performance. Conceptually, I am augmenting and enhancing the performers' movements. By doing this, I am also investigating the artistic qualities of this medium and technique. The artistic considerations in the live interactions with live performers, beyond just automation, have been also synthesized by Wechsler:

> Thus it is that we must think of interaction primarily as a psychological phenomenon, rather than a technical one. One certainly doesn't need cameras and computers to be interactive. Interactivity is simply the instinctive back and forth of energy which occurs when animals come together to speak, gesture, touch or, in the case of humans, create art. (2006, p. 64)

In this project, my goal was to research the artistic application of improvisational interactive environments and investigate interactive computer-generated imagery as extended agent and choreographic partner for the dancers. By adopting commercial and off-the-shelf technologies, I explore the potential to use them at a higher level of expression. This synergy and creative interaction beyond automation that occurs between the physical and the virtual, and thereby between dance performance and visual art, provides the conceptual framework for this exploratory research and performance.

CONTEXT

> Dance has always used the ultimate technology – the human body – to create magic through movement (De Spain, 2000, p. 2).

Dance as a manifestation and expression of emotions has been practiced and ritualized in various cultures since the beginning of mankind. The practice, aesthetics and intentions are vast. My initial focus and analysis goes towards the understanding of dance as a fundamental part of human behavior, communication, and expression. Venera Anker defines dance as “an expression of emotions, mostly engaged spontaneously and therefore appearing as an inherent, if not primal, instinct.” In order to understand dance as a creative process, the author also raises a fundamental question: “What exactly makes dance an art?” In his analysis, what distinguishes dance from other activities that focus on the beauty of physical movement, such as sports, is the message that the performers transmit to the audience. This message can be communicated by different means, but the intention is central to the creative process (2008, p. 11).

Choreographer Jacqueline Smith-Autard defines dance as the composition of three elements manifested through the creator's intentions: “To transform a vocabulary of movement into meaningful visual images, the composer is dealing with three tangible elements: movement, time and space” (2005, p. 17). These three tangible elements represent the attraction to experience alternative and parallel worlds, places that don't need to fulfill the same roles and functions as the real. Physics and logic can be manipulated, reverted, and transformed. The ability of creative expression through this medium extended the practice and the understanding of dance as an art form. The practice of dance has been associated with music along with visual elements such as sets, props, costumes, sculpture, architecture, and lightning to transform and enhance the body moving in space. It is and has been a collective effort and process generated by the integration of various experimental art forms, such as the work of Loie Fuller (Figure 9.). To create art is to discover meanings that connect artists and audiences. This shared meaning in dance is extended by several technologies. Authors such as Steve Dixon and Johannes Birringer, experts in new media performance, describe dance as, similar to theater, an interdisciplinary and "multimedia" art form (Dixon, 2007, p. 39; Birringer, 2002, p. 87).

Figure 9: Loie Fuller's dance *Serpentine* (1891)[1]

[1] *Serpentine* was recorded by filmmakers Auguste and Louis Lumière (1896), and became famous in America. Fuller's work reveals a search and practice focused on the augmentation of motion through the perception of light and allows the naked eye to embrace more complex dynamics of human motion by combining fabric with light design.

Computation and Dance Performance

One of the earliest pioneers in exploring this convergence between computers and choreography and dance was the engineer Michael Noll. In 1961, he began work as a researcher with Bell Labs and started to explore computational aesthetics and three-dimensional computer graphics. In 1965, he created one of the earliest computer graphic art and digital animations of stick figures on a stage, entitled *Computer-Generated Ballet*. The first article connecting computing with dance performance directly was written by Noll in 1967 for *Dance Magazine*. In this visionary article, he stakes a claim for the artistic potential of choreographic notation and the ability of computers to analyze motion within 3D environments. Noll envisioned what became the computer graphics technology available in the last decades. He revealed a new creative process and framework that later generated the foundations of digital dance performance.

Coming from a dance performance background, instead of the pure computer science field of people such as Noll, choreographer Merce Cunningham was one of the first to incorporate computers in his study of movement. Cunningham was one of the most famous American choreographers and dancers, and he devoted himself to the exploration and manifestation of pure movement. Cunningham modernized dance performance, in particular, the influence of technology in his choreography. One of his innovations lay in how he separated music and dance into two clearly distinguished elements, a project he worked on with John Cage. They both used unconventional methods for composition, such as randomness. Cunningham also explored film collage and the editing process, through video recordings of dance. This experience was crucial to the body of artistic work and research he developed some years afterwards with computers.

Motion Tracking and Dance Performance

Although the introduction of digital media platforms to dance practice can be traced back to the experiments conducted in the 1960s as well as ambitious and visionary analysis of how dance could expand and be augmented, it was only in the beginning of the 21st century that this area became a distinct artistic genre. The creation of collaborative networks between the cultural/artistic and the academic world created a collaborative platform of knowledge equipped with machine ensembles, hardware, and engineering departments that collaborated with artist-researchers to examine and extend the field.

Dance has also been one of the most challenging and complex forms to be integrated and transformed by computers. DeLahunta describes the convergence between dance performance and computer technology as "periodic" or "episodic," mostly developed by pioneer engineers and artists that prototyped concepts and visions that only in the last decades became possible to achieve. DeLahunta summarizes the limitations of a long tradition in live performance to be incorporated with new technologies: "Computer-related technologies have not attained the level of integration within the field of dance as other art forms for the obvious reasons that as a material the body in motion does not lend itself to digitation" (2002, p. 66). The body is a complex organism to digitize and the access of artists and dancers to motion tracking technology was scarce. Until the 1990s, the implementation of custom and original interactive software and hardware systems by dance artists was summarized by Dixon as somewhat "fragmentary and individual" (2007, p. 206). The high cost and complexity of systems such as Vicon were not used in real-time performance settings. Cunningham pioneered capturing the human body in motion and its expressive artistic qualities in the virtual space in collaborative work and process alongside computer scientists and digital artists Paul Kaiser and Shelley Eshkar.

LifeForms was the first software designed to address the need to digitally codify and embody the language of dance. Schiphorst, a programmer with a background in dance, and a member of the original LifeForms software design team, collaborated with Cunningham. She describes the software as "an idea generator":

> It lets you see even very complex movements as many times as you want from different perspectives. It's hard to ask a dancer to do a strenuous leap 17 times just to get new ideas. LifeForms lets you see movement through 3-D. (Schibsted, 1996)

LifeForms for the first time provided stylized animated characters for choreographers to pre-visualize, annotate, and digitally record in motion. It visualized automated poses and animated dance. Schiphorst, a member of Simon Fraser University, worked directly with

Cunningham and tutored him in the use of LifeForms to support the creation of digital movement (1993).

In 1997, Kaiser and Eshkar invited Cunningham to collaborate in a virtual dance installation entitled *Hand Drawn Spaces*. The custom-made software was called Biped and it was presented a few years earlier at the international conference and graphics trade show SIGGRAPH98. Cunningham choreographed and motion captured 71 short phrases, labeled the "motion alphabet." The animation mapped onto this data and movement was given the appearance of hand-drawn figures. Eshkar created sets of five drawn figures to represent Cunningham's movements and Kaiser used Character Studio figure animation (a commercial version of Biped) to compose the movement sequences in virtual space (Spain & Kaiser, 2000) (Figure 10). The creative process joined the motion-captured data with the recorded phrases. This was accomplished with the help of animation software developed for the project titled "the motion flow editor" (Anker, 2008, p. 67).

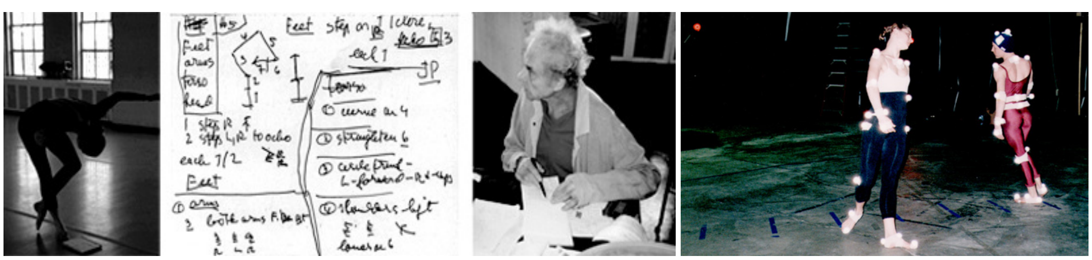

Figure 10: Left: Notes from the "motion alphabet" created for *Hand Drawn Spaces*, 1998; Right: Optical motion capture using infrared-reflecting sensors at the Biovision studio in San Francisco, 1998, for *Hand Drawn Spaces*

In 1999, Kaiser and Eshkar partnered with dancer and choreographer Bill T. Jones to create the digital animated film *Ghostcatching,* a piece that merged dance with drawing and computer animation (Figure 11). *Ghostcatching* was created using optical motion tracking techniques with video cameras for 3D movements of 24 sensors in Jones's body. Kaiser and Eshkar later manipulated the data in post-production, generating what Dixon describes as “genuinely new aesthetic phenomena.” (2007, p. 194) The digital animation was shown at the Cannes Film Festival. This series of collaborations between this collective of artists and developers gave birth to *Biped*, a full-length dance performance collaboration between the choreographer Merce Cunningham, Kaiser, and Eshkar in 1999. The previous projects *Ghostcatching* and *Hand Drawn Spaces* generated the foundations at a technical and conceptual level to give birth to one of the most iconic digital dance performances using motion tracking, dance, and visual arts in the generation of digital choreography. *Biped* juxtaposes video projections with live dance in the same environment through the use of a translucent scrim located in front of the performers. It transforms the perception of space from the perspective of the audience into a unified light field of movement between the digital and the physical. *Biped* is an exploration of the possibilities of animation technology and motion capture. The dancer’s movements were recorded and converted into abstract shapes and figures consisting of several lines that represent the body forms and joints. The programming of the stick figures was created by Kaiser and Eshkar as an extension of the work developed previously in *Hand Drawn Spaces*. These figures were animated with human movement captured from the dancers as digitized bodies in order to be subject to transformation. The sequences of the animations were numerically altered, taking advantage of the possibilities of digital environments to explore movement and dance beyond the physical body.

Cunningham's work and knowledge in dance combined with notation animation software and 3D motion tracking technologies, created the framework for developing the digital choreography and projection design in *Biped*. The piece merges virtual, pre-rendered animations of the dancers with the physical body in the live performance. These figures were projected in a translucent gloss and overlaid onto the dance performer. This particular technique for video projections allows the integration of the media content with the dance performer in the same space. This creates an intrinsic dialogue between them and represents a key point in how media and video design became integrated with dance performance (Figure 11).

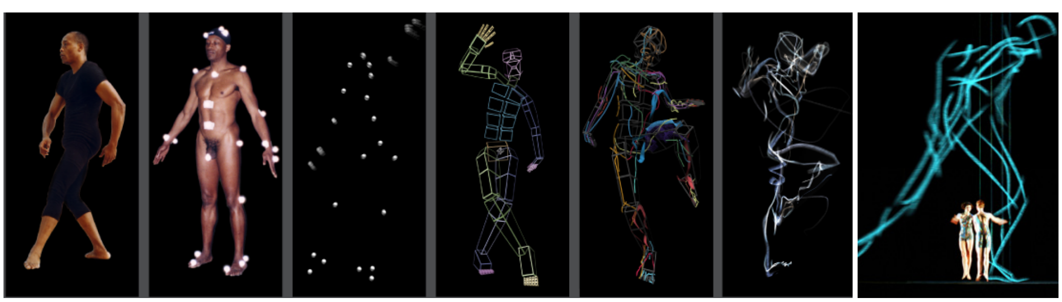

Figure 11: Left: Seven stages in the transformation of Bill T. Jones from motion capture to abstract animation as the virtual dancer in *Ghostcatching* (1999);
Right: *Biped*, 1999, by Eshkar and Kaiser, juxtaposes the abstract body shapes from the *Hand Drawn Spaces* film on the dance performers through the use of a scrim.

Computer Generated Imagery and Live Dance Performance

The use of computer vision software using lower-cost video cameras gave access to this technology to a wide range of users in the performing arts. A series of creative tools for interaction design were created using the body as an interface using real-time Open Graphics Library (OpenGL). Some dance companies that focused mainly on the artistic exploration of motion tracking and real-time visualization systems in the 1990s include Ventura Dance Company, Palindrome, and Troika Ranch.

Media artist and programmer Mark Coniglio, along with Dawn Stoppiello, founded the multi-media company Troika Ranch in 1993. Troika Ranch is a performance collective that integrates interactive real-time systems. Coniglio created most of the software for their shows. He combined the functionalities of different software into one unique application that is simple enough for non-programmers to use. Isadora was one of the first software applications created and intended for use for interactive installation and live performance. Early in 1989, Coniglio developed the group's movement-sensing wearable hardware, MidiDancer. The system sends wireless MIDI signals from the dancer's joints to the computer through the use of a wearable single-chip computer. Via the MidiDancer's sensors, the encoded information of performer movements is sent to another computer, enabling control of the music and video projections' dynamics and behavior. Isadora also provided custom-made plug-ins that provide a multitude of video processing on the fly with intuitive interfaces for the user. In 1994, the group produced the dance *In Plane*, using bending sensors in the joints of the dancers and using the

MidiDancer system to allow the performer to control the generation of music and trigger the video signal. The piece explores a direct dialogue between the dancers and their video image representation, which is projected at the same time.

MidiDancer revealed the technical and creative strategies within interactive media and dance performance, but there were still technological limitations to generating interactive live visuals. Only a decade later the level of integration and juxtaposition between computer generated imagery and motion tracking achieved higher forms of expression.

Figure 12: *In Plane* (1994) by Troika Ranch used the MidiDancer sensing system.

Klaus Obermaier's work revolutionized the relationship between the moving body and augmented architectures in dance performance, generating a fundamental reference in the artistic expression of augmented dance performance. *Apparition*, presented in 2004 at the Ars Electronica by Klaus Obermaier added a new layer to Obermaier's previous works, such as *D.A.V.E* and *vivisector*, through the creation and implementation of interactive technology with projector-based augmentations. Using motion detection by computer vision without wearing sensors and transmitters on the body, *Apparition* allowed performers to move freely and improvise on stage. The usage of natural interfaces created no restriction of movement besides the predefined interactive zone for the dance performers (Figure 13). Obermaier describes the theme of *Apparition* as interactivity itself. The author addresses fundamental dimensions in interactive design transcending the one-dimensional triggering, or controlling, approach to interactivity. Deactivating hierarchies creates understanding between the performer and the interactive partner as equal partners:

> The goal is to achieve the same quality between two or more human performers. To reach that level it requires a highly sophisticated technical setup and programming and the flexibility of real-time generated content. By analysis and interpretation of specific dance parameters -such as volume, direction, intensity of motion, velocity, approximation, etc. - the acquired data influences, simulates and changes the digital, real time-generated content, which again retroacts by its modified behavior to the performer. (2008, p. 260)

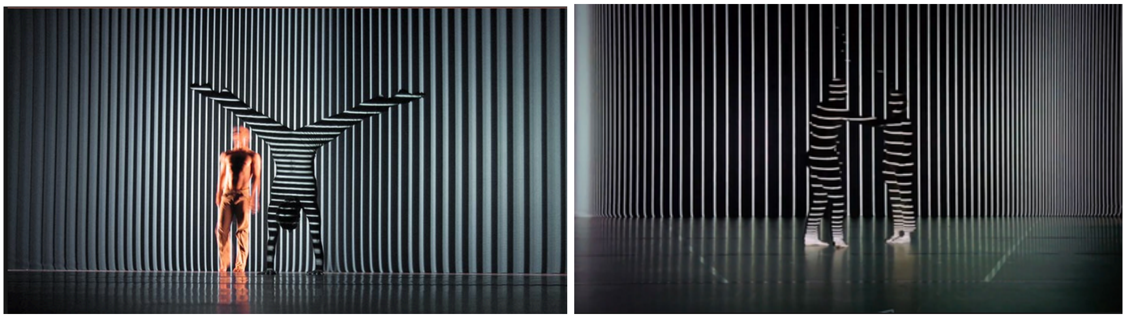

Figure 13: ***Apparition*** **by Klaus Obermaier, was presented in 2004 at the Ars Electronica.**

O'Dwyer, in his critical analysis of *Apparition* by Klaus Obermaier, elevates the computer to the status of "symbiotic performance partner." This symbiotic character of the digital performance system is also described by the author as a new storytelling paradigm and a genre that is specific to art (2015, p. 36). On his website, Obermaier raises this question, and makes an important point regarding the conceptual approach of *Apparition* in media design: "What choreography emerges when software is your partner?" *Apparition* has a particular relevance in mixed reality performance and the historic integration of motion tracking technologies with projection mapping and choreography. In particular, it focuses on the transition between the virtual space to reality, and vice versa. With interactive technology and motion tracking systems, such as Klaus Obermaier's *Apparition*, a new layer in the relationship between the live media and dance performers is established. The integration of real time and motion tracking-based interactive technologies used in *Apparition* reached a level of maturity and development that represents a real challenge to the hierarchy of perceptual importance. Gunduz argues that this specific integration of interactive digital communication process in dance cannot simply be seen as an extension of the commonly accepted role of technology as assistants for the dance as film and video playback technologies (2011). Instead, interactive digital technologies have a more fundamental role in dance practice in which they are not mere technical assistants, but performers in their own right. Downie describes this relation as an extended agent (2005) and Obermaier defined software as “a dance partner” (2008).

In 2005, Paul Kaiser, Shelley Eshkar, Michael Girard, Trisha Brown and Bill T. Jones created the dance performance *Motion-e*. Fifty markers were distributed across four dancers captured by 16 infrared motion capture cameras, and instead of creating standard skeletal models recreating human anatomy, the datasets were treated as “raw marker data, just points in 2D space that were sampled at 100 times per second. The raw data was then parsed to decipher patterns” (David, 2005). Such strategies illustrate a more abstract approach to motion tracking as a medium of its own in order to establish new ways of communicating and augmenting dance. The collection of data and the visual metamorphosis give *Motion-e* an important role in history, establishing abstract connections between human movement and data visualization.

Another company that explored real-time visualizations with motion tracking was Chunky Move, an Australian contemporary dance company from Southbank, Victoria. Founded by artistic director Gideon Obarzanek in 1995 and led by choreographer Anouk van Dijk, Chunky Move pioneered the use of interactive media in digital dance performance by the interactive software creator Frieder Weiss. In 2006 the group created *Glow*, a sophisticated video tracking system with Weiss's interactive system design.

Gideon Obarzanek, the choreographer/co-creator, creates a piece that consists of a 30-minute dance solo performance on the ground with a single video projector in the ceiling. It is projected directly from the top to the floor, using real-time generated graphics to work with the movement of the dancer. Using an infrared video camera to communicate with the computer, the motion-tracking device runs Weiss's custom made software Calisto. From this data, the computer creates and develops algorithms that respond to the performers movements. The live response of reactive light is probably the most interesting aspect and challenge in Chunky Move's work. In 2008, the group presented *Mortal Engine*, an interactive dance piece that also incorporates projector augmentations. The point at in which sound meets visuals and the performer, the graphical display, is activated by this input. This gave the show a visionary and augmented poetic approach to contemporary dance performance.

Both performances represent an important milestone in the introduction of computer vision for motion tracking through infrared video cameras. Using the video projector as the only light source for the most part of the show, infrared signal allowed Frieder Weiss to feed data directly to the system even in total darkness. The integration of the dancer with the projection imagery blends in one reactive augmented environment.

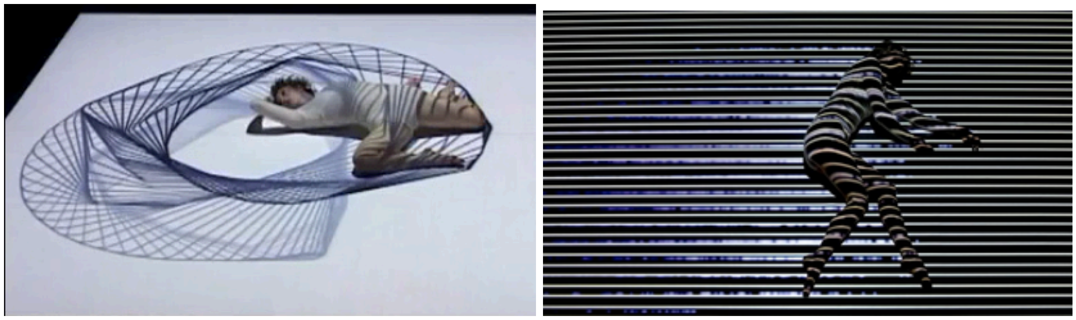

Figure 14: Left: ***Glow*** **by Chunky Move (2006);**
Right: ***Mortal Engine*** **by Chunky Move (2008)**

Informed by the work of the early artists and scholars who merged computer technology with dance performance, *Two&For* follows in the same vein, seeking to explore the ways the interactive and real-time visual medium can enhance the exploration of movement, time and space, through increased immersion founded on digital augmentation of the “real” and vice versa. Ultimately, the project seeks to understand the needs to design interactive environments for sensing the performer's body through generative computer imagery.

TECHNICAL DESCRIPTION

Multi-Touch Interface [Input]

The technology used for the exploratory research in *Too&For* had to provide a quick and instantaneous source of interactive visual graphics—more precisely, an interface able to generate live 3D visualizations beyond the automation and limitations of buttons of controllers. I started by experimenting with a Wacom tablet and digital pen to draw in real time, but due to the presence of multiple performers on stage moving in different directions and at different speeds, I realized the potential of multi-touch for this kind of motion tracking. The use of multi-touch refers to the ability of a touch-sensing surface, in this case a touch screen, to recognize the presence of two or more points of contact. With this technology, I could follow multiple dancers on stage and engage better with the notion of space both between them and within them.

In order to choose and control particle systems with multiple performers and commands, I migrated to using multi-touch interfaces. Multi-touch interfaces have unique qualities for live manipulation and expressive control. They have been widely used for musical performances, but they also bring exciting new possibilities for live animation and drawing. The relationship of the media performer with the interface is highly intuitive and expressive, and it allows the performer to establish personalized sequences, modes of interaction, and visual displays. As these technologies expand and become more sensitive in the ways they respond to our fingers and gestures, they become a more precise medium of expression and representation. This allows a higher level of interaction for the user, and a tactile extension of the physical body to manifest rhythm and overall expression.

The intrinsic operational simplicity of multi-touch interfaces provides a dynamic and intuitive medium to interact with the performers. It engages the stage performers and the visual performer—myself—in simultaneous interaction and dialogue, through the use of a multi-touch tracking particle engine interface.[2]

Touchscreen technology provides a direct manipulation type of gesture-based interface. Such interfaces provide a different opportunity for manipulation by allowing the user to interact with 10 fingers directly within the interface. It is a more intuitive and natural form to interact with and express motion and rhythm—in particular, to manifest and represent the perception of depth through movement in a hybrid environment.

Software

Through the use of tactile-based commands, I was able to interact and generate 3D particle systems in real time, which are based on large number of very small sprites 3D models. To develop real-time live animation and track the performers, I selected a series of applications based on kinetic multi-touch particle visualizing systems on the iPad, a multi-touch device. Such systems and applications can be described as dynamic generative particle systems; they allow the user to customize and program the interface.

The application Uzu (Figure 15) was the main tool used for the live animation through the development of multiple sequences of settings and modes. It was used for the duet and quartet. The main feature of this application for this specific project is the wide range of customization available to the user. Thus, it is possible to create from scratch a

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[2] Particle systems are graphic objects constituted by a large number of very small sprites and 3D models to simulate complex and chaotic rendering techniques that usually occur in nature, such as natural phenomena and chemical reactions.

high level of detail related to the generation of particles, such as speed, color, gravity, and more. Also, the mapping of the number of taps on the monitor associated with specific functions had a major role in the technical development of the live animation design process. Defining and designing each individual action in response to the touch of one or multiple fingers was fundamental for the creation of a personalized interface and setup. It also allowed the user to activate the second monitor output, and use the main monitor as an interface—the front end—for live customization. This way, it was possible to control several parameters in real time from different modes designed for different moments of the performance. For example, the settings used for the duet, in which the visibility and engagement of the live animation surrounded the performers in a 3D environment, were possible because of an extensive use of these specifications.

For the first solo, I used the application Gravilux, and for the second solo, I used the application Trippin II. Both of them are also kinetic multi-touch particle visualizers with different levels of customization and design of the particle generator display and gesture interface.

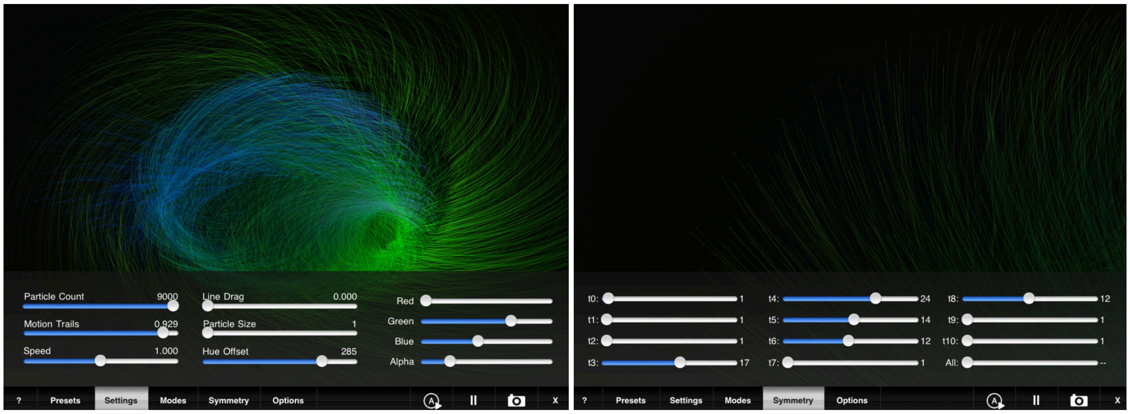

Figure 15: Uzu Particle System Generator interface and settings (back end interface)

Projection Design [Output]

The layout strategy for video projection was inspired by the piece *Biped*, a full-length dance performance collaboration between Cunningham and installation artists Paul Kaiser and Shelley Eshkar in 1999. *Biped* juxtaposed video projections with live dance in the same environment through the use of a translucent type of screen, known as a scrim, located in front of the performers. It transforms the perception of space from the audience's perspective into a unified light field of movement between the digital and the physical. It allows the integration of the media content with the dance performer in the same space, and reinforces the intrinsic dialogue between them.

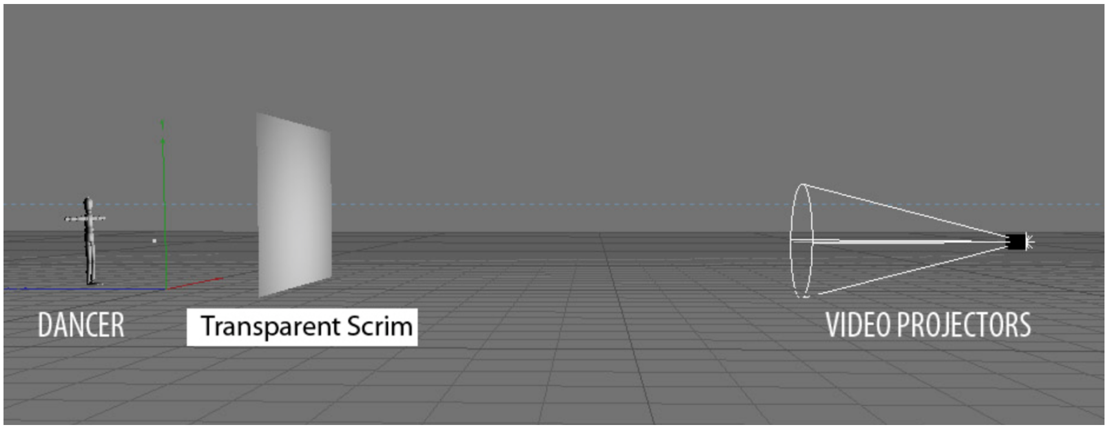

Figure 16: ***Too&For*** **projection design setup (side view)**

Scrims have been widely used in theater displays since then to integrate virtual and projected content with performers directly on the performance space without the use of background screens. The scrim is a piece of gauze cloth that has an opaque appearance and is used as a screen or backdrop. As the light travels through the gauze, it creates a large semi-immersive display overlaid with the performer's body. The scrim creates the illusion of holography by combining physical and virtual agents in one mixed environment. Sharir highlights the creation of this mixed reality display experience for the audience: “Together, the dancers and projections generated in real time created a colorful visualization and boundless energy that gave way to a world of virtual existence and the emergence of a hyper-real world” (2013, p. 171).

Conceptually, this allows us to explore depth and the perception of projected light on stage as one hybrid and interactive environment. From the perspective of the audience, the virtual content and the dance performer can interact and communicate in real time in this mixed reality, performative space (Figure 16).

THE PROCESS

The key element required to create successful dance performance and computer graphic projects is collaboration, as they by nature have different life cycles of production and development. In this case, though, both disciplines were combined and articulated in one workflow: the rehearsal. The collaborative and communication process in studio provided an essential workflow for both dancers and media designers, allowing it to evolve quickly and to develop improvisational expression based in practice and training.

Rehearsals

After the first few meetings with the choreographer Sharir and the dancers, it was established that the animations would be generated live using a manual approach to motion tracking. These abstract digital animations would be projected onto an almost transparent screen covering the dancers. The particles, which took the appearance of moving swaths of light, would interact with the dancers' movements according to my improvised choice of expression during the show.

The first part of the process was following the choreography dance design with the dancers in rehearsal. By understanding their movements and patterns, I started to explore different generative systems for "live drawing" or "live animation," translating dance movements into physical movements with my hands by using multi-touch interfaces. I was looking for something that could translate my interpretations of the dancers' movements and rhythms into a 3D visual representation. This required me to observe the dance design and very closely analyze the choreography. Like the dancers and the choreographer, I attended eight rehearsals and became familiar with every motion of the dancers. I also used video documentation of the rehearsals to practice and study their movements.

In order to come up with an effective strategy for the different configurations of the performers on stage during different moments of the dance, it was necessary to program different modes for the 3D particle generation. For each of the acts, a different strategy was defined. This meant using different software, aesthetics, rhythm, and screens. Through the use of those video recordings, I began to explore live drawing directly with my fingers over the touchpad surface. This was accomplished by adjusting the parameters and requirements of the particle emitters.

The last week before the show, the rehearsals moved to the final performance site, the Payne Theater. One of the challenges in the transition and migration from the rehearsal space to the theater is the difference of dimensions. The scale of the theater stage and the body of the performer is different from what we could simulate in the studio. Some ideas and visual strategies were rethought, and new plans were defined during the days leading up to the first show on the actual stage.

Performance

Generating all the media in real time and interacting directly with the dancers allowed this performance to place a special emphasis on the meaning of liveness in the context of media arts. The experimental and collaborative role of the media was also extended by my physical actions during the show, as a part of the performance. Sharir describes my role as a media performer as a form of dance and choreographed patterns of motion, and also as a performative agent beyond the stage:

> While the onstage projections reflected the product of Beira's labor, he sat in the theatre among the audience, and those near him could see the screen of his iPad as he manipulated and switched between programs. Indeed, all actions were transparent, performative in nature, and made available (as an added instrument) to the benefit of the overall visual output. As we privileged live performance inclusive of all collaborators, we sought to foster awareness of the creative/creation process by demonstrating what it meant to be a member of the performative team. Like the dancers and myself, Joao Beira attended most rehearsals, studied the choreographic patterns, video taped the process, and was familiar with every move of the dancers. Thus, he did far more than execute visual and audio cues – he was the real time sound and animation performer. (2013, p. 170)

This is an important transition from the traditional role of media and projection designers in dance performance. Traditionally, media designers and projectionists are removed from live performance settings and display, but in this case there was interaction and communication between the performers, dancers and media designers. The audience was able to experience this dialogue and synergy.

The interactions generated between me and the dancers were created spontaneously, under the creative direction of the choreographer. This relationship between the virtual environment and the physical body was manifested sometimes in pure synchronicity, but at other times asynchronous, in order to subvert the logic of reactive and automated systems. During performances, the dancers' movements and live visuals operated in sync and harmony, as a direct cause and effect enacted by the dancers and the particle systems. At other moments, the relation between them was purposefully executed in a subversive and random way.

The solo section was a direct dialogue between a single dancer and msyelf. I focused mostly on the amplification of movement and emotion from the dancer through strong and expressive movements. It can be described as a more flat and two-dimensional experience for the audience, but with an interwoven relationship between the moving body and the virtual agent (Figure 17).

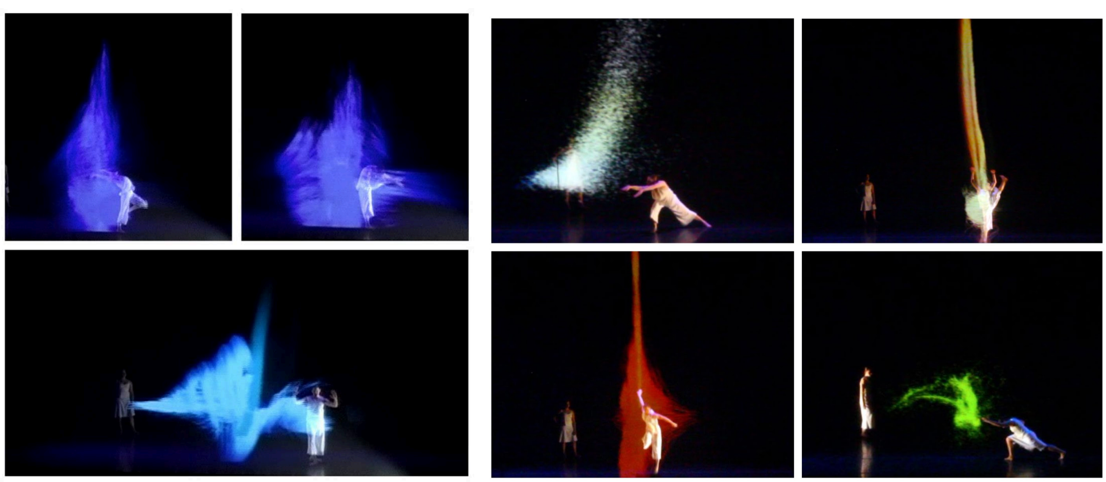

Figure 17: *Two&For* - Solo. Projections were overlaid directly on the performer's body to create one hybrid environment for the audience. This performance was held at the University of Texas at Austin in 2012.

The duet section choreography was focused on the relationship between the dancers and the space between them. It guided and inspired me to naturally control the particles in an organic dance, similar to the movement of a flock of birds. The perception of unity between the dancers and the virtual agent became clear, and I felt that the qualities highlighted previously by Wechsler (2006) came through. The relationship between the input (motion tracking) and the output (the visualizations) established cohesive mapping and a natural flow. I truly felt the performative character of dancing through visual imagery generation. Improvisation came through as I was able to master and control the virtual agent as an extension of the dance performers (Figure 17). Sharir concludes: "Dancing and interaction with the technology became a single, integrated whole and an augmented artistic experience. The imagery and artistry were initiated by the dancing bodies, which were, at opportune times, also the instigators of the particle visualizer" (2013, p. 180).

Figure 18: Duet from the *Too&For* performance at the University of Texas at Austin in 2012

PERFORMANCE ANALYSIS AND CONCLUSIONS

Two&For uses performance as research and investigates the artistic qualities in generative systems to sense and interact with live performers. The collaborative process between the dancers, the choreographer and myself—the media performer—created an instrument of augmentation without the use of any sensing technology. This was possible because of the rehearsal process and routines established between the live media and the dancers' improvisation. Overlayed in the same frame, virtual and physical coexisted in one dynamic and hybrid environment.

The key element in this mediated process came from the properties of the interface and technology adopted. By adopting commercial and off-the-shelf touchscreen applications to generate interactive, generative computer imagery, I focus on the artistic exploration of these tools and technologies for real-time performance. Touchscreen technology provided a gesture and haptic-based interface that gave me a higher level of control to manifest and express myself through visual patterns. The technology provided a more intuitive and natural form to interact with the dancers. The expressive qualities of this particular interface for the media designer are highly interactive and expressive. The improvisational and organic communication process between the physical and the virtual agent transcended the linearity of automated systems. There was no automation to digitize the dancers' movement and performance beside my own perception. It was an open dialogue between the dancers and myself. The performance evolves with practice—just like the skills gained from the practice and interaction with a musical instrument. In some particular ways, I embraced the process just as the dance performers do: using my hands, senses, memory, and rhythm to fully engage as a performer. By incorporating myself in the role of technology sensing acquisition of data, I challenged the principles of what designers can do with the technology instead of what the technology can do for us and for the performance. By doing so, the creative decisions and improvisational flow with the system is similar to playing a music instrument. We have to master the instrument itself in order to generate meaningful results and performance. I believe that such a system allowed me, as a performer, to establish meaningful interactions with the dancers and, ultimately, with the audience. Those interactions created augmented forms of expression connecting the dancers with the virtual agent in one hyperreality that I classify in this study as mixed reality performance. The primary source of augmentation changed according to my focus of representation and observation, either from the dancer or the live visuals.

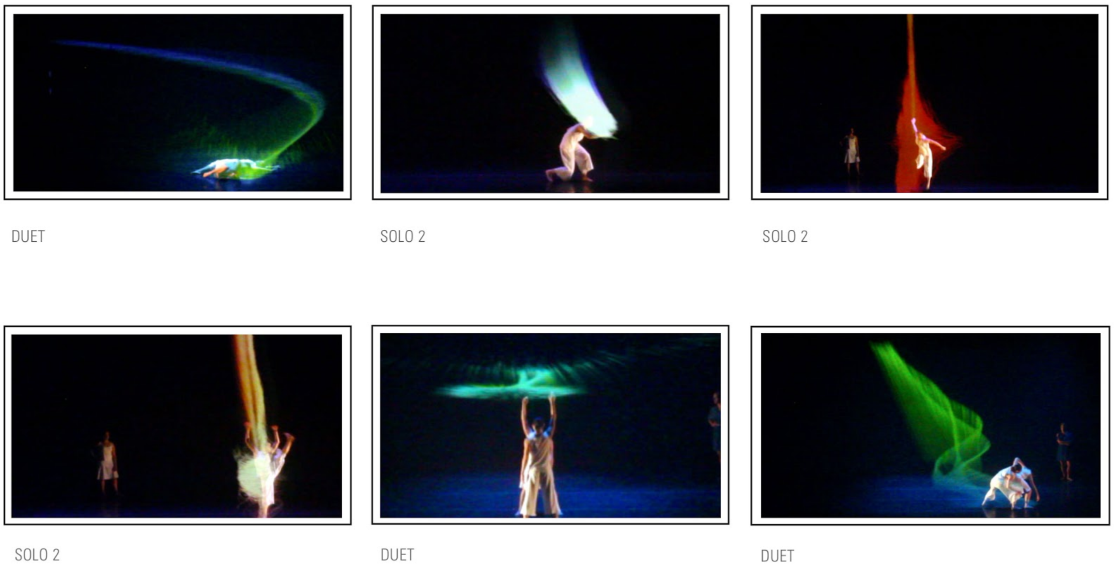

Figure 19: Additional stills from *Two&For* performance

Two&For created emotional and intuitive emotional feedback loops between dancers and the live visual, mediated by the touch-based interface. While there are several advantages towards the use of multi-touch interfaces to generate live visuals with dance performers, I also felt that most of my focus and processing capacity was being consumed. Dictating and generating all the commands in real time takes a high level of concentration and a large processing capacity. The human error involved in the organic process of rehearsal is perhaps one of the most interesting features of the interactive design of *Too&For*. But, just like when you play an instrument on stage without the use of automation, it leaves little to no space to explore mediated forms of creative and augmented expression.

As a media performer and projection designer, I needed to be able to automate the motion tracking to a certain degree in order to add new layers to the augmentation process in real time. This created the motivation to create and explore sensing technologies to incorporate into performances. Super Mirror, the following chapter and the second project created in this study, will reveal the ability of computer vision systems to provide data sets of skeleton tracking for live performance. The ability to combine the artistic and organic qualities of tracking and sensing bodies in movement acquired in *Two&For* is a major contribution of this exploratory research study. It provided a deeper understanding of the qualities of interactive and generative embodied design.

Chapter 3: Super Mirror:

A Gesture-Based Interface for Ballet Dancers

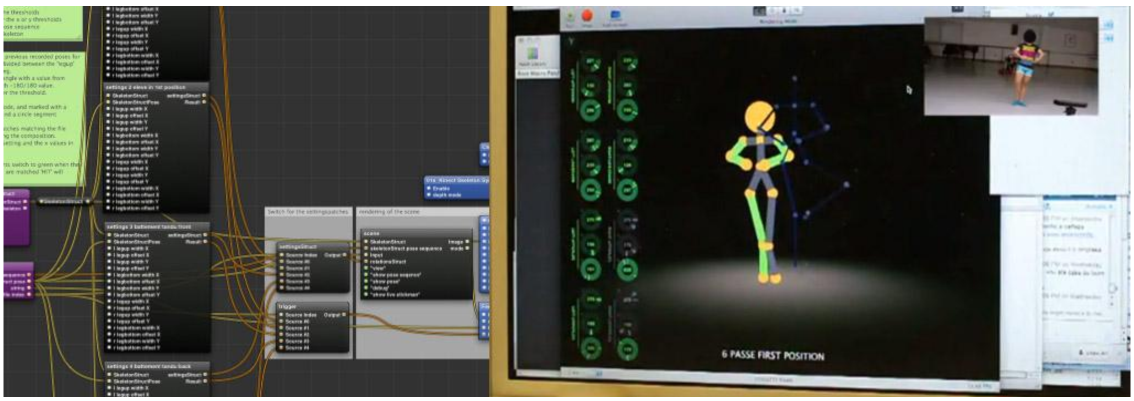

Figure 20: Super Mirror research project, 2012.

Left: Back-end of the prototype system;

Right: Front-end of the system including view of a dancer

INTRODUCTION

Super Mirror is a research project, and the first custom software created in the context of this research that addresses the fundamental need to digitize the moving body in order to enhance the practice of dance. Super Mirror is a gesture-based system that augments the functionality of studio mirrors to provide the user with instructional feedback in real time[3]. The working prototype allows us to record ballet movements, also called “poses,” and to collect joint data information for each pose. The system then captures live motion from the dancer and compares the differences between them to provide real-time feedback to the dancer. It is a way for beginner and intermediate dancers to improve the precision and accuracy of technical movements. In this chapter, we conduct a comprehensive study and analysis of the Super Mirror system with ballet students from the University of Texas at Austin.

Our study focused on the development and evaluation of the Super Mirror system prototype and its capacity to identify in real time the execution of seven ballet poses. This process required four testing sessions, each held in the same studio (Advanced Ballet class) at UT-Austin. We asked three consulting dancers to perform basic ballet movements in front of a Kinect interface. Their performances were represented through the movements of a skeletal model; they did not receive feedback from the system regarding the “correctness” of their movements.

The Super Mirror project started in Fall 2012 after the exploratory research study and performance *Too&For* (Chapter 2). The need for an automated system of motion capture and skeleton tracking was the motivation to create Super Mirror. The recently introduced depth sensor camera and sensing interface Kinect v1 provided the technical

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[3] I previously presented a co-authored paper on Super Mirror at the 2012 ACM SIGCHI Conference on Human Factors in Computing Systems in Austin, TX May 5-10. See Marquardt, Z., Beira, J., Em, N., Paiva, I., & Kox, S. (2012). Super Mirror: A Kinect Interface for Ballet Dancers. In CHI '12 Extended Abstracts on Human Factors in Computing Systems, ACM, New York. pp. 1619-1624.

capacity to capture data for an interactive computer-based agent to analyze and support ballet poses. It also allowed me to test the qualities of a particular sensing technology, the Xbox Kinect, for live performance. Super Mirror is a fundamental tool in this research as it provides the motion tracking for our visual programming environment used later in *[3D Embodied]* performance (Chapter 4).

CONCEPT

Super Mirror explores the concept of augmenting a fundamental technology in dance studios and rehearsal spaces: the mirror. Mirrors are a fundamental technology for dance instruction and training. They provide visual real time feedback for the users, a reflection, but do not indicate what the dancer should do. They do not instruct or assist. Prescriptive texts, such as *Ballet Technique* (1989), or even video recording tutorials, provide dancers with step-by-step illustrations of individual movements but do not provide real-time feedback and show the users and students how their movements fit in. A successful combination of these existing pedagogical tools would provide a ballet instructor and student with an additional means of communicating their respective interpretations of the students' performance during rehearsal and expectations for specific elements of choreography. Moreover, it could be a means of extending ballet instruction beyond the classroom, providing individualized feedback.

RELATED WORK

The notation in dance has always been a challenge due to the complexity of expressions in practice. Many notations have been proposed and developed in the last century. Some of the most relevant are the Labanotation (1977; 1980), Benesh notation (1956) and Eshkol-Wachman notation (1958). Labanotation is widely used in the United States and Europe. The movements of the body are represented by abstract symbols. According to the Laban movement, notation is the objective representation of human movement, such that movement may be recorded, preserved, archived, and communicated as a literary form (Laban, 1977).

There are a series of problems in using Laban notations as a system to document dance. Don Herbison-Evans summarizes these:

> 1. It is difficult to write a score in real time, especially if more than one user is involved.
>
> 2. The symbols used in notation are unusual and demand careful calligraphy to be drawn correctly.
>
> 3. It is difficult to make changes without having to rewrite substantial parts of the final score later on.
>
> 4. Few dancers and choreographers can read and write notation.
>
> 5. It takes months of study both to learn a notation and to become fluent in reading it and writing it. (1988, p. 47)

The introduction of video recording provides an effective solution for the limitations of written notation and a more effective medium to assist the rehearsal process for dancers. It provided the fourth dimension, time, to the mirror as a technology. The dancer can rewind and playback the capture of the movements and overall performance. The introduction of computers extended the capacities for electronic notation. In 1968, Merce Cunningham envisioned the principles for a computer technology designed for dance:

> I think a possible direction now would be to make an electronic notation . . . that is three-dimensional. . . . It can be stick figures or whatever, but they move in space so you can see the details of the dance; and you can stop it or slow it down . . . . would indicate where in space each person is, the shape of the movement, its timing. (Cunningham & Starr, 1968)

The combination of the 3D visualization of the body and a timeline are two essential features for such a system, but the system also needs to address the direct relationship and interactions between instructor and tutor. The process of learning dance is a highly interactive, practice-based process.

Sukel identified four principles for such an interactive computer-based dance tutor. The first requirement is to present movement to the user. The second is that the system needs to observe the students' or users' movement. The third requirement is that data necessary to process the feedback from the system to the user must be collected. The fourth requirement from the system allows interaction and communication: the interface.

The major requirement is the ability of the digital system to recreate the interaction between the dance professor and the student by adapting to different dynamics in the human computer interactions (2003, pp. 239-240).

These principles can be identified in dance-related applications of motion capture technology applications developed in the last decade in performance and choreography (DeLahunta & Bevilacqua, 2007; Meador, Rogers, O´Neal, Kurt & Cunningham, 2004) and in entertainment and gaming (Raptis, Kirovski & Hoppe 2011; Usui, Hatayma, Sato, Furuoka & Okude, 2006). One particular application is e-learning, developed by researches at Motion Lab to assist ballet tutoring. The focus is generating automatic compositions from ballet sequences based on the specific parameters the user inputs. The e-learning graphical interface displays a virtual ballerina on a rotatable 3D stage (Umino, Longstaff & Soga, 2009). The system is structurally similar to Super Mirror as it uses a collection of motion data to synthesize real-time analyses from the user input, but the focus is in the automation of the choreographic process.

While this is certainly not the first application of Kinect technology created for the practice of dance or other forms of structured movement (e.g., Xbox's *Dance Central* and Ubisoft's *Your Shape Fitness Evolved*), it is unique in its focus on ballet movement and instruction. This project also differs from previous academic work in movement recognition in that its goal is not to develop a more accurate and efficient method for classifying generic classes of gestures, but rather to identify pertinent features of specific movements that, when implemented, provide helpful feedback to the system's users.

TECHNICAL DESCRIPTION

The motion capture is performed by joint skeleton tracking through an Xbox Kinect camera. The data captured is processed in our system and projected back to the rehearsal space through the use of a projector.

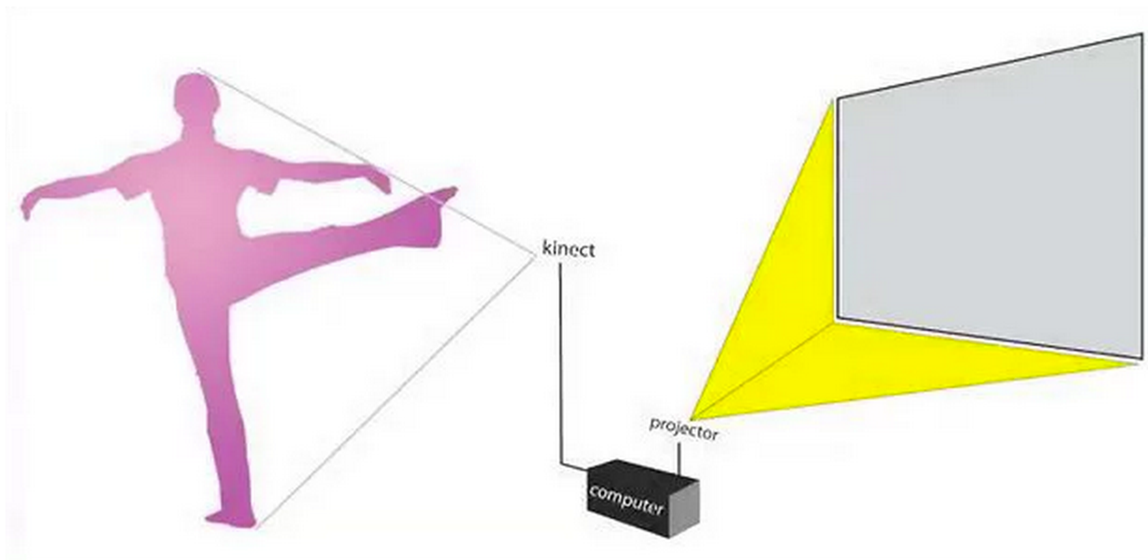

Figure 21: Technical setup for Super Mirror system

We use the synapse application to mediate the input from the camera to our system and patches. These applications use the Tryplex toolkit, a set of open source macro patches for Quartz Composer. The Kinect only operates from one angle, so the dancers face the depth sensor in front position. The dancers also must first calibrate the system for skeleton tracking to work.

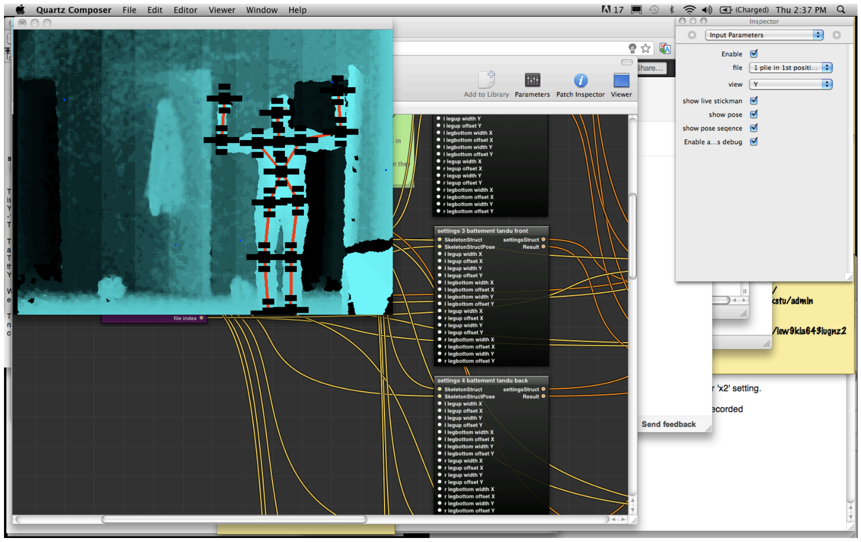

Figure 22:

Skeleton tracking with synapse and Quartz composer macro patches, with joint data

Pose Recording and Collection of Data

Because of the specialized nature of our interface, we choose to gather data from each pose from a sample of trained ballet dancers, who provided us not only with "training data," but also insights into the performance of the system. In order to develop a patch that could provide feedback for a movement performed in real-time—in terms of its resemblance to a predefined pose—it was necessary to establish a method of comparing recorded angles of each joint pertinent to the pose with data corresponding to the position of the participant performing the movement in real-time. For our first patch, we selected seven basic ballet movements (Figure 23).

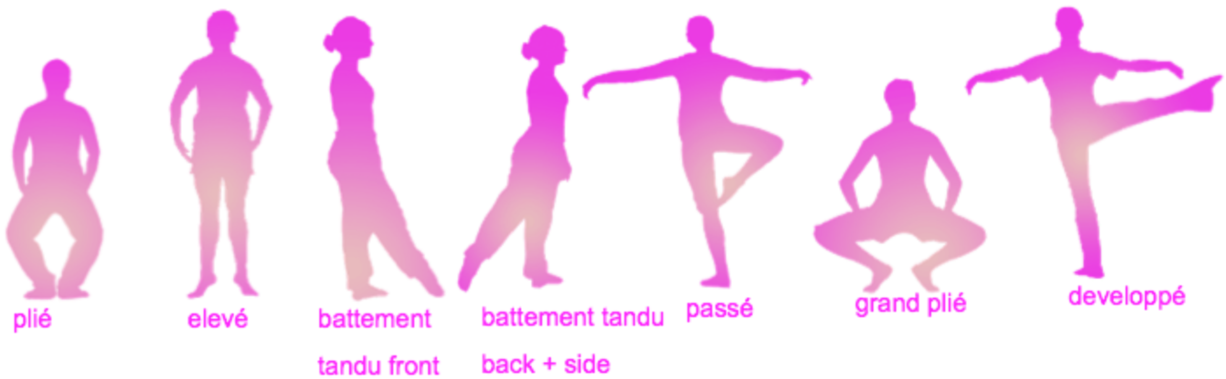

Figure 23: Ballet poses digitized and supported in Super Mirror

These movements were performed by one of the researchers, and joint information was recorded in XML. A file of each of the movements was also created, so that they could be played back.

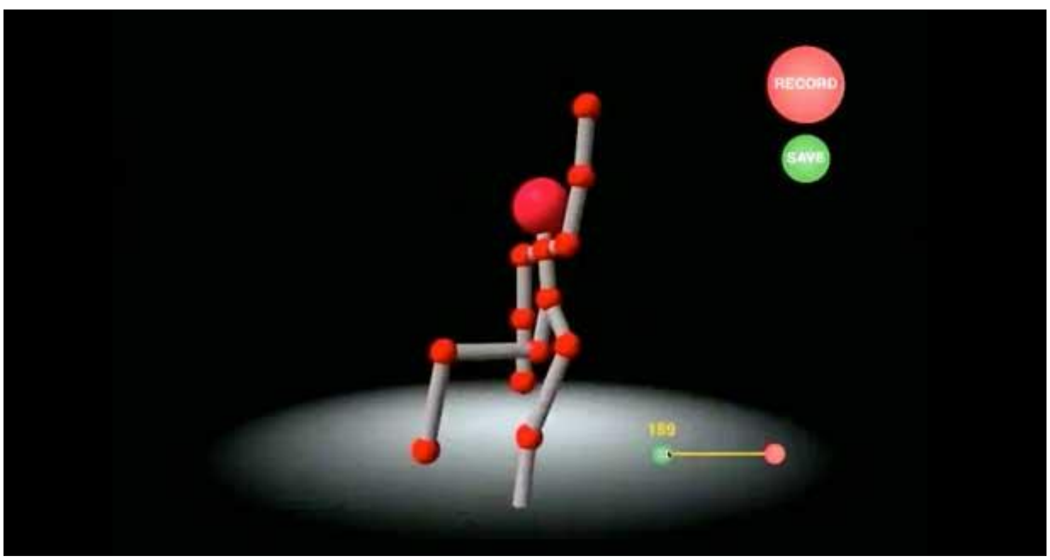

Figure 24: Pose recording interface using Tryplex toolkit

Comparing Real-Time and Recorded Poses

In each of the study sessions, a real-time skeleton model of the participant was displayed, along with a representation of a pre-recorded position, on a laptop monitor. The user could choose to match his or her movement to the selected pose (by standing so that her skeletal model overlaid the pre-recorded model) or to stand to the left or right side of the pre-recorded image without affecting the performance of the system. By establishing the *x*, *y*, and *z* coordinates of limb segments (right and left; upper and lower; arms and legs), the system can compare the dancer's position in real time to pre-recorded movement.

For the system to analyze a leg, for example, the method is created not in terms of limb measurements, but in the relation between the angle of knee and hip joints. A set of thresholds with minimum and maximum angle values are available to the user to calibrate in more detail the extent to which real-time and pre-recorded angle widths can vary. It allows the user to correct the angle of each joint. A match, or using our terminology, a "hit," is triggered when the pre-recorded pose and the real time input are synchronized. The hit is a form of sampling, a digital snapshot that determines that all technical criteria were met by the dancer in his or her movement.

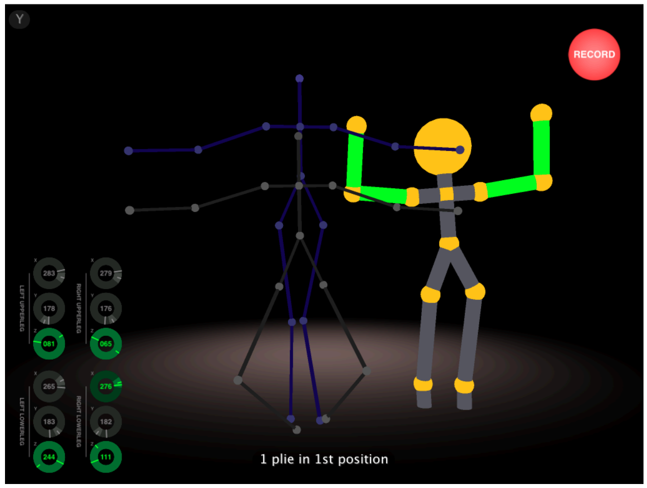

Figure 25: Super Mirror interface in 2012

Three Interfaces

The first interface juxtaposed the pre-recorded animation with the real-time skeleton tracking data. Every time a "hit" is triggered, the color of the pre-recorded models changes color. Though it provided validation and real-time feedback, it did not provide and store data for further analysis.

For the second interface, we implemented two new features. First, a record button recorded snapshots of the joint positions of the live dancers. The information and data was stored in an XML file. In the testing session, the button was pressed by the researcher running the computer each time a participant indicated that she was in the position specified by the patch. We added a "hit icon," which flashed on the screen when the threshold requirements were met. The second version of the patch also contained three additional poses (grand plié, passé, and developpé), which used data recorded during an earlier test session as the basis for comparison. Second, the "hit" display was added to the front-end, and it flashed on the screen when the threshold requirements were met, to generate a more effective visualization of the match for the dancer. The improvements allowed us to collect additional information for analysis but did not provide tools for the user to address specific needs regarding the pose recording and joint angles.

The third interface allows the user to specify the thresholds for a movement by setting the values of one or more angles with respect to the corresponding pre-recorded value. A simple graphical user interface, visible in the debugging mode, helps the user visualize the difference between the pre-recorded and adjusted angles (Figure 26). A larger angle width corresponds to a higher threshold. This feature, in theory, allows users to define the desired pose in contrast to the recorded pose, as well as to change the level of precision required to achieve a hit.

The graphical interface element, visible on the left-hand side of the screen, displays the values of certain angles of interest in real time in relation to the predetermined values for that position or pose. When a threshold is met, the representation of that angle turns green. When all of the required thresholds for a movement are met, the word "hit" appears in the top right corner.

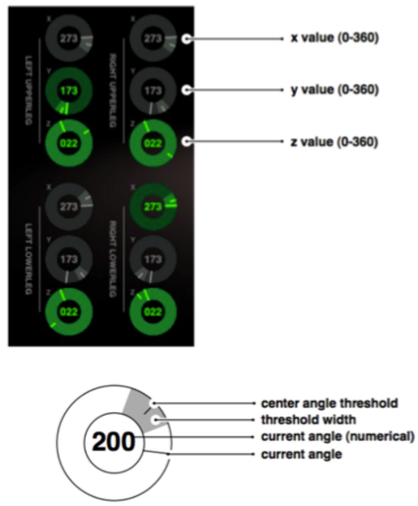

Figure 26:

Super Mirror interface to adjust *x, y*, and *z*-values and angles of position (3rd interface)

Research Design

In order to evaluate the Super Mirror system, we developed a comprehensive study in the evaluation of system recognition of position data, combining qualitative with quantitative methods. The users performed five dance movements (plié, elevé, battement, battement tandu, grand plié and developpé) in four sessions, followed by an interview in the second session. Each user individually executed a series of poses with the technologically-simulated mirror and received real-time feedback and visualization from the system. Three different and successive prototypes were tested based on the criteria of system performance and improvement of the system. The system performance tested the accuracy of the system to recognize specific ballet poses and movements, and also identified variables that cause problems to the system. The goal was to identify the requirements for the system and support subsequent iterations.

The qualitative and quantitative data collection evolved throughout the different sessions. During the exploratory session, consultants filled out background questionnaires, reviewed a list of basic ballet movements compiled by the researchers, and provided recommendations for potential patches. Their interactions with the Kinect system were recorded in screenshots (displaying skeletal models of the dancers) and photographs (which were later edited, rendering their subjects unidentifiable). At the second session, researchers recorded the consultants' interactions with the prototype in screenshots and photographs, similar to the first session, and noted (in writing) the degree to which the system appeared to work with respect to each tested movement.

Participants' Demographics and Ballet Experience

Any student enrolled in the class and who was at least 18 years old was eligible to participate in the study. Upon approval of the Advanced Ballet class instructor, team members introduced the study after sitting in on a class, and requested that students interested in participating in the study provide their first name, email address, and availability to the researchers. In total, five dancers participated in four sessions. The class from which we recruited participants included one man and 15 women, and its students represented multiple ethnic backgrounds. The first session had three participants, the second and fourth session had two participants, and the third session had five participants. The participants ranged in age from 19 to 24 years. All of the participants were females, which is not surprising, given the gender distribution of the class. Three of the participants were juniors and two were seniors. All of them began ballet training at a young age (between three and seven years old), and all of them had experience in at least one other form of dance, including contemporary/modern, jazz, tap, or traditional Chinese dance. Four of the five dancers were enrolled in at least one other dance class during the fall semester. The researchers recruited participants from the Advanced Ballet class not only because they represent a subsection of the ballet student population but also because many of them also have experience as dance instructors and/or intend to teach ballet as part of their professional careers. The three consulting dancers all had experience teaching beginner ballet classes, and two of them noted that they planned to teach ballet in the future.

Method

Four sessions were conducted for testing with a total of five dance major students at the University of Texas at Austin. During each session, we measured and registered the system accuracy to capture the performance of each pose. Participants in the first and third sessions were asked to execute correct and incorrect movements for each pose. This process allowed us to evaluate the level of accuracy in terms of false-negative and false-positive results.

The first session was formative to test the proof of concept and overall performance.

For the second session, we tested three new poses and also the capacity to record and store numerical information of each match or "hit." Also, two of the dancers who participated in the previous session were asked to test preliminary patches specific to the following ballet moves: plié, elevé, battement tandu front, battement tandu side, and battement tandu back. Because each patch was providing an unusual number of hits, the researchers decided to test both positive (i.e., correctly performed) and negative (poorly performed) iterations of the movements. Since there are multiple ways to incorrectly execute a movement, the researchers requested that the dancers verbalize a brief description of each negative movement's flaw (e.g., hip displacement, bent supporting leg, foot flexed, or feet turned-in). The participants also correctly performed three additional movements—grand plié, passé, and developé—recordings of which served as the basis for three new patches.

In the third session, five dancers—the three consulting dancers who participated in the first session along with two additional dancers—also enrolled in the Advanced Ballet class to test the existing patches. Because of the researchers' uncertainty regarding the accuracy of movement labels, only three positions were tested in full: plié, passé, and developpé. "Full" testing, in this case, meant that each of the five dancers performed all three movements six times. (The order in which they performed the movements was random). Whereas, in the previous session, dancers were asked to perform a couple "good" versions and a few "bad" versions of each movement, participants in this session were asked only to perform "good" versions of the movement. The researchers adapted their initial plan of recording both correct and incorrect movements once they realized, while in the pretesting phase, that the system was registering far fewer hits than it had in the previous test.

Following the testing session, the three consulting dancers stayed to answer interview questions concerning the interface. Their answers to the questions were recorded using voice-recording devices, and two of the researchers wrote notes during the interview. Through this semi-structured interview, we solicited comments about the system's potential uses, recommendations for possible functions, and suggestions for the user interface implemented in subsequent iterations.

For this session, the researchers also attempted to record dancers' movements as XML files, each of which would contain data specific to the coordinates (x, y, and z) associated with each of the eight variables tracked by the system (right and left upper arm, lower arm, upper leg, and lower leg).

4. The fourth and final session included the two consulting dancers who took part in the second session. In each case, session attendance was determined mostly by participant availability. The researchers decided to only invite the consulting dancers to participate in the fourth session, having agreed that the presence of five dancers lead to an unnecessarily chaotic and therefore unfavorable testing environment. Each of the two dancers performed the eight recorded movements in the following order: plié, elevé, battement tandu front, battement tandu side, battement tandu back, passé, grand plié, and developpé. When asked if they wanted to alternate performances, they declined: thus the

first consultant performed all eight movements (six iterations of each) in a row, and then the second consultant performed the same eight movements, in the same order, in a row. Because of improvements made to the third iteration and interface, which were apparent in the pretesting phase of the session, the researchers decided to test both positive and negative iterations of each movement: for each movement, the first three iterations were positive, and the fourth, fifth, and sixth iterations were negative.

Data Analysis

The researchers used both quantitative and qualitative methods to analyze the data from the four sessions in order to make generalizations about the current prototype's accuracy in recognizing movements and make recommendations for future iterations. Researchers compiled error analysis tables from video recordings of the interface and notes taken during the third and fourth sessions, in which each iteration of a movement was marked either as a "hit" or "miss" (Figure 27). Because participants in the third session were asked to perform only "good" movements (and had the option of scratching a performance from the record if they felt it was below par), the number of hits associated with a movement divided by 30 iterations provides a measure of the system's accuracy with respect to each of the three tested movements (each of five dancers gave six performances). However, in order to determine the system's error rate in the fourth session, it was necessary to consider both false-negatives and false-positives, since participants in that session performed three good movements, followed by three flawed movements.

In order to gain a better understanding of system requirements for future prototypes, both sets of error analysis results are interpreted alongside the respective patches used to record them. Similarly, by analyzing the system's accuracy with respect to different movements, I hope to present useful information about the strengths and weaknesses of their prototype, and possibly Kinect systems in general.

While the analysis of error detection data reflects the relative accuracy of the second and third iterations of the Super Mirror system, the participants' responses to interview questions suggest potential improvements that could be realized in subsequent iterations of the system. In analyzing this qualitative data, the researchers considered feedback pertinent to the current design prototype, as well as feedback that might be useful to designers of other systems that involve motion tracking and skeletal modeling.

Quantitative Data Analysis

The researchers' notes taken during the second session, in which the first patch was tested, indicate that the first prototype worked well, perhaps too well. With one exception, the two dancers who participated in that session consistently received hits for each of the five movements that they tested: the plié, elevé, battement tandu front, battement tandu side, and battement tandu back.

The error analysis results from the third and fourth test reveal substantial improvement in the system recognition of pre-recorded movements. In the fourth test, the system performed better to recognize the plié, developpe and elevé. On the contrary, however, it revealed problems in recognizing the battement tandu and passé poses. Figure

27 shows the relationship between these poses and the accuracy of the system. The blue indicates accurate hits and red indicated inaccurate hits.

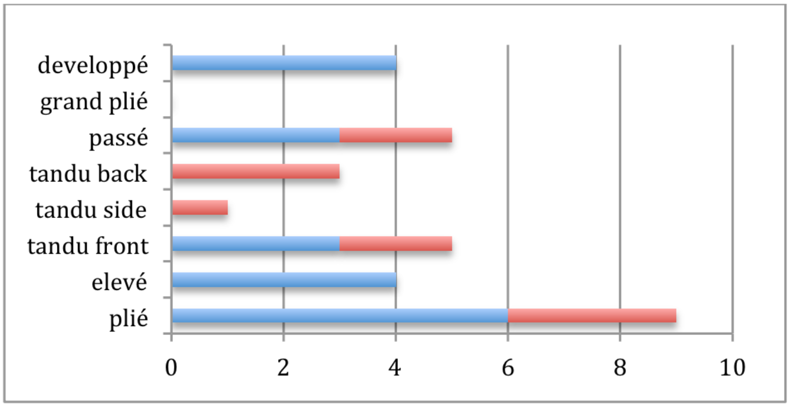

Figure 27: Results from hits in the fourth test

The plié, which in theory one may assume would be easy to validate (because the displacement of the legs occurs primarily on vertical and horizontal planes, making the angle formed by the knees readily visible from the front) was one of the most problematic poses. While one of the consultants consistently received hit feedback for her pliés, the other did not receive a single hit for this movement. The participants suggested that this discrepancy reflected the different lengths of their Achilles tendons since it is a requirement that the heels of the dancer remain planted on the floor for the duration of the plié. Dancers with longer Achilles tendons tend to have deeper pliés than those with shorter tendons.

The frequency of positive hit feedback for the other movements prompted the researchers to question the extent to which the system could recognize improperly executed movements as such. By asking the consultants to perform incorrect versions of some of the movements, several flaws were revealed: the interface indicated a hit, even when the active leg of the dancer performing a battement tandu (to the front or side) was bent, and when the dancer turned in her hip as she extended her leg. Additionally, it was noted that, if the dancer executed the more advanced version of the battement tandu back (in which the toe of the back leg is placed directly behind the heel of the front leg), a hit would not be registered. If the more basic version of the movement was completed (in which the toe moves straight back), a hit would occur.

More specific error rate data was collected during the third and fourth sessions. In the third session, only three movements were tested by all five of the participants. Of the 30 pliés performed by the participants, approximately 7% resulted in hits; none of the 30 passés registered as a hit; and approximately 13%, or 4 out of 30, of developpés resulted in hits.

	plié	elevé	tandu front	tandu side	tandu back	passé	grand plié	developpé
consultant 1	Y	N	N	N	N	N	N	N
consultant 1	Y	N	N	N	N	N	N	Y
consultant 1	Y	Y	Y	N	N	N	N	Y
consultant 1	Y	N	N	N	N	N	N	N
consultant 1	Y	N	N	N	Y	Y	N	N
consultant 1	N	N	Y	Y	N	N	N	N
consultant 2	Y	Y	Y	N	N	Y	N	N
consultant 2	Y	Y	Y	N	N	Y	N	Y
consultant 2	Y	Y	N	N	N	Y	N	Y
consultant 2	Y	N	N	N	Y	Y	N	N
consultant 2	N	N	Y	N	Y	N	N	N
consultant 2	N	N	N	N	N	N	N	N

Figure 28: Session 4 error analysis

While the results from the fourth session, presented in Figure 29, cannot be compared directly to those from the third section, they do suggest an increase in system accuracy. Because the participants in the last session were asked to perform three good examples followed by three bad examples of each movement, the accuracy of the hits—not the total number of hits recorded during the session—is of interest. The graphic in Figure 29 presents the results of the fourth session in terms of false-negative and false-positive values. Together, these values give a more complete picture of the system's performance, representing not only its ability to register hits, but its ability to distinguish between correctly and incorrectly executed movements.

	plié	elevé	tandu front	tandu side	tandu back	passé	grand plié	developpé
1-consultant, false negative	0	67	67	100	100	100	100	33
1-consultant, false positive	67	0	33	33	33	33	0	0
2-consutant, false negative	0	0	33	100	100	0	100	33
2-consultant, false positive	33	0	33	0	67	33	0	0

Figure 29: Session 4 false-negatives/false-positives

Figure 30 shows the *x* and *y*-axis rotations of the joints rendered into one graph per bone element. The pre-recorded pose value is the center of the graph and the dotted box is a combination of the preset *x*/*y* thresholds and offsets. The z rotation is rendered separately, in a flat graph. The *x* and *y* rotations provided more useful data for analyzing and identifying patterns between matches.

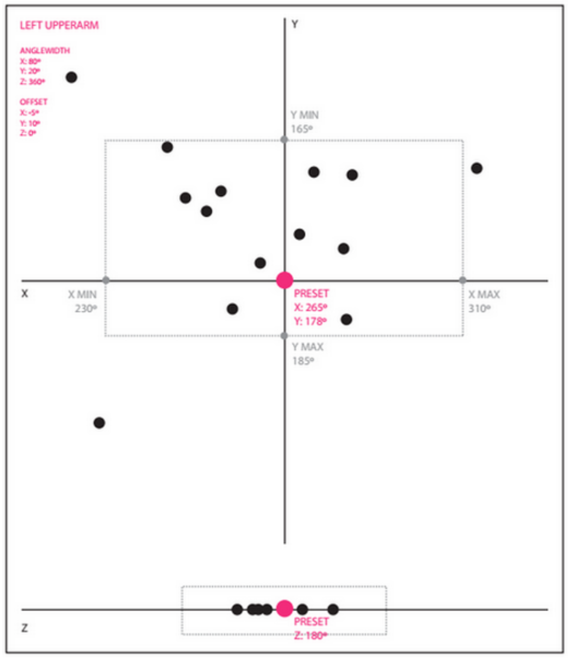

Figure 30: Visualization of the *x*, *y*, and *z*-axis rotations of the joints

Qualitative Data Analysis

Following the principles of the participatory design method, we asked our subjects several questions about potential interfaces that could be implemented in future iterations of the system. When asked what kind of feedback they thought would be most helpful, the participants' opinions split between video and audio feedback. Some strongly preferred video feedback, while for others an audio feedback would be more useful than a feedback on the screen. Most of the participants agreed that it would be helpful to get prompts of correction or praising similar to those they hear in the ballet class. While one of the participants was positive about the system's ability to recognize movements, the rest of the dancers indicated that it would be also important to get feedback on how the dancer gets to the position. In addition, the participants noted that a summary of dancers' mistakes in a form of snapshots would be very helpful in correcting mistakes. In addition, absolutely all participants agreed that seeing their side view along with the front view would be helpful in, for example, correcting one's alignment, or leveling a leg in the attitude position.

The consultants unanimously choose gesture (given the options of voice, gesture, or remote control) as the preferred method of navigating the Super Mirror's hypothetical user interface (from which they would be able to access pre-recorded movements, record new combinations, etc.), and noted that the mandatory use of a keyboard would be disruptive.

The participants suggested the inclusion of a "playlist" feature, to automatically group series of movement combinations and poses, which could be divided by level of expertise (beginner, intermediate, or advanced). They also suggested for the system to have the ability to record additional movements. This would allow users to create their own personalized libraries beyond the conventional ballet poses. It would also allow the user to explore "different ways to make the same movement," as one participant suggested. This would extend the application of the system towards other forms of dance expression and particular rehearsal settings.

The participants were not only asked to suggest high-level features that should be supported in future iterations of the system, but also to comment on specific elements of visual design. In order to clarify the questions pertaining to visual design, and generate discussion, researchers presented the participants with several screenshots of high-fidelity interface designs. When asked to recommend colors or color schemes for the interface, they suggested red and green.

After mentioning that the project seemed to be moving in a good direction, the participants noted that subsequent iterations of the system should address the diversity of dancers' bodies and consider the effect of a dancer's physical proportions and musculature on his or her performance of specific movements. Future design efforts should focus on the tracking of the position of the dancers' feet and hands, as they provide fundamental reference to the execution of ballet and the transitions between poses.

DISCUSSION: ANALYSIS AND CONCLUSION

Super Mirror is only able to assess and recognize the partial complexity of ballet poses—more precisely, the angle of joints of the movements analyzed. But the efficiency of the feedback and effectiveness of the technology reveal potential to incorporate Kinect-based technology and interfaces in rehearsal spaces as tutoring agents.

The main conclusions from the Super Mirror research study came first from a technical evaluation of the technology used, and the validation of the level of accuracy necessary in using a low-budget and inexpensive natural interface for motion capture and skeleton tracking. The system provides a significant contribution in its capacity to assess the partial complexity of movements and poses, but within certain limits. Movements such as grand plié indicated severe tracking problems. In opposition, poses such as plié, in which the feet movement and position do not move and produce relevant angle, the tracking was accurate. This technical limitation, such as the tracking of the joint in the lower feet of the user, allows us to have a better understanding of the technology. Consequently, it showed me fundamental principles of how to effectively create a design framework for my live performances.

In the context of this study, the Super Mirror system will be implemented and extended for interactive graphics and 3D visualizations, but such system could be useful for a large number of domains that evolve full-body movement training—for example, yoga, martial arts, and any other dance style, as well as for therapy (e.g., physiotherapy). Future displays for such systems could benefit from the use of augmented reality display for the dancer. It could be an augmented agent and assistant that moves and overlays joint skeleton information by utilizing the peripheral vision of the user—a display that follows the dancer's movement, without the limitations of screen-based displays.

The results of the four study sessions, along with the evolution of the system's patches, demonstrate the need for a balanced approach to prototype design—i.e., an approach that considers both the features of skeletal tracking technologies and the principles of ballet. For example, the researchers' assumption that the plié would be an easy move to validate, was completely off-base: the angle of the knee will vary from dancer to dancer, but the requirement that the heel remain on the floor will always hold true. Better hit-accuracy for the plié, and other problematic movements, might be achieved with the implementation of improved foot detection technology and/or by adapting the patch to focus on more nuanced indicators of correct plié execution (visible to experts). One possible solution is to incorporate a second Kinect depth sensor camera to track the dancer from different angles: the front and the side. This would provide more detail and a more accurate acquisition of the dancers' position and movements.

The introduction of a user interface to administrate the system's library and the ability to record new movements and calibrations seem to be central features to implement in the system and suggest future work.

Trajkova and Ferati at the South East European University in Macedonia did a usability evaluation using the Super Mirror system and software to investigate the impact of a technology simulated mirror in ballet instruction—more precisely, the type of feedback provided to dancers during remote ballet learning. The research Trajkova and her team conducted utilized different research methodology to evaluate eight ballet movements (passé, élevé, grand plié, battement tendu [front, side and back], plié, and développé) provided by the Super Mirror's system. The research investigated such a "prove[s] to be as accurate as a ballet teacher in assessing the quality of dancer's movements" (2015, p. 465). Trajkova and Ferati applied a new methodology focused on the level of effectiveness and efficiency of the system and software by comparing it with analysis by a professional ballet teacher.

The results were concentrated on three specific movements: élevé, plié and tendu front. The authors attribute the inability to the system to collect conclusive data for the other five movements due to the height of the dancers. The authors concludes, "Super

Mirror shows a consistency of scores among the students for the same movement regardless of the opposition of the teacher that gives an opportunity to calibrate the system to match the teacher's scores" (Trajokva, 2015, p. 475). The authors also suggest that further investigation is needed to accurately calibrate the reference template to the specificity of each dancer.

The Kinect Xbox depth sensor provides a reliable tool for interactive applications and to establish networks of communication between the human body and digitally-augmented environments. The interactions with the dancers and the analysis of ballet poses revealed some of the limitations of the technology, in particular the capacity to effectively track the 3D motion of feet.

Future work and development of Super Mirror should be focused on the integration of augmented reality, or virtual reality head-mounted displays in order to integrate the 3D visualization of the body into the dancer's field of visio

Chapter 4: *3D [Embodied]*

OVERVIEW

3D [Embodied] is a digital dance performance presented at the Payne Theater at the University of Texas at Austin on April 18-23, 2013. I created the concept, projection design, and choreography, Yacov Sharir choreographed the performance, Bruce Pennycook designed the sound, Marta Ferraz further collaborated with us on animation and system controls. The performance had four dancers, and was organized in two main acts over a period of 12 minutes.

This chapter presents the performative research project *3D [Embodied]*. As the name indicates, the work focuses on the connection of the virtual world with the human body. I combine motion tracking with 3D video mapping and create an environment in which the performer's body interacts with three-dimensional augmented and physical space. By using this framework, I investigate the qualities of spatial augmented interactions in live dance performance[4].

[4] I previously presented a co-authored paper on 3D [Embodied] at the 2013 ACM ImmersiveMe Proceedings of the ACM International workshop on Immersive Media experiences in Barcelona, Spain. See Beira, Carvalho & Kox (2013) Mixed Reality Immersive Design: A Study in Interactive Dance Mixed Reality Immersive Design: A Study in Interactive Dance. Barcelona, Spain. pp. 45-50

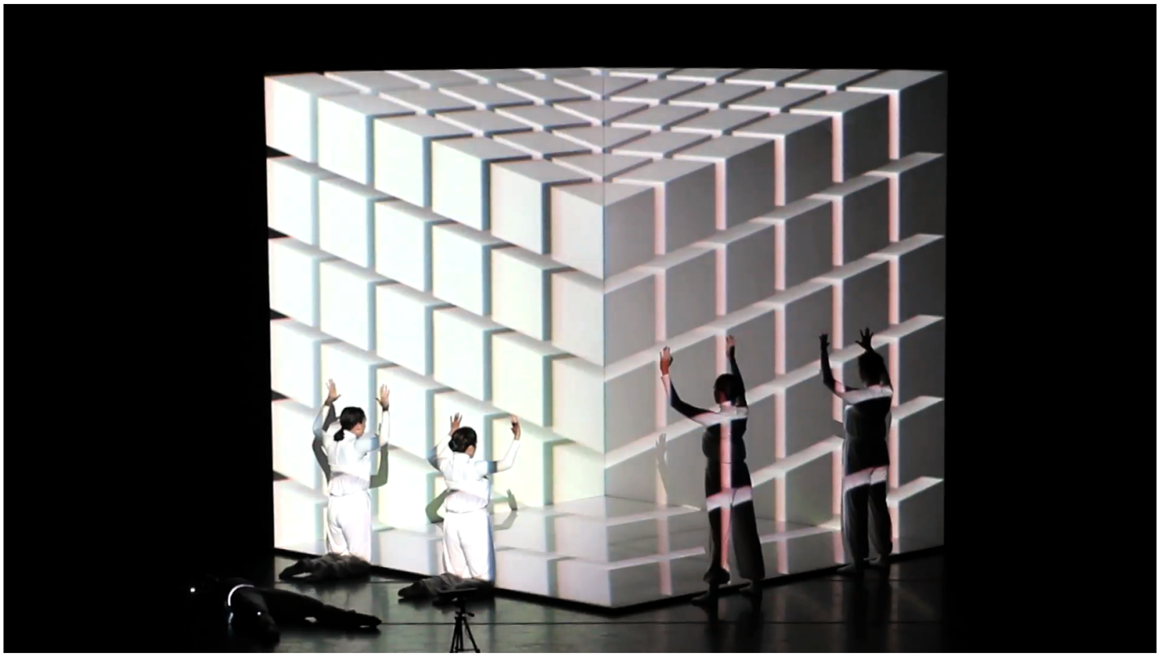

Figure 31: ***3D [Embodied]*** **is a mixed reality performance involving a virtual world as a platform to explore 3D immersive spatial virtual and physical displays.**

I start by contextualizing and discussing 3D projection mapping as an augmentation display. Most projector-based augmentations are non-interactive and raise design problems between the user(s) and the display.

Next, I present the framework design and technical implementation of our system to make projection mapping interactive for the dance performers, outlining relevant problems and solutions we find in the process of developing the performance.

The mapping implemented between the virtual and the physical is generated in two proof-of-concept systems that implemented the use of spatial of augmented reality with dance performance. The first system, which I define as modulation, creates a continuum feed of motion tracking of the dancer with the 3D geometry of the augmented space. The second method triggers pre-rendered 3D projection mapping visualizations. Both methods created different strategies for improvisation and creative expression in live performance setups.

Finally, the conceptual, design and technical framework is validated through a field experiment: the performance. The analysis of the *3D [Embodied]* performance and system is also extended to perspective of the audience and performers through interviews. The strategies we used for real time processing and interactions of computer-generated graphics are presented. Also, the problems of overstimulation of visual information and the lack of interactivity in the second method we used are analyzed. At the same time, the dynamics and detail presented in Method 2 have the unique ability to generate visual illusions by merging the physical body and space with the virtual world. I conclude that the combination and aggregation of both methods in one integrated system can create a more interactive and augmented process by combining higher levels of interactions with more dynamic and unexpected visual illusions. This also promotes the improvisational capacities of the media design for the dance practice and contributes to the experience of augmented virtuality as a form of digital dance performance.

CONCEPT

3D [Embodied] is an experimental dance performance based on and inspired by the connection between the human body with virtual and augmented environments. The performance investigates 3D immersive spatial embodied design principles. It materializes the core concept of this study by investigation 3D video mapping interactions as an extended agent for the dance performer. It connects real time interactions between 3D geometry perspective calculations and the body in motion. By relying on the physical body, dance performance intertwines the perception of space and movement and creates a privileged framework to design and research immersive augmented environments. Three faces, left, right and bottom, representing half-cube constitute the physical stage design. This three-perspective axis provides the main reference and concept towards content and interaction design. They create the augmented environment to overlay the 3D virtual world within the 3D physical space. The ability of the dancers to control, generate and trigger the virtual space based on their physical activity is the core concept of *3D [Embodied]*.

As analyzed previously in Chapter 2, mixed reality environments are comprised of interactive virtual visualizations overlaid onto the physical space. The first step is to collect the data the dancers' movements in real time. This process is described in our framework as the input. With these datasets, the mapping between the skeleton tracking and the 3D virtual world are established. Finally, the output is generated by projecting this virtual environments and objects directly over the physical space, the 3D stage cube, and the performers.

To concept is then to aggregate 3D projection mapping with interactive design, and create a unified audiovisual experience between the physical body and virtuality. The audience sees spatial augmented virtuality, as the primary environment to be augmented is virtual (Figure 33). The primary source of augmentation was the 3D computer-generated world created through visual programming. The dancers interact with the virtual world, using similar principles to computer game theory, but projecting the virtual environment directly over the physical space. Projection mapping becomes not just a display technique but also an interactive agent for embodied expression.

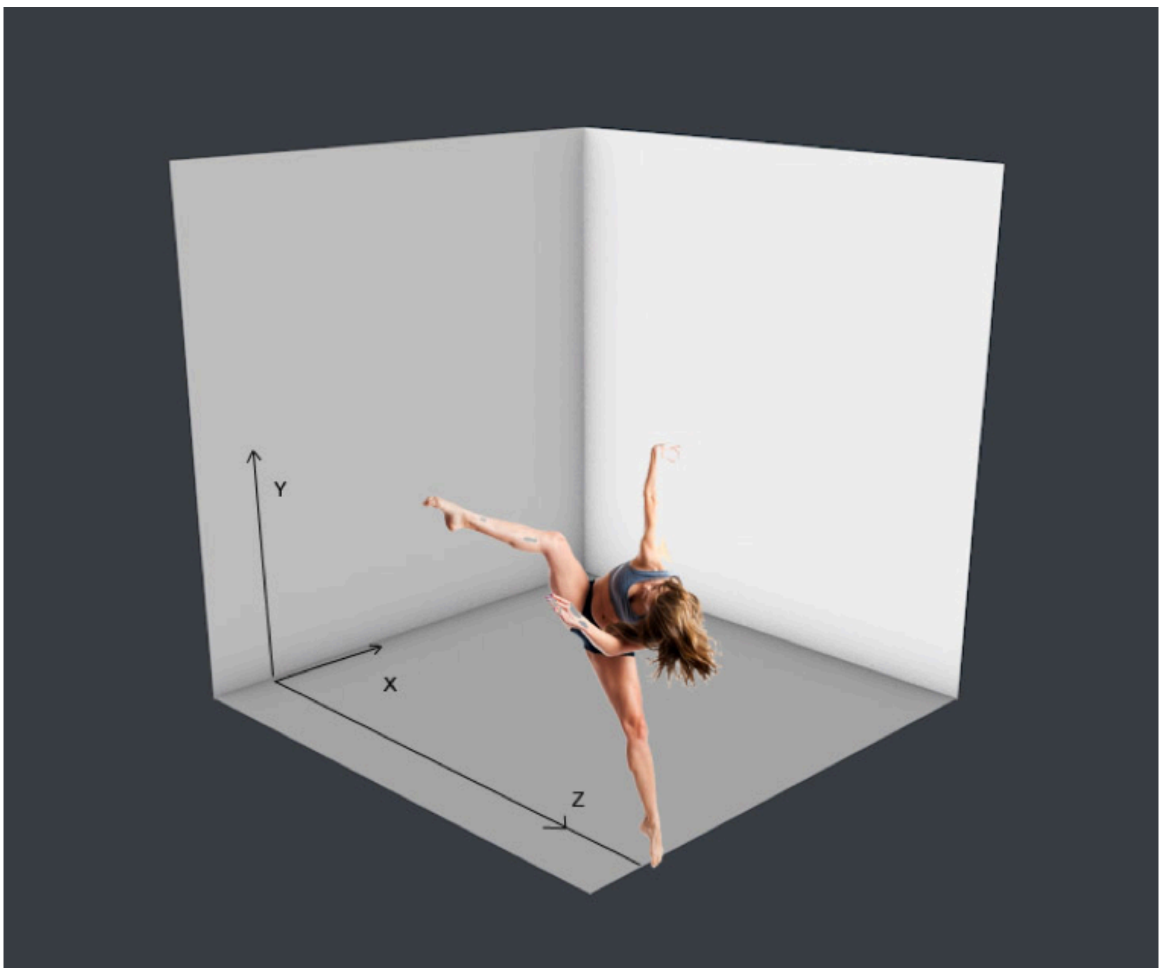

Figure 32: Concept design for *3D [Embodied]* performance:

The performer's body interacts with the 3D augmented space by combining motion tracking with 3D video mapping projection.

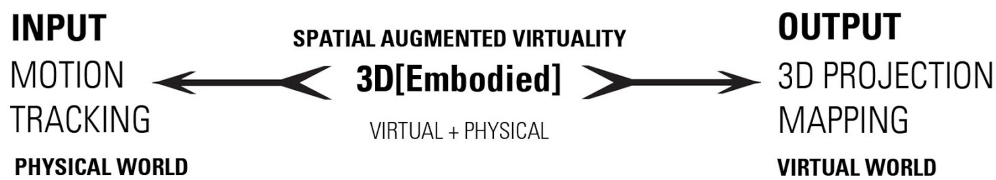

Figure. 33: Conceptual framework for *3D [Embodied]* in the virtual continuum. Primary source and system to be augmented is the 3D virtual space.

RELATED WORK

The Medium of Illusion

Audiovisual magical environments have been imagined, explored and created by artists, scientists, designers, engineers, writers, and others, to generated unique sets of autonomous spaces and environments throughout the history. More specifically, the use of projected light in performance settings and experimental live settings to invoke illusions, fantasy and unnatural phenomena can be traced back several centuries. Visual styles and other forms of expressions such as *trompe l'oeil* evoke and represent some the fundamental elements of the generation of augmented forms of visual illusion. The creation of optical devices to reproduce an inverted image of reality in a flat surface inside a dark chamber using natural light and a hole were fundamental tools used by artists and scientists in their experiments with optics since the 15th century. It was discovered by Italian artists, such as Filippo Brunelleschi, that started to use reflection techniques with mirrors to represent architecture in their paintings directly over the surface. Such devices became known as the *camera obscura* and produced a live projection of the visual spectrum. By converging parallel lines into a single point such technique provided the technical principles to produce images with a linear perspective. This discovery expanded the representation and perception of three-dimensional objects in drawings and paintings, dramatically affecting a number of artistic styles. It was adopted to create the illusion of depth codified into a two-dimensional plane.

The Renaissance period provided fundamental technological development in visual technology involving light, lens and optics. One of the most important scholars was Giovanni Battista della Porta (1538-1615), an academic who devoted himself to a wide range of different fields: mathematics, astronomy, optics and philosophy. His work on projection, reflection and optics provide the fundamental basis to the creation of the magic lantern (Zielinski, 1999). The magic lantern was a technology that reflected light and created an inverted image of reality on a flat wall. It can be described as an early form of a projector. The illusionistic potential of magic lantern shows created what can be today described as multimedia events, laying the foundations for photography, film and screen-based displays.

Projection Mapping

Video projection, also known as projector-based augmentation, in flat and cylindrical/spherical surfaces has a long history and predates the invention of cinema.

However, the use of projected imagery onto 3D complex surfaces goes back only a few decades.

In 1969, Disneyland engineers projected flat images onto the three-dimensional sculptures of the busts of characters of the Haunted Mansion. This was accomplished by filming headshots of the actors on 16mm film and then projecting the film back on the busts.

Figure 34: In 1969, Disney projected flat images onto the three-dimensional sculptures of the busts of characters of the Haunted Mansion.

Michael Naimark's work in the 1970s using immersive video and film projection pioneered the application of such technology. In 1980, he created the installation *Displacements*. It applied the principles of projector-based augmentation by video recording a living room with a rotating camera and then recreating the same living room but everything painted in white to use the space as a screen canvas. First, the author recorded the room with actors and ambient light. Then, he added a video projector positioned exactly where the video camera was. The camera movement used to record the video, a 360 rotation, was reproduced by the video projector, but this time onto a room painted in white and without any actors. This way, Naimark was able to position perfectly the recordings with the projections using two different sets that ultimately complemented each other to create augmented reality before it became a well know area. Naimark's video installation lays out the foundations of projector based augmentations before digital video processing. It reveals the understanding of the volumetric qualities of textures in 3D objects and video projectors.

Figure 35 Left: *Displacements* video installation by Michael Naimark (1980); Right: Media Room of the Future prototype by MIT (1979) was a spatial interactive visualization using rear projection as well as touch and pressure sensitive instrumentation in the arms of a chair.

The idea of incorporating live computer-generated imagery into architectural spaces is firstly introduced in academia through the augmentation of a personal office. In 1979, MIT ArcMac published the concept of the Media Room, an office space with rear projectors designed for users to interact with wall-displayed applications through a multiplicity of input mechanisms such as physical gestures, voice recognition, eye tracking and physical controllers such as buttons and joysticks (Bolt, 1980). The extension of the personal office inspired engineers to conceptualize and ultimately create interactive strategies with sensing and display interfaces. Several research projects used projection mapping in physical space as a new approach to experience virtual reality environment.

Disney not only pioneered the first use of this projection technology but they also patented it some years later. In 1991, they patented an "apparatus and method for projection images upon a three-dimensional object," describing a digital system that overlays an image onto a "contoured three-dimensional object" (Marshall, Monroe, William & Redmann, 1994). The patent describes the projection of an image onto a three-dimensional object with various contours and shapes in digital software and also deals with proper keystoning and corrections to ensure prospective appearance and aligning the projection with the specified range of depth (Cruz-Neira et al, 1992, p. 67).

The introduction of interactive systems with projected based augmentations was introduced by the research project CAVE (Cave Automatic Virtual Environment) premiered at SIGGRAPH'92 and proposed a new strategy to experience virtual reality—more precisely, by creating an integrated immersive and interactive environment for users to experience the visualization of 3D graphics projected in the walls of a closed room. By projecting and aligning the user with the virtual world, in the physical world, the CAVE pioneered the exploration of interactive projector based augmentations in mixed reality. The authors suggest this new approach to be a fourth solution for virtual reality display strategies. The first VR display was through a simple computer monitor display, which they described as Cathode Ray Tube (CRT), the second was through the use of a Head-Mounted Display (HMD), the third was the Binocular-Omni-Oriented Monitor (Boom), and finally the fourth was the Audio-Visual Experience Automatic Virtual Environment (CAVE). CAVE is described by the authors as a new virtual reality interface and, as the authors described it, as a "virtual reality theater" (Cruz-Neira, 1993, p. 136). It consists of a room-sized cube (10 x10 ft.), fully covered with projected 3D graphics in rear projection screens. The user interacts with it without the bulky head mounted display used in VR, instead wearing a special pair of active stereo shutter goggles and carrying a wand tracking device in the hand that interacts with the space. The viewer-centered perspective simulates and calculates the perspective visualization from the location of the viewer in real time. In the past, the norm was to base the camera position on the axis perpendicular to the center of the screen. The system is able to calculate the viewer's position and calculate the prospective adjustment of the 3D graphics in real time. The CAVE architecture has been refined and improved over the last decades, but remained fairly expensive and limited to a single user experience. Still, it created the foundations and first working prototypes to experience spatial augmented reality and experimented with a new strategy of experiencing mixed reality environments (Cruz-Neira, 1992; 1993).

In 1998, Raskar also published in SIGGRAPH *The Office of the Future* and introduced digital 3D projection augmentations to academia. It is an augmented reality environment with projectors covering all the surfaces of the desk space. It was conceptualized to display high-resolution images on designated display surfaces.

Figure 36: Left: Conceptual sketch for the Office of the Future (1998); Right: The CAVE virtual environment with rear projection screens

In 1999, designer John Underkoffler created the I/O bulb, "a pervasive transformation of architectural space, so that every surface is rendered capable of displaying and collecting visual information" (Underkoffler, 1998). Using a video RGB camera and a video projector, the project is the conceptual evolution of the ordinary light bulb. The camera provides information through data analysis from the objects and interface on a table, and the video projector projects high-resolution information directly in the physical space. This spatial interface shows the ubiquity of digital media by start to occupying the physical surroundings. In 2001, Raskar created Shader Lamps projecting 3D virtual content directly into physical objects and textures. The project created 3D computer graphics of the physical object that projected upon through the creation of algorithms to calculate the rendering process: “We introduce the idea of rearranging the terms in the relationship between illumination and reflectance to reproduce equivalent radiance at a surface” (Raskar, 2001, p. 2).

3D Projection Mapping as an Art Form

At this point in history the technical foundations to create a new kind of art and medium were established. Perhaps the most impactful and iconic work presented to public in an art gallery was the installation series from Pablo Valbuena entitled *Augmented Sculptures* presented at Medialab Madrid in 2007. The author described it as “a volumetric base that serves as support for a second level, a virtual projected layer that allows controlling the transformation and sentimentality of space-time.” It is focused on the temporary quality of space, investigating space-time not only as a three-dimensional environment, but as space in transformation:

> Two layers are produced that explore different aspects of the space-time reality. On the one hand the physical layer, which controls the real space and shapes the volumetric base that serves as support for the next level. The second level is a virtual projected layer that allows controlling the transformation and potentiality of space-time

Valbuena’s use of spatial augmented architectures introduces the qualities of the digital medium to create illusions that challenges our perception of reality.

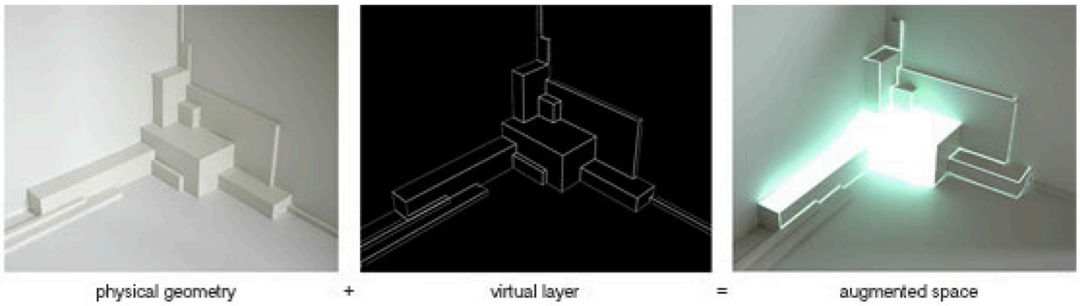

Figure 37: Pablo Valbuena's *Augmented Sculptures* v.1.0 (2007)

Some of the pioneers in applying this medium in their artistic expression include visual artists such as Ricardo Rivera, James Turrell, H.C. Gilje, and collectives of designers such as Anti Vj and 1024. These artists explored 3D projection mapping creative potential using digital tools, expanding the possibilities to conceptualize and prototype architectural mixed reality environments. Though, despite the adoption of 3D projection as a display technique, the majority of the projects are not designed to integrate the viewer/user. They are created for passive visualization and the contemplation of the illusion. By incorporating 3D projection mapping with sensing capture technologies, *3D [Embodied]* creates an immersive experience to engage intuitive and engaged interactions with the dance performers.

FRAMEWORK DESIGN AND TECHNICAL SYSTEM

The integration of 3D projection mapping with interactive design raises technical challenges. Anthony Rowe describes "most projection mapping experiences and events are non-interactive, partly because of the many inherent design problems in designing for interaction is such situations” (2015, p. 197). In order to establish interactive systems for projection mapping, it becomes necessary to create dynamic relationships of relational architecture. Creating multidimensional tactile extensions to physical environments through movement involves the programming of interface parameters, tracking, navigation, and mapping. The feedback process in such relational architecture is designed and conceptualized to be able to generate complex and dynamic interactions. Performers, visual artists, and programmers become creative co-participants in the creation of these hybrid environments.

3D [Embodied] system used advanced gesture tracking and recognition in order to generate and control spontaneous adaptations of the 3D visual space. There were three fundamental stages and processes for creating a system that combines live dance interactions with visual augmented art. The narrative and overall creative direction of both sections was based in the exploration of augmented embodied interactions. Each section provided the dancers different situations for the dancers to express their creativity and improvise.

1) The first process was the collection of data by digitizing the human body. Through the use of motion tracking and computer vision technology we were able to create a real time perspective calculation of the dance performer’s position and movement relative to the computer-generated 3D graphics.

2) The second process was defining the interaction language and overall expression and augmentation strategies between the dancers and the 3D virtual objects.

3) Finally, the third process was designing the output modalities using projection mapping.

Setup

The stage was a custom-made structure that provided three individual screens to display video projections. In front of the stage, a Kinect camera scanned the dancers movements and captured a 3D image. This data was processed and manipulated by the motion capture software Ni Mate in order to track the position of the skeleton joints in 3D space in our customized software based in Quartz Composer. The information from the data from the skeleton joints is sent to our network system and visual programming environment by OSC protocol to control and generate live visuals. Finally, the output signal is projected directly over the performers and stage design.

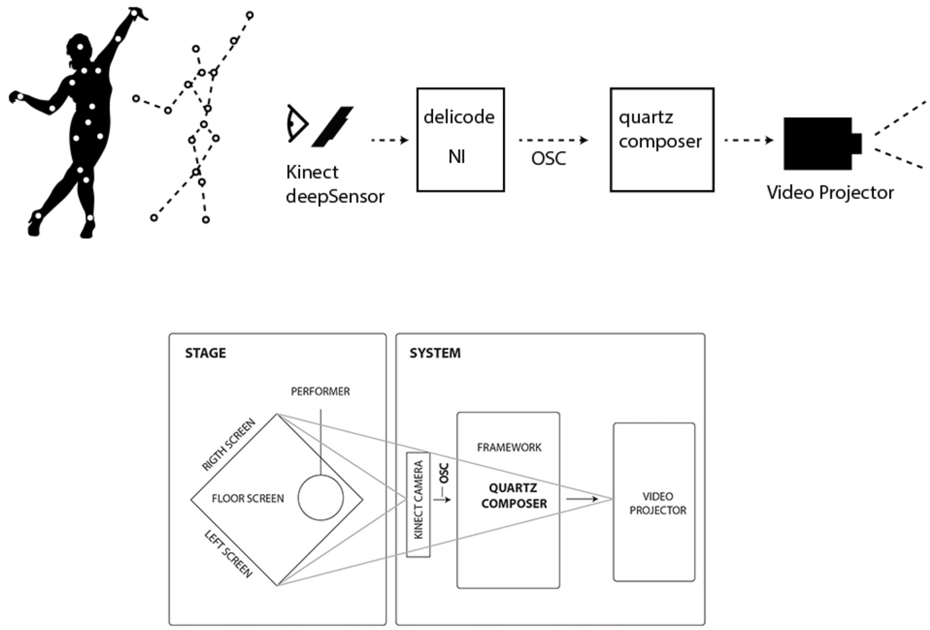

Figure 38: System architecture (top) and physical and spatial setup (bottom)

Motion Tracking

The Kinect camera and depth sensor, located in front of the performer, provided information on the performance bodies relative to the space and released the performers from wearing obstructive hardware devices and sensors. The intrinsic non-obstructive and transparent qualities of the interface allow the performers to move freely and more expressively. This increases the engagement and creative expression for the dancers.

The previous chapter on Super Mirror presents the technical implementation for the motion tracking system for *3D [Embodied]*. The research project describes the benefits and limitations of the software and hardware framework created to digitize the performers' movements into datasets. By using the same hardware and custom-made software, we address those problems, by for example avoiding motion tracking the feet of the performers. The main tracking system and input from the performer's body was designed to either treat the body as one unit or to use the hands to give a more dynamic and expressive range of movements. Both tracking systems translated *x*, *y*, and *z* values to the 3D environment.

During the rehearsals and first studio tests to connect the 3D space and graphics with the skeleton joints, it became clear that the hands provide a more efficient interface for the performers to express movement. Still, conceptually, the integration of the body as a whole was a fundamental part of the show. Combining both inputs, either the whole body tracking or hand tracking, and linking them to different output modalities in the graphics created the technical implementation for the mapping and tracking of *3D [Embodied]*. According to Wanderley and Rovan's definition of mapping for interactive systems, such correspondence between the performer and the media is "divergent mapping" or one-to-many (1997). This means that an individual parameter in the performer's body is connected to simultaneous parameters in the space. By using this method, the relation between the bodies and the virtual space transcends the predictability of automated systems.

Computer Generated Graphics and Motion Tracking

Generative design is a particular design method in which the output is generated by an algorithm. This involves formalization and then a definition of starting parameters that will be the source of the code. Once interpreted by the computer, an output is generated, and the designer is able to modify the rules and parameters within the algorithm.

Creating computer animation through mathematics and numerical expression creates the possibility of establishing a vast array of numeric parameters. The interactivity in real-time graphics expands the level of manipulation and control from sensing technologies and interfaces. The spontaneous, experimental character associated with the creation of real-time graphics contrasts with the premeditation associated with video and film recordings. The combination of physics and animation techniques through the use of datasets creates a privileged environment through which to explore spatial and temporal dimensions directly with real-time generated content. This exploration of real-time visualization dynamics builds on the research into real-time visualizations for dance performance initiated with the *Too&For* performance and the Super Mirror research project.

The software and overall system design is also an extension of the framework created for Super Mirror. Using Quartz Composer for generating, processing, and rendering graphical data, I developed graphic processing modules and established direct relations with the body joints from user input. I also used Kinect v1 sensors to capture the user position and motion and communicate directly to the Delicode NI mate software skeleton tracker, which refined and calibrated the position of the joints and orientation values. These values were transferred and processed through OSC protocol (Figure 39)[6].

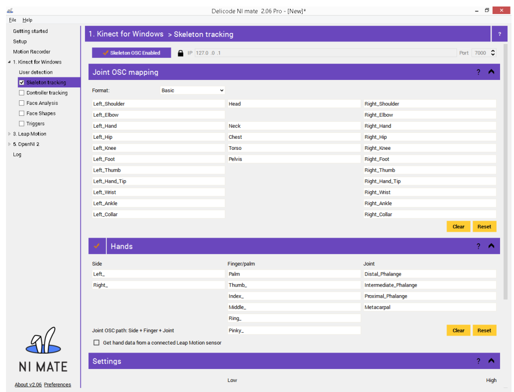

Figure 39: Delicode Ni Mate interface for OSC joint mapping

Using Quartz Composer node-based visual programming and 3D transformation graphic animation patches, the input from the Kinect camera is mapped onto the geometry of the 3D shape or object. By transforming the generative proprietes in the node, such as direction (along the *x*,*y*, and *z*-axes), speed and scale, the user can control and transform the 3D objects in real time.

[6] [OSC] - Open Sound Control (OSC) is a protocol for networking and transferring performance data such as gestures, parameters, and note sequences.

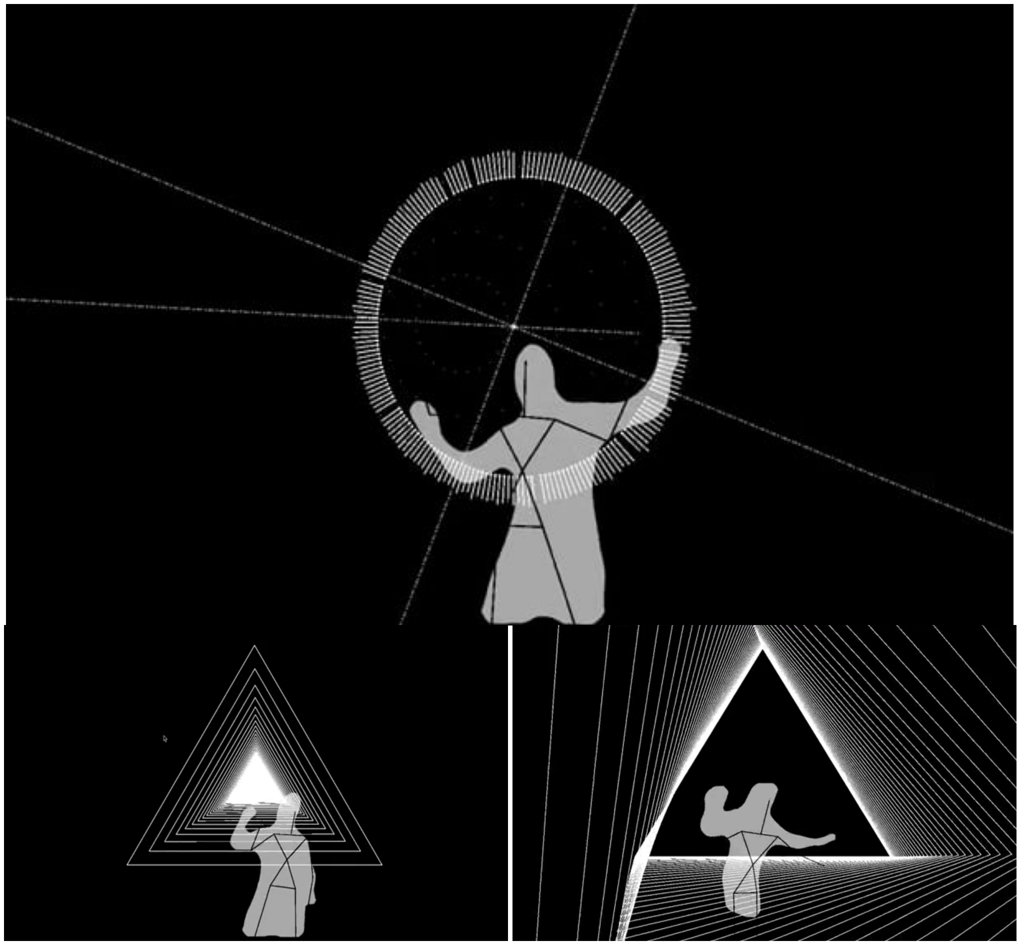

Figure 40:
Computer generated 3D graphics connected with motion tracking in Quartz Composer

PROJECTION DESIGN

In order to generate immersive and real-time mapping for the three panels of the stage design we used the method known as “cube mapping.” This process uses the six faces of a cube as the map shape. In our projection system, we implemented the same principles for the three panels (left, right, and bottom). Each side was rendered individually in Quartz Composer and grouped in the final shape of the stage design. The method used to simulate the 3D environment on flat surfaces was created by a single video projector source. By doing this, there was a loss in pixel count and focus, due to the depth of different surfaces to the projector. But at the same time, by using only one light source positioned strategically at a higher angle from the stage, there were no visible shadows from the performers on the stage to audience field of view. This created a more effective and engaging blend of virtual and physical elements in one hybrid and mixed environment.

The design of the stage had three surfaces and an open 90-degree angle between them. This is an adaptation from the cube shape that creates a limited field of view to the audience.

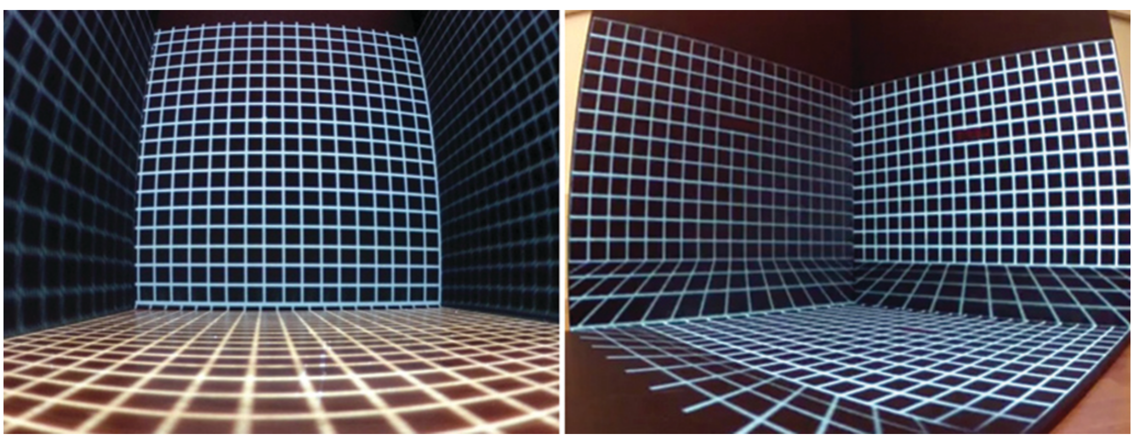

Figure 41: Left: The original concept for the show, using four planes; Right: Final design using three planes with an open 90-degree angle, using one video projector source

Mad Mapper provided a quick and effective solution to adjust the perspective transformation and the warping of different planes individually. The video projector is positioned towards the middle audience area. One of the limitations of projector-based augmentations is the fact that the light source, in this case the video projector, dictates the optimal position for the viewers to experience the illusion. The full effect is perceived along the video projector's point-of-view, and as the viewer moves to the sides there is a displacement of the apparent position of projected imagery with the physical object that is referred as parallax. One way to avoid this with video mapping is to use multiple projectors and create more individual light sources for audience to experiences the full effect of the augmentation display.

The projection design is created and optimized to look correct from the position of the audience. They experience the full effect of the overlay of digital animation mapped to the stage design. By thoughtfully arranging the position of the video projector we remove shadows from the dancers and also optimize the full optical illusion toward the center of the audience.

MAPPING/INTERACTION DESIGN

Two different mapping methods were established to create a direct correspondence between the performers and the 3D geometry control parameters.

Method 1

The first part of the show was based in the real-time tracking of one dance performer in order to transform the three planes (left, right, and bottom) on stage. These three planes had video 3D video projections overlaid onto dance performers. The performers inside of this “cube” were interacting with the space and the “activator” dancer. The dialogue between them and the perception of the augmented space in one continuous and improvised signal created the main structure of the beginning of the performance.

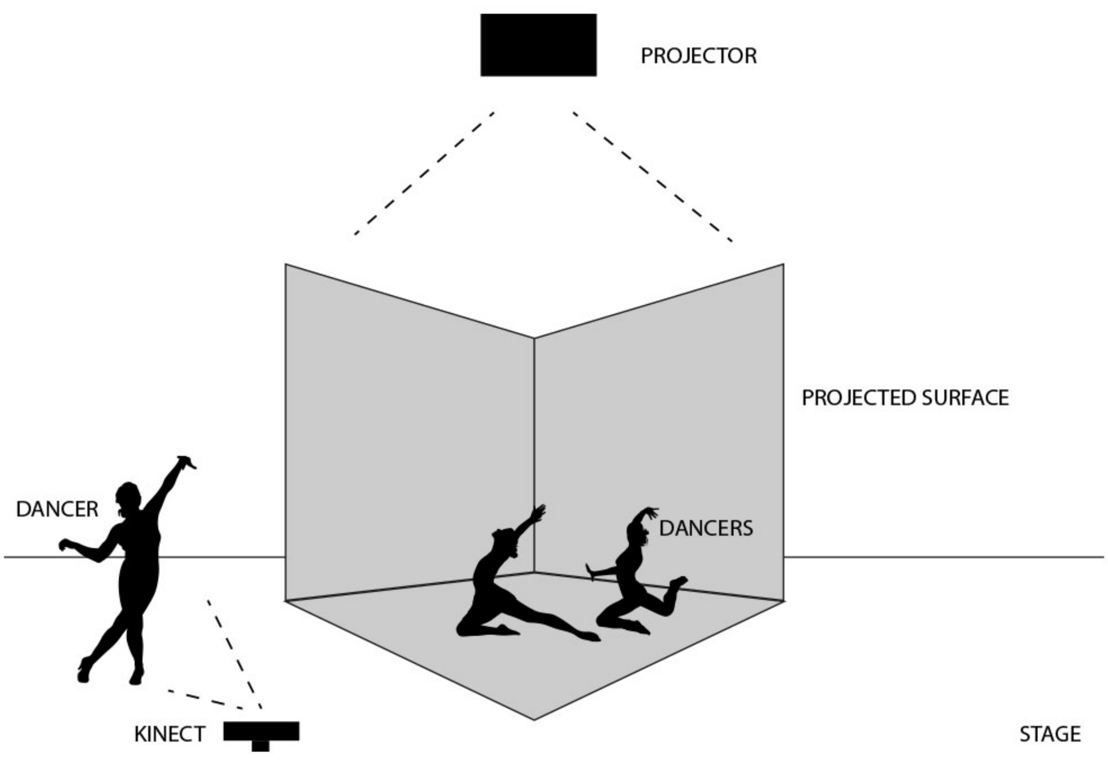

Figure 42: Physical setup for *3D [Embodied]* Method 1

The first method established a continuous stream of full body tracking information from one performer to the texture map of the stage design geometry. The visual programming framework Quartz Composer assembled the texture maps for the three different planes (left, right, and bottom) by warping quads individually. Each plane is processed according to the unique specifications of the 3D object geometry and architecture. By doing so, the perspective alignment and augmentation of the virtual and physical space were always in sync. The perspective in the three planes is composed and transformed dynamically by the body input in Quartz Composer, but the output signal is processed in MadMapper and mediated through Syphon.

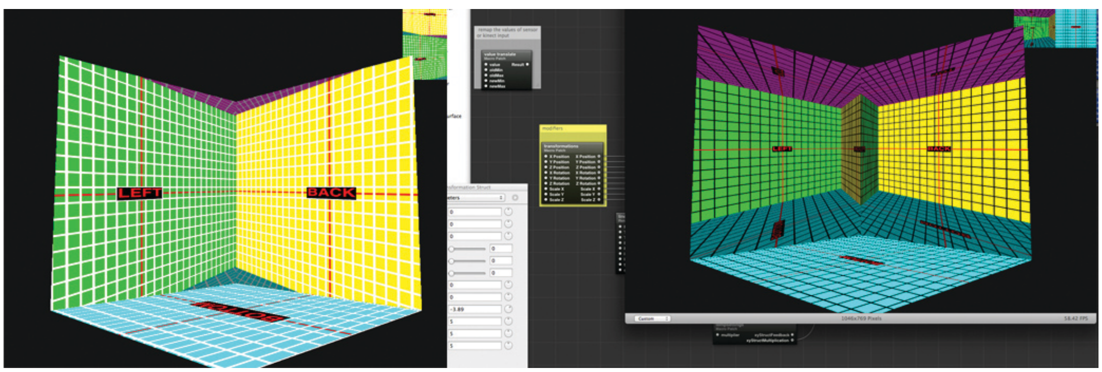

Figure 43: System architecture and physical setup in Quartz Composer for Method 1 using Perspective Matrix plug-in

Quartz Composer did not allow the proper 3D environment settings needed to create real time adjustments in the perspective transformation and a seamless cube map. In order to emulate the cube map of three different planes method and apply the same rotation transformation in each instance, we had to use a third party plug-in called Perspective Matrix from 1024 collective (Figure 43).

The plug-in allowed us to create a perspective transformation in each individual plane and to simulate a proper overlap of the different planes. The plug-in accurately created the simple cube environment but generated problems when applying external 3D objects into the same environment.

The mapping relations between the motion tracking input and the geometry transformations evolve progressively during the show. The dynamic flow is initially established by the skeleton tracking mapped to the *x*, *y*, and z rotation transformation axes of the 3D perspective mesh.

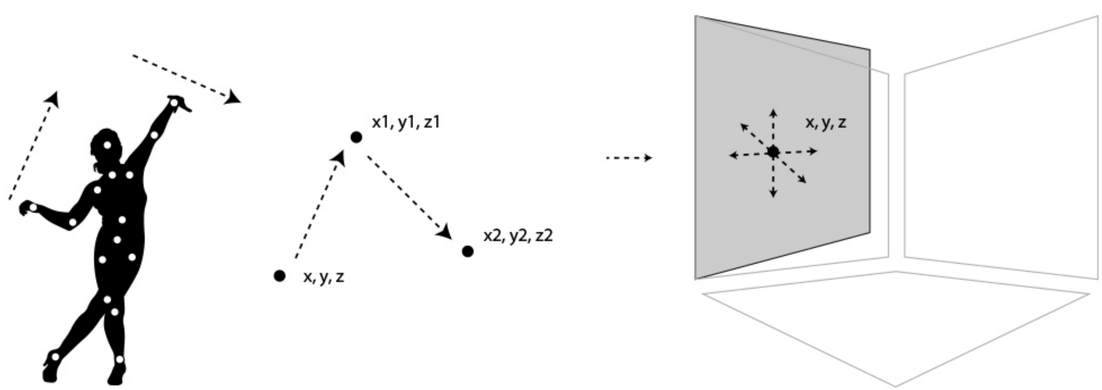

Figure 44: Method 1:
Continuous stream of full body tracking information with geometry calculation grid

The show starts with a simple 3D geometrical look by projecting a wire grid representation of the 3D space, and progressively transforms to more abstract and extreme visual geometry perspectives. The mapping between the three axes (*x*,*y* and *z*) and the 3D transformation object and mesh evolves as the show goes on, lending an element of surprise and unpredictability (Figure 45). The interaction design also evolves from a predictable cause-and-effect relationship between the body and the virtual space to more unexpected correspondences and behaviors between the two agents.

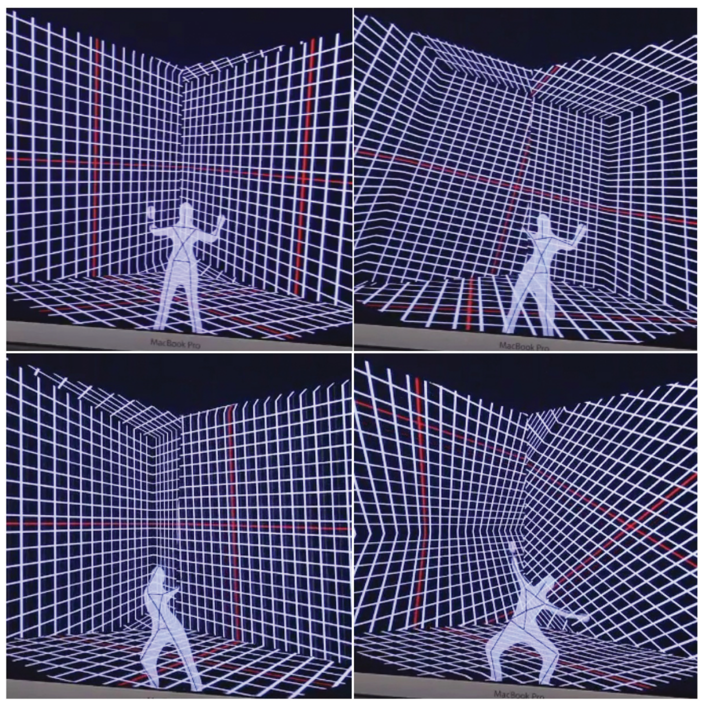

Figure 45: Motion tracking and geometry depth mapping in Method 1: The dancer practiced with the software in rehearsal in order to be able to integrate as a choreographer partner in the live performance.

Using computer-generated imagery (CGI) gave real-time rendering capacity to our system in order to create continuous interactive actions between the performer and the live visuals. This method created a dynamic visualization feedback for the dancer and provided a privileged interface for the dancer. The creation and development of the CGI software came from a process of months working directly with the dancer and the choreographer in the rehearsal. Similar to a computer game simulation, every session the dancer practices and experiments with the system. Between me, the dancer and the choreographer Yacov Sharir, we discussed and improved the software to reflect the performers capacity to improvise and express creatively to the audience embodied interactions with the 3D environment.

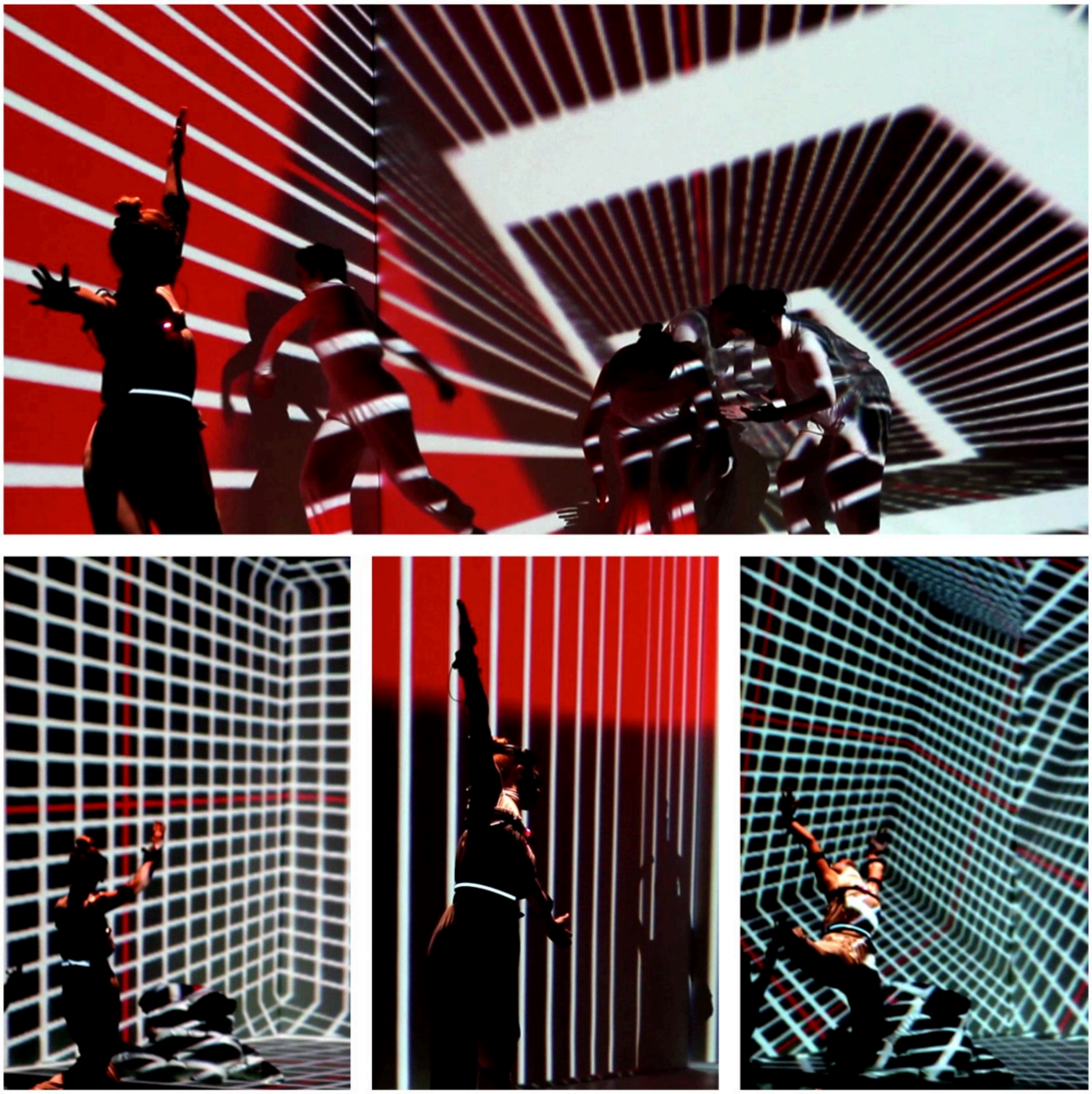

Figure 46: ***3D [Embodied]*** **performance Method 1: continuous stream of full body tracking information with geometry calculation grid**

Method 2

For the second part of the show, I established a different interaction strategy and mapping between the performer and the visualizations. Instead of using real-time generative graphics like in Method 1, I created pre-rendered 3D animations. The performers triggered these animations according to gesture recognition. This created a different human computer interaction and overall interface for the dancers. The performers were able to trigger predefined poses in order to activate media content.

The ability for the performers to engage in improvisational dialogue with the system is limited and restrictive for the dancers to engage in feedback process with the computational system. By only being able to trigger an animated action, the role of the software as a dance and choreographer partner is restricted to a one-way form of communication.

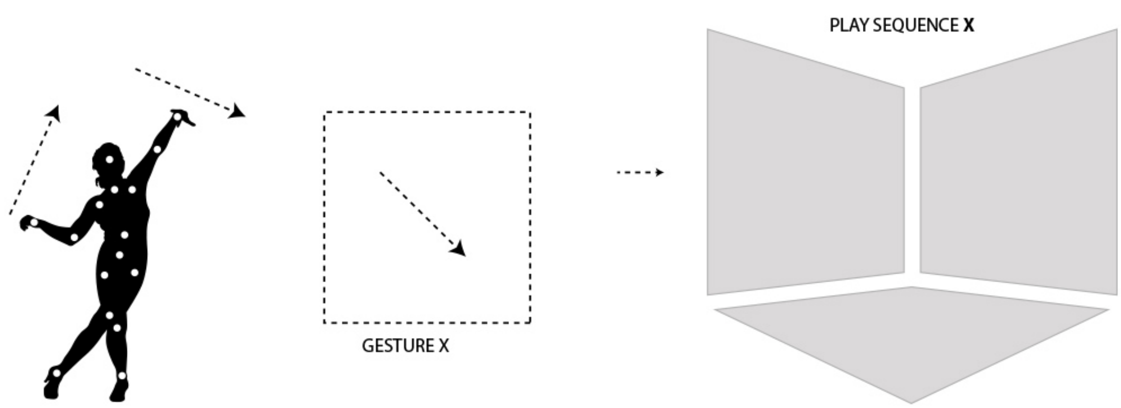

Figure 47: Interactive design for Method 2

This created a different workflow and integration between the physical movements and the complexity of 3D animation. It creates a lower level of interactivity for the dancers and restricts their ability to manipulate and transform the live visuals, but it creates opportunities to present more detailed animation design. By overlaying these complex 3D animations directly onto the performers' space and body and matching the movements of the performers to activate them as one, we create a strong perception of this hybrid space. The dynamics and variations of the animations push the limits of imagination to deconstruct the three planes into individual objects and multiple dimensions of perspective (Figure 48). The overall setup was similar to Method 1, using a Kinect sensor, Quartz Composer, MadMapper and Syphon. By using the video projector as the only light source for this part of the show, the bodies of the performers are seamlessly merged with the projections that fill the three-dimensional stage. The capacity to generate illusions through projected light revealed more efficiency in this method, but it lacks interactivity and the capacity of the system to develop creative dialogues with the dancers beyond the linear and temporal automation of sequences.

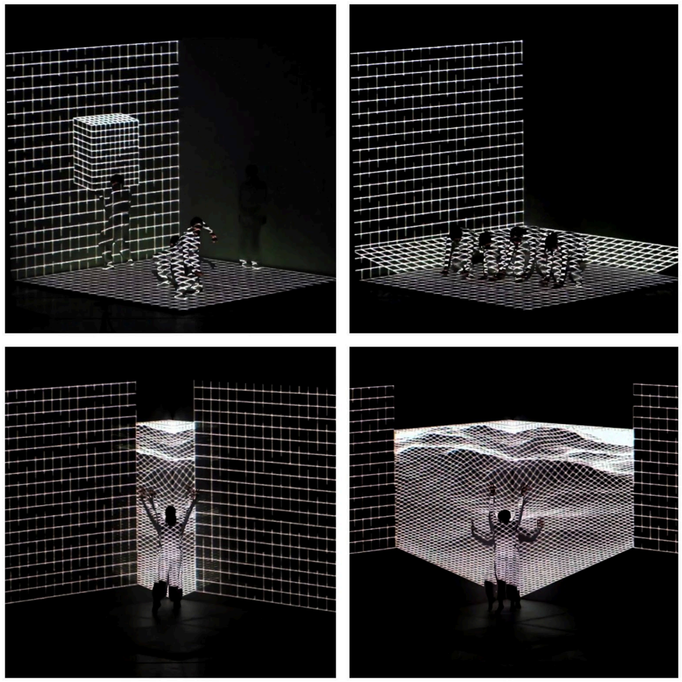

Figure 48: Method 2: Triggering of pre-rendered 3D wire frame animations creating direct interactions between virtual objects and the performers.

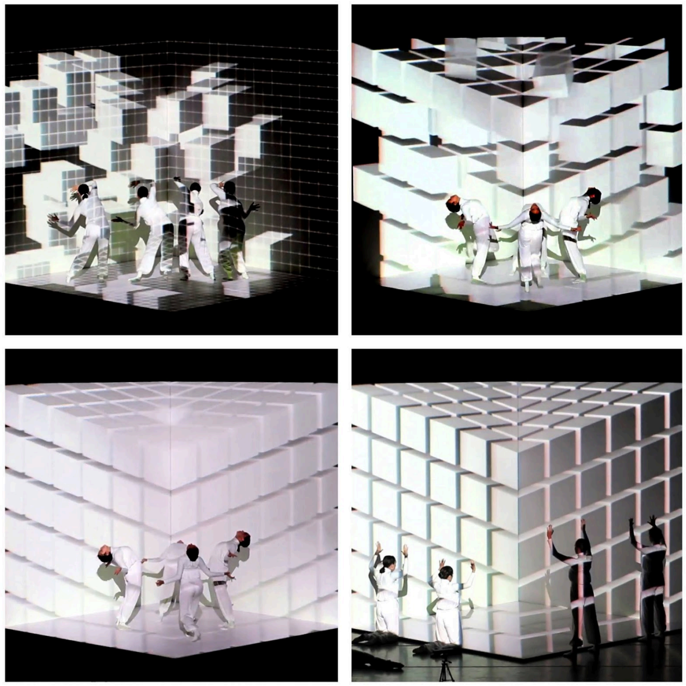

Figure 49: Method 2:

Triggering of pre-rendered 3D animations exploring more detail and complex interactions between the performers and the perception of three-dimensional space.

Discussion and Conclusion

3D [Embodied] explored real time spatial interactions between dance performers and 3D augmented environments. By overlaying the digital 3D graphics with the physical space and the performers bodies, the audience experiences augmented virtuality as a form of digital dance performance.

Audience Reaction/Feedback

Several interviews with audience and the dancers were conducted after the shows to analyze the role of the interactive projection based augmentations for live dance performance from a variety of different perspectives. A common topic of reflection and analysis from the audience concerns the ways their perception was affected by the overlay of 3D graphics onto physical environments. Some audience members acknowledged that they felt confused and visually overstimulated, and they were distracted from the dancer's movements, usually the primary focus of a dance performance. The nature of dance performance was reformulated and extended with our introduction of interactive media art, and there is a shift of attention and in the overall dynamics of the show. In digital dance performance, the dancer and the augmented environment became one source and body of expression. The amount of information to process in a mixed reality environment is significantly larger, and it challenges the audience.

The design process should intentionally avoid these obstructions and overload of information for the audiences. Instead, the media design should primarily amplify and augment the expression generated by the performers. This was clearly the case in Method 1. By using a continuous stream of tracking, where even subtle movements from the dancer transformed the geometry of the immersive mapping, we expanded the creative flow for the dance performer. The focus length was centered on the performer's action, which created a direct extension of their behavior. One of the audience members mentioned that these dynamic augmentations somehow related to Butoh because a small motion from a dancer can create a dramatic impact and on the environment and inspire an extreme emotional response.[7]

The process between the creation of the interactive visualizations and the choreography design changed profoundly depending on the nature of interactive design used for each method. The approach to workflow in rehearsals was different for each method, and this dictated different choreography design processes. This in turn created different creative interactions and interfaces for the performer with the virtual world.

Method 1 used a continuous tracking signal, generated real-time responses, and provided a high level of interaction and integration between the dancers and computer-generated imagery. This particular framework and media design created a platform for the dancer to express her creativity in real time by allowing the performer to improvise. It also motivated the choreographer to assign a more creative role to the dancer. The rehearsal process was created by direct interactions between the performers with the system, similar to interactions created by playing a computer game or playing a musical instrument. The outcome of the live performance of the dancer was a direct result of the honing those skills in practice and rehearsal space.

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[7] Butoh is a form of improvisatory Japanese theatre using slow, hyper-controlled motion to explore the intentionality of emotions. The following chapter, on *Luxate [Komorebi],* will examine the framework of Butoh more thoroughly.

The dance performer in control of the augmented system reported that she felt in control of the system and could sense a good level of feedback: "I can control my body and movement in specific directions in order to shift the environment." She also reported some tracking issues when overlaying one hand over the other at specific moments. This is also one of the limitations of using one depth sensor to do a full 3D tracking of the human body. By using multiple sensors and cameras this limitation can be solved and create a more detail real time scanning of the 3D space. The performer also highlighted, based in her previous experience with sensing technologies, the advantages of natural interfaces. She felt more expressive control: even though at some moments the accuracy of our system might not be as precise as wearable technologies, she was able to move her body more freely and engage in more natural creative settings.

Method 2 used more conventional media strategies to organize and design the choreography. The choreographer analyzed my animation design in order to collectively find ways to engage the performers in mixed reality environments and find specific events to trigger new sequences in the system. The improvisatory role of the performers was clearly limited, but the complexity of the visual outcome and dynamics of the pre-rendered content was visually very appealing to the audience. This particular method reveals to the audience a complex integration of augmented virtuality environments but limits the role of the software as an extended agent for the dancers. It promotes the capacity for the performer to simulate complex relations between the visual feedback and their actions.

I conclude that Method 1 limits expressive control of the dance performers to transform and modulate the media in real time. The generative continuous tracking and signal processing between the performer and the 3D environment of Method 1 provides a higher level of integration of the media with dance expression. The combination and aggregation of both systems in one integrated system will create a higher interactive and augmented system from Method 1 with a higher level of visual immersion for the audience from Method 2. This way, the pre-planning process of the choreographer and the improvisation skills of the dancer can generate a better balance and flow between them.

Limitations of 3D Projection Mapping

3D [Embodied] also presented some of the limitations of using video mapping as display technique to create augmented virtuality environments. Primarily designed for the audience perspective, the optimal positions for the full effect of the projected illusions are experienced by the video projector position. This means that audience members located towards the side of the audience will have a different visual perspective of the illusion, a displacement in apparent position of an object that is referred as parallax.

Future Work

Future work for the integration between computer generated graphics and live performers would benefit from using a more advanced render framework of a multi-platform game engine, such as Unreal engine and Unity 3D, to create more advanced 3D rendering in real time. This particular game engine allows the generation of more complex and detailed 3D shapes, exploring elements in the 3D object such as shadows and shaders.[8]

The use of shadows, as we confirmed in the second part of the performance—Method 2—is highly effective at creating the illusion of 3D space and visual immersion in the mixed reality environment. Being able to render them in real time connected directly with the performers' continuous tracking and input is an important milestone to achieve for future work and similar systems. It generates a more effective visual strategy for creating augmented virtuality dance forms.

While this project connected the tangible space to the virtual, we identified some of the limitations of generating this type of illusion in dance performance. The next project continues to use dance and moves toward the creation of a holographic representation of space that goes beyond the physical dimensions of the theater to project not onto physical space but into "thin air."

[8] Shaders, also know as depth shaders, are applications created to produce special effects to the 3D object. Most shaders are coded for graphics processing unit to be rendered in real time systems.

Chapter 5: *Luxate [Komorebi]*

Overview

Luxate [Komorebi] is a digital dance performance that explores the interactions between the dancer and 3D light projections that exist beyond the screen and the tangible physical space. It is an exploration of the infinite and non-screen-based, projector-based augmentations. It was commissioned by Julia Kaganskiy and presented at the Dee and Charles Wyly Theater as part of the Aurora Festival in Dallas, Texas on October 16, 2015. I created the concept, art direction and visual design, Echo Higuchi was the solo dance performer, and David Wesley and Gustavo Magalhães created the sound design. The performance had one dancer, and it lasted for 8 minutes.

Komorebi is a Japanese word to describe the light and sunshine filtering through the leaves of trees. It refers to the magical and spiritual dimension of light filtered through nature. It was the starting point and inspiration to explore interactive display techniques of projected light with haze combined with projector-based augmentations.

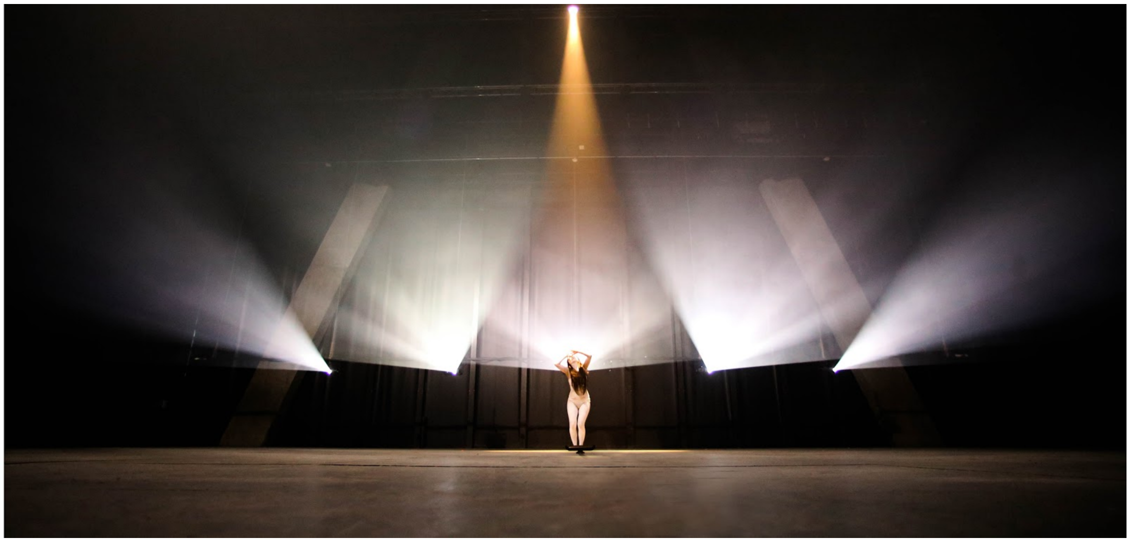

Figure 50: *Luxate [Komorebi]* performance at Aurora Festival in Dallas (2015)

In this chapter, I start by contextualizing research into the sculptural exploration of light by analyzing the work of Anthony McCall, Sebastian Huber, Jayson Haebich and Nonotak. Through installation and performance art, these artists explored the use of projected light as an immersive, volumetric, 3D shape. In a different approach than traditional projection mapping, the light is projected directly towards the eyes of audience members and filtered by haze, similar to what is commonly perceived as holographic displays. This allows me to investigate the creative qualities of the projected light beam in the three-dimensional space created by digital video projectors and smoke.

The relation between gestures and body movement with the graphical programming environment was established through simple iterations. This dialogue is possible through precise calibration between the six video projectors output and one Kinect sensor area. The tracking and mapping was based in basic geometry and generative design with positional tracking of the performer, either from the whole body or the hands in the *x*, *y*, and *z*-axes.

In order to make this digital light field and virtual environment interactive, I invited the participation of a Japanese Butoh dancer. Butoh, as an improvisational, hyper-controlled dance form, focuses on the emotional dimension of dance beyond the physical movement. This particular relationship between body and space was established by the interactive design principles that connected computer generated graphics to the physical body of the dance performer. By connecting the physical body with virtual space, *Luxate* creates a reactive environment between the dance performer and the perception of a three-dimensional light field. According to our conceptual framework, *Luxate* is an augmented virtuality performance and generates "holographic" augmented interactions and environments in live dance performance.

I conclude that this particular display technique is limited and restricted to the representation of bidimensional simple shapes. But, by applying those simple 2D shapes generates highly immersive 3D illusions and create a high sense of depth to the audience. By making them interactive, the physical body and physical environment communicate in real time, connecting dance and space as a form of augmented virtuality art and expression.

CONCEPT

Komorebi is a Japanese word to describe the interplay between the light, the leaves and the reflection after the rain created by the water vapor, atmospheric haze and dust particles. This phenomenon is usually perceived as a spiritual and mystic experience. This particular form of projections floating in midair, generated by nature, motivated me to use digital technology to make such environments and displays interactive and embodied.

Figure 51: First tests using projection mapping directly to the audience's eyes with haze and the integration with the dance performer

Luxate explores infinite and non-screen based projector based augmentations. Exploring the qualities of the projected light beam in the three-dimensional space created by digital video projectors and hazing machines, we create a reactive environment between the dance performer and the perception of a light field. The minimal and digital nature of the automated system is embraced and contrast with the conceptual inspiration for the performance, in komorebi and the perception of light being filtered through nature and threes. In *Luxate*, the dancer filters the light, and fills the role of the trees in komorebi. Including an improvisational Butoh dancer, we explore the emotional and abstract expression of Butoh transformation and mapping towards tangible physical and automated systems of 3D projected light.[9]

Activated by motion, *Luxate* is a dance performance that generates a live dialogue between the performer and the overlaid virtual 3D imagery, beyond the physical dimension of the projected image (the screen or display area). The combination of video projection with smoke and haze creates a holographic dimension to the light beam that is being projected into the audience's eyes. *Luxate* is an exploration of new approaches and strategies of projector based augmentations. The project investigates the tactile dimension of light in spatial augmented virtuality (Figure 52).

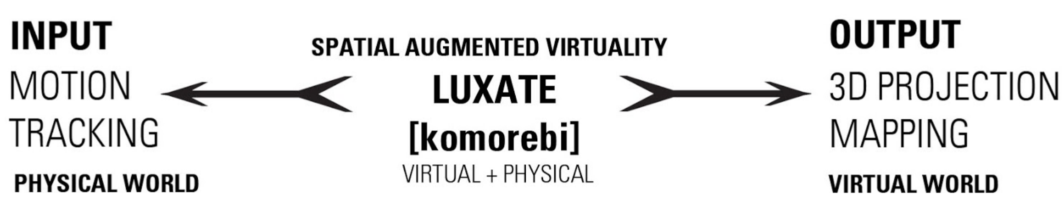

Figure 52: *Luxate [Komorebi]* is positioned as spatial augmented virtuality in the mixed reality theoretical framework.

[9] Butoh is a form of Japanese theatre exploring the intentionality of emotions to produce slow hyper-controlled motion and dance expression. Butoh's origins are originally attributed to Japanese dancers Tatsumi Hijikata and Kazuo Ohno (Barber, 2006).

Related Work

Holographic Environments and Simulation Displays

The inspiration for *Luxate* was the exploration of automated and interactive digital light without using a physical surface projection area. Previous performances, such as *3D [Embodied]* used projection techniques based on the use of physical objects and environments to overlay with digital imagery. These projection mapping techniques can also be applied to physical environments without the use of screens or any physical surfaces by filtering the passage of light using fine suspended particles in the air through the use of haze or smoke. Such techniques have been used since the 19th century to simulate the presence of ghosts and spirits. Etienne Gaspard Robertson, a Belgian optician, opened an exhibition in an abandoned chapel using this particular technique to invoke the presence of ghosts in the height of the French Revolution: "All these wonders were perpetrated through the medium of a phantasmagoric lantern, which threw images upon smoke. This was a great improvement on the simple concave mirror... The effect of this entertainment was electrical: all Paris went wild over it" (Hopkins & Evans, 1897, p. 7).

The exploration of 3D holographic projection simulations can be traced to illusional theater Phantasmagoria using magic lanterns. Invented in the mid 17th century by Athanasius Kircher and Christiaan Huygens, magic lanterns created for the next centuries a wide range of projection-based illusions on unconventional display materials such as fabric and semi-transparent screens. Directors such as Gaspard Robertson created audiovisual performances around the 18th century "by manipulating light, shadow, mirrors, projections on glass, transparent screens, projection on glass, moving lanterns and magic lantern" using the theme of terror and demons as inspiration (Burns, 1999).

Around 1862 John Henry Pepper and Henry Dircks co-created the technique known as *Pepper's ghost*. This is an illusion created by a glass, plexiglass or plastic film positioned in a vertical axis of 45 degrees with the scene and the audience. This technique has been widely used in the past centuries and decades in entertainment because of its qualities to perceive depth and to represent the illusion of holography on stage. The 2D display creates the illusion of 3D displays for an audience located at 90 degrees from the screen and has been the easiest only way to effectively create the illusion of 3D volumetric display. The term *hologram* has been widely used and adopted as simulations of 3D volumetric displays but the scientific meaning is closer to a photographic medium as "it captures an imprint of the light waves that bounce off an object" (Neal, 2016).

The Exploration of the Sculptural and Holographic Dimensions of Light in New Media Art

As previously described, the combination of video projection with smoke and haze creates a holographic dimension to the light beam that is being projected. This is inspired by Anthony McCall's work with light and perception of light waves. In particular, in his seminal *Line Describing a Cone*, a volumetric form of projected light was created and exhibited throughout its slow evolution in the three-dimensional space. Independent filmmakers were among the first that began to explore the sculptural dimensions of film in the late 1960s. Usually referred as “expanded cinema” or “structuralist film,” their guiding principles introduced the idea of working with light as a medium to other artistic approaches. Gene Youngblood presented the visionary concept of the Kinoform, a computer-generated Holographic movie (1970, p. 414).

Also during the 1970’s, Anthony McCall was one of the filmmakers who rejected the linear narrative of Hollywood cinema. His experimental approach into cinematography and video can be described as expanded cinema, as defined by Youngblood (1970). McCall developed the *solid light* film series and *Line Describing a Cone* in 1973. The series is created through video projections that focus on the sculptural qualities of a beam of light. The relationship between the viewer and the film is experienced in infinite space, as opposed to a screen, that displays a clear image in a surface. The viewer is invited to watch the film backwards, looking along the beam towards the projector itself:

> Line Describing a Cone is what I term a solid light film. It deals with the projected light beam itself, rather than treating the light beam as a mere carrier of coded information, which is decoded when it strikes a flat surface. (McCall, 2003, p. 42)

Because of the transformation of a bidimensional simple line to a complex three-dimensional shape through projected light, *Line Describing a Cone* is considered by McCall to be the first film to exist in real, three-dimensional space. The movement of the audience along the installation area affects the perception and point of view of the light form, incorporating a participatory element in the experience and allowing participants to interact freely in the space.

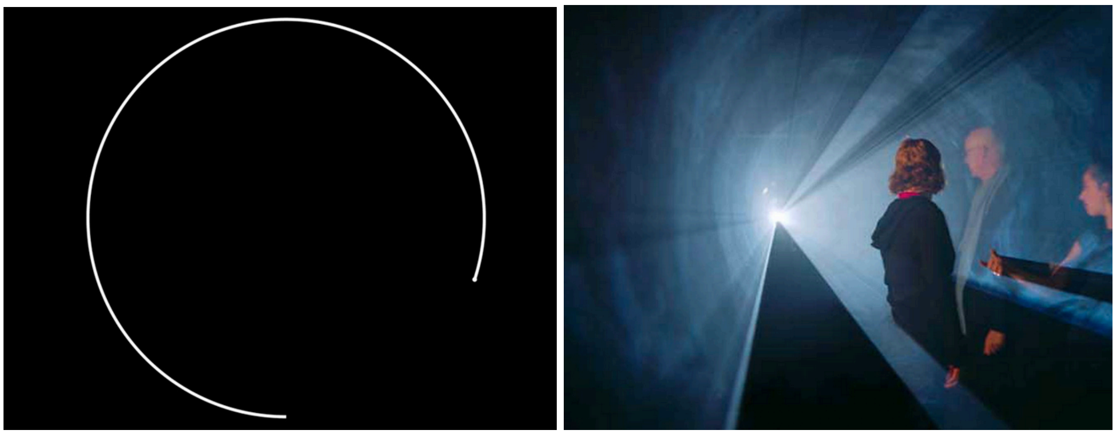

Figure 53: Anthony McCall's *Line Describing a Cone* (1973)

In a recent interview, McCall described the characteristics of solid light as a sculptural experience as the paradox of solid light: "The membranes of light are so palpable that spectators often test them by reaching out to touch them, even though there is only thin air. And yet, the planes of light are not an illusion: they are actually, I might say physically, present in three-dimensional space" (2014). McCall explains that the drawing is central for this particular medium, but the three-dimensional volume created by the planes of light give it a unique character with unique features of perspective rendering. This particular manipulation of light played an important role in the visual and installation art world as well as in avant-garde films. McCall has been developing a new series of computer-animated, digitally projected "solid light" projects since 2003, employing the same formal vocabulary but with digital techniques of animation and projection, such as *Breath* (2004), *You and I, Horizontal* (2005) and *Coupling* (2009).

A more recent installation from the Brazilian artist Ernesto Klar named *Luzes Relacionais (Relational Lights)* in 2010 also uses light, sound, and haze, morphing sequences of geometric light forms and sounds. The installation projected a line directly on the floor, and guests were invited to touch the beam of light. They could simultaneously control the movement and gravity of this project line and light beam. The guests are invited to interact with the projected light-space in a collective space with multiple beam lights and video projects (2011).

Epilog is also an interactive installation exploring a beam of light projected onto the floor. It incorporates a tracking camera device. The project was created by Sebastian Huber, Johannes Timpernagel, and Michael Burkn in 2013 using vvvv and pure data. The reactive floor uses physical forces to generate real time interactions with the users. This installation has a performative dimension, in the sense that the audience has to move along the physical space, and projection similar to the movement of a video camera (2015).

Noemi Schupfer and Takami Nakamoto, also known as Nonotak, presented the audiovisual installation *Parallels* in 2015 at the STRP Biennale in Eindhoven. Inspired by McCall's exploration of light as a material and beyond the screen frame, it uses space as a performance stage that becomes the screen. As an installation, the direct interference of the audience crossing the space generates a direct intersection with the light beam.

This particular setup, using multiple projectors, explores the sequence alignment between them. This method and projection technique was adopted in *Luxate*, which also uses multiple video projectors. But contrary to *Parallels*, which was pre-rendered, *Luxate* uses real time interactive generated visualizations.

Figure 54: *Parallels*, an audiovisual installation using multiple projector sources pointed directly at the audience by Noemi Schipfer & Takami Nakamoto (2015).

FRAMEWORK DESIGN AND TECHNICAL SYSTEM

Setup

Luxate uses motion-tracking recognition to control the projection of light created by computer generated graphics in real time. Through the use of motion tracking I created perspective calculations of the dancer's location, position and movement to the 3D generative light field. Our system uses touchdesigner as the main visual development platform to combine the input modalities of the body in movement with the computer generated graphics and projection design.

The input data from the skeleton tracking was mapped to 2D vector black and white computer generated graphics. The output signal was projected primarily from six digital video projectors pointing directly to the eyes of the audience and another video projector pointed in the opposite direction, towards the stage and the dancer (Figure 55).

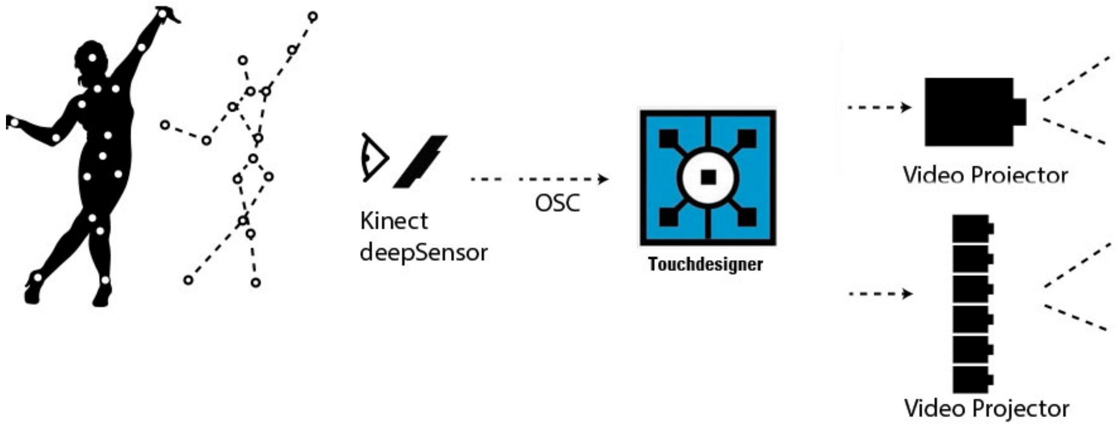

Figure 55: System architecture for *Luxate [Komorebi]*: The input is established by the skeleton tracking data captured by the depth sensor camera, processed in Touchdesigner in order to send the output signal for two frontal and rear digital video projections.

Motion Tracking

The 3D depth-sensing camera is mounted on the floor directly facing the center of the stage and the dance performer's position. The performer's body tracking process is similar to the one created and described in *3D [Embodied]* performance, which treated the whole body either as one unit or using the hands to explore a more dramatic and expressive range of the movement. The skeleton tracking captured data of the 15 body joints. The tracked body data is reconstructed in a virtual OpenGL 3D environment using Touchdesigner**.** The tracking is established by a combination of two distinct methods to collect and process the movements from the dancer. First, by tracking the full body skeleton uses the data as one unit of *x*, *y* and *z* values. These values were processed mainly for speed and acceleration of the joint movements, the inclination of limbs, and the distance between selected joints, such as legs and arms. Secondly, by tracking the hands independently to establish a micro control and more define control between the performer and the 3D projection light design. More precisely, the speed and acceleration of the hands combined with the 3-axis accelerations of the hands.

PROJECTION DESIGN

Six 3,000 lumen-projectors of are set up on the back of the stage facing the audience, aligned to the center of the stage and to the audience's eyes. In the opposite direction, one 10,000-lumen video projector is pointing towards the stage. By situating them in opposite directions, I am able to merge both signals, either the six projectors from the back, and the one projector facing the stage (Figure 56).

The performer is centered on the stage and facing the audience. Projecting directly in open air and pointing directly to the audience creates a collective experience and display that can be viewed from multiple angles and by different spectators. Still, just as in 3D video mapping, the illusion is more effective when the viewer is aligned and centered with the position of the video projector. All the video projectors are aligned at the same height and centered to the dancer position of stage. The haze machines are located towards both sides of the stage, to create a uniform and balanced distribution of haze in theater space.

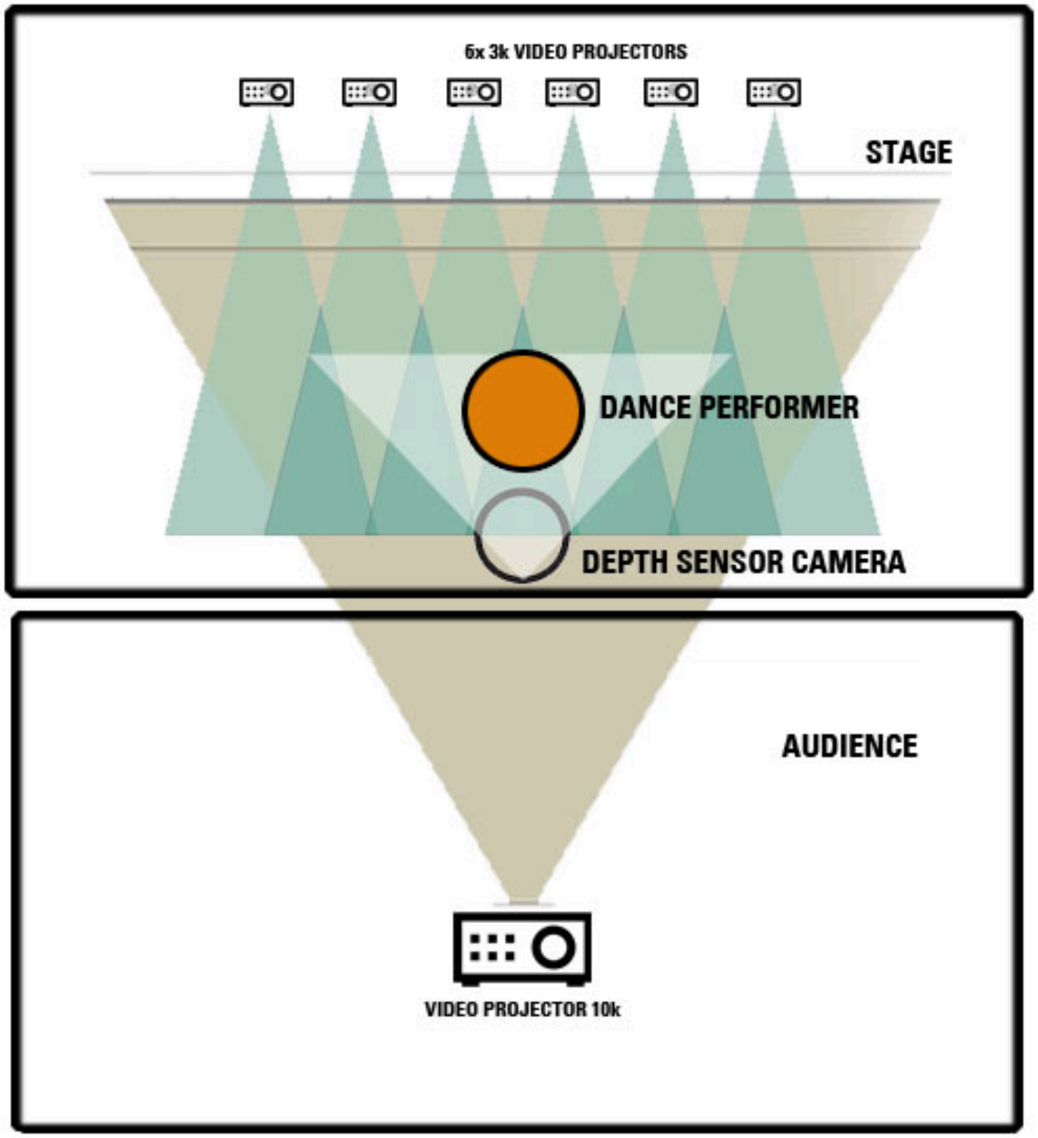

Figure 56: *Luxate* projection design and spatial setup: view from the top. Six digital video projections point directly at the audience's eyes, with one video projector pointing in the opposite direction. A Kinect depth sensor camera points towards the stage and tracks the body of the dance performer.

Creating content for multiple projectors to be experienced by looking directly to the light beam is a defined alphabet and grammar for projection design. It was necessary to decode the basic geometry elements and geometry connecting the digital graphic with the light display output.

The “alphabet” of light is processed according to basic principles in using simple bidimensional vector graphics to generate 3D visualizations:

1. A point creates a 3D line
2. A line creates a 3D plan
3. A circle creates a 3D tunnel

These simple translations illustrate the passage from the 2D designs on screen to what the audience perceives with the use of projected light. Using these guidelines distributed in six different outputs and modalities as the only light source created a fully immersive dynamic light architecture. The light displayed and projected by the video projector does not stop reproducing itself until it reaches the walls of the theater space. For example, by projecting a circle, the audience experiences a 3D “tunnel” effect generated by the light and haze (Figure 57).

Figure 57: *Luxate* performance: audience view. A circle projected from the front creates a 3D tunnel to the audience. A line creates a solid plan, and a point creates a line.

Just as in conventional 3D projection mapping, the position of the viewer is central to the illusion generated. The alignment with the projector necessary in projection mapping is the same as when you project from the front. In order for the viewer to be "inside" of the tunnel, he needs to be situated towards the center of the circle. This form of projection converges the light source with the viewer's horizon. The illusion of depth on a flat surface, also referred as linear perspective, converges a single 2D point into a 3D horizon line.

This particular form of light display has a limited range of elements that are perceived as 3D representations to the audience. The most effective 3D illusions are generated by simple 2D shapes such as a point, line and circle. Using multiple video projectors allowed to us to explore the individual signal and the transition between them.

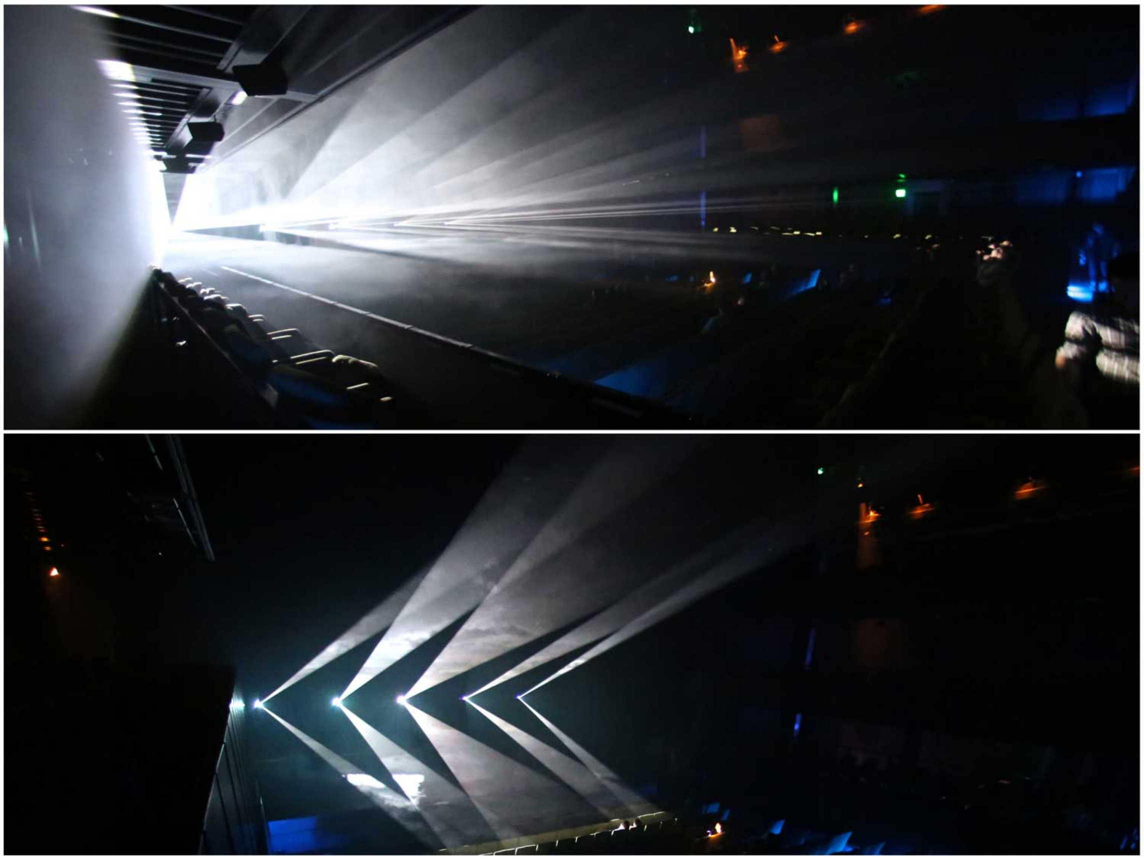

Figure 58: *Luxate [Komorebi]*; The alphabet in this display technique established direct correlations between bidimensional simple shapes and 3D visualizations for the audience. The creative and design process was created by using simple 2d computer generated geometry between the five video projectors,

MAPPING/INTERACTION DESIGN

The mapping between the physical body and the virtual body is developed to transform and overlay the virtually generated geometries directly in the physical performance space. The virtual layout and space is overlayed one-to-one with the physical space. By doing so, the motion of the physical space matches the movement of the tracked skeleton in the virtual space in the scale and proportion of our 3D virtual environment. This particular process is essential to successfully establish a 3D video mapping output. In this case, by projecting in the fog by the respective beamers.

The same method established previously in *3D [Embodied]* using a continuous tracking signal between the 3D skeleton tracking and computer-generated imagery was adopted (Method 1). The overlapping of virtual imagery in the physical space creates bodily interactions with the projected lines, tunnels and abstract shapes. For the first part and beginning of the performance, I created a virtual line that the performer can control with her body, using the tracking method as one data unit of x,y and z values. The performance starts with a vertical line projected from the back using the six independent signals, aligned to the performer's body (Figure 59 and Figure 60). As the performer's hands move to the left or right, the lines follow the movement in space, creating an overlay of the vertical lines centered on the performer's body.

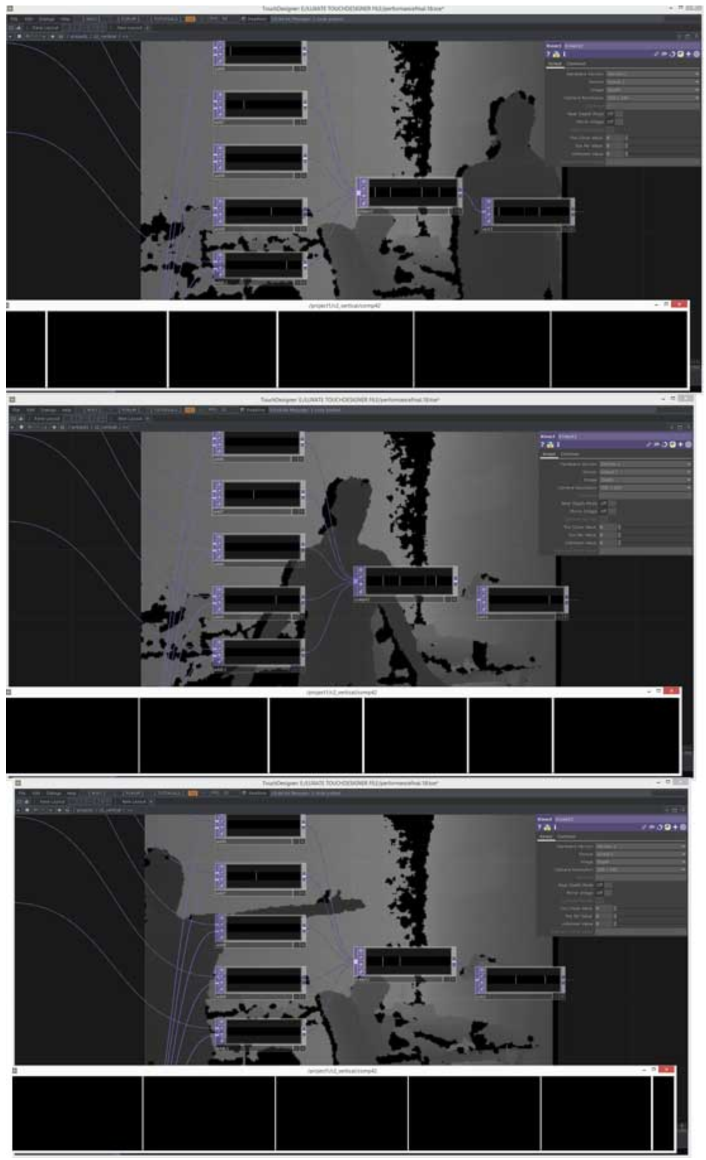

Figure 59: Image illustrating hand tracking controlling digital vertical lines in rehearsal, such that all the planes are oriented towards the dancer. This is a backend screenshot showing the computer-generated imagery in the bottom and the performer's body on top. The image is processed in touchdesigner, which positions the performer's location, the virtual imagery and the projection design output.

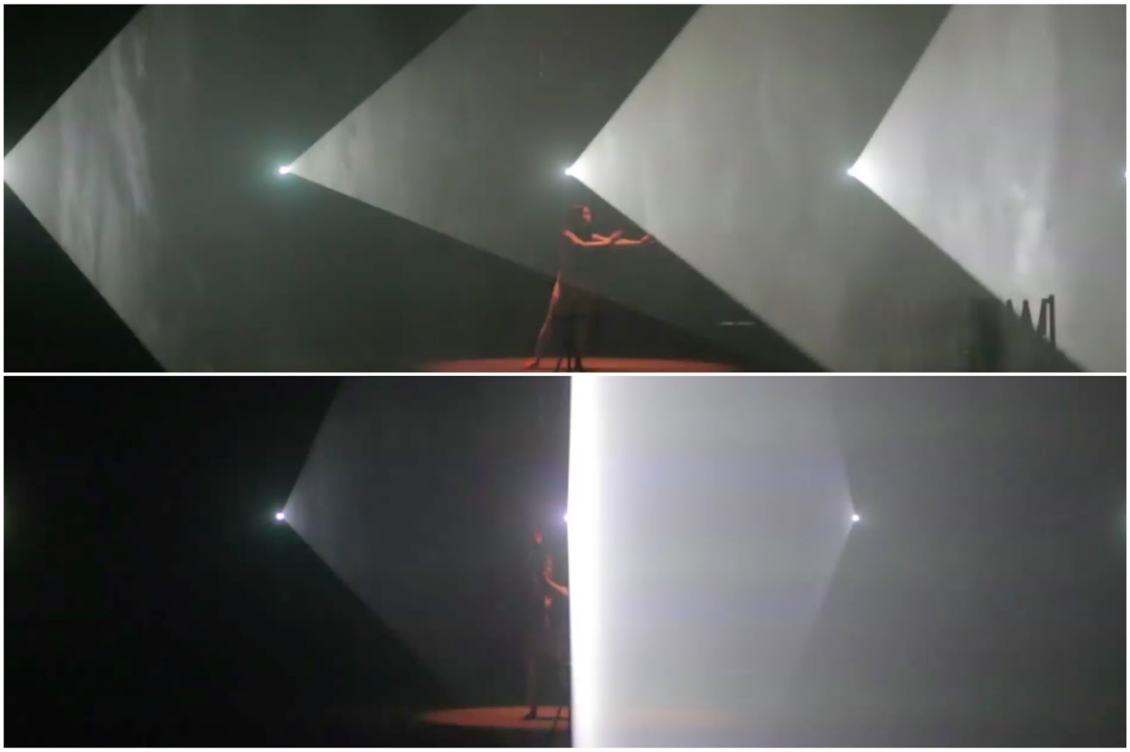

Figure 60: *Luxate [Komorebi]* rehearsal (hand tracking controlling digital vertical lines in rehearsal): When the hands are located in the center, the vertical lines aligned in the middle. This was the starting scene of the performance, initially controlling one vertical line that multiplies to one line per projector.

Even though the graphics and visualizations are generated in real time, there were pre-programmed scenes set in a timeline. For example, the first scene will bring one vertical line, and in ten seconds will fade in another line per video projector pointing and centered towards the performer. A broad range of different configurations and scenes were built on top of this model, slowly developing and expanding the perception of the embodied 3D space to the audience. These relations created a complex network of physical interactions with virtual geometry based environments by mapping the tracking to core model transformations, behaviors and graphic rendering. Also, the audio signal is processed also in real time using the skeleton tracking data to transform the generative audio synthesis. The design process is created to aggregate the physical performer location with the reactive light field. At the base lies a simple geometry design of vertices of 3D vector graphics. This relationship is central to exploring the creative and improvisational dialogue between body and space in our augmented audiovisual system. It ties the light, sound, movement and presence output into one multidimensional mixed reality environment.

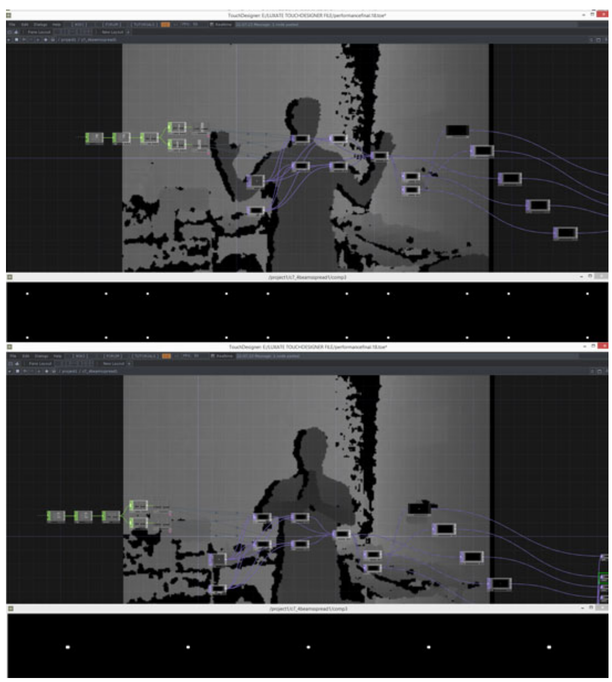

Figure 61: Hand tracking using simple dots in rehearsal. The speed and acceleration of the distance between the hands is controlling in real time the position and the multiplication of the computer graphics.

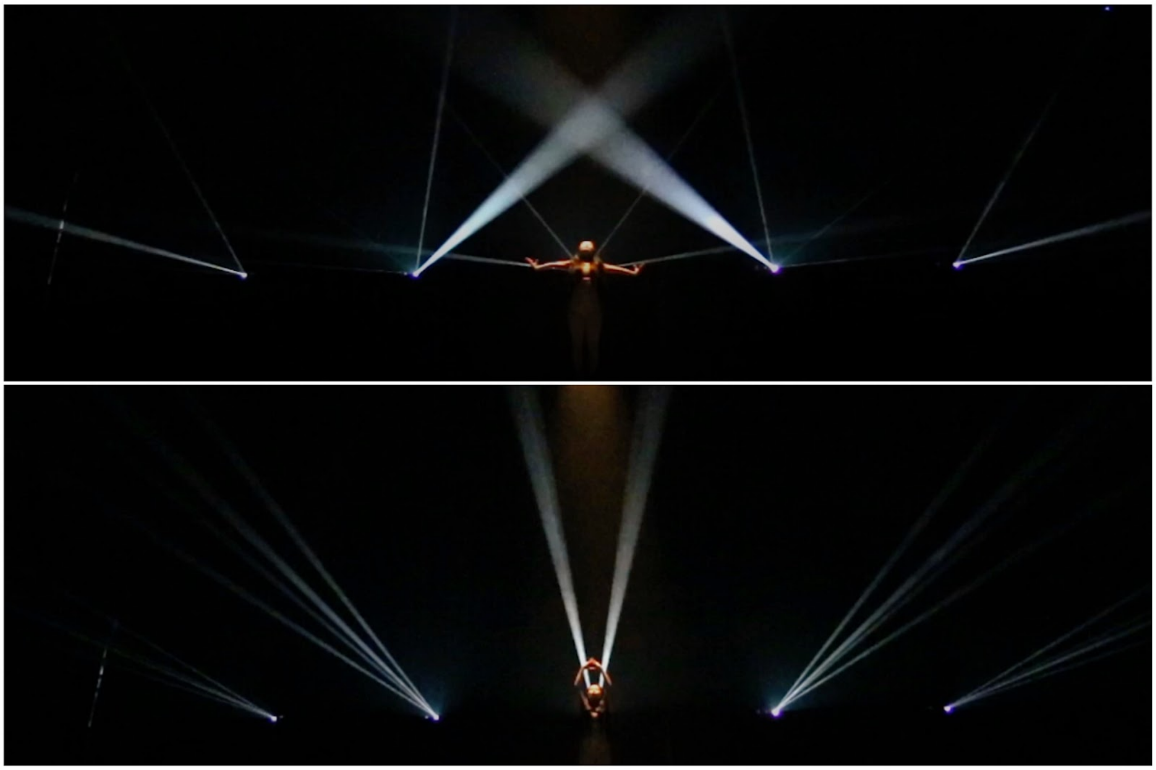

Figure 62: ***Luxate [Komorebi]*****: Hand tracking using simples dots live during performance (compare with previous figure)**

PERFORMANCE ANALYSIS AND CONCLUSION

Butoh dance expression introduced challenging improvisational and abstract attributes to creatively explore the relationship between the interactive hybrid three-dimensional light field and the dancer. Improvisation is central in Butoh expression, making it necessary to correlate abstract characteristics of human emotion with 3D motion. This relationship uses depth as a expressive dynamic and integral part of the augmented process. Butoh also combines meditation with hyper-controlled slow motion expression (Barber, 2006). This tension was creatively explored and executed through slow motion and highly reactive interactions between the 3D lightfield and the performer. The emotional abstraction of Butoh is then mapped and linked with motion and is experienced through projected reactive light.

The interactions of the performer with the 3D light field incorporated levels of improvisation, with the body sculpting the space with sound and light in real time. In the climax of the performance, an independent light source from the top was used to create a new light source and to cross the five rear projections with the frontal projection. This created one of the strongest integrations and interactions between the performer and the project light, allowing the dancer to control and modulate the light beam with her hands, as an extension of her body. By using light and geometry, the spiritual and mystical dimension are intertwined (Figure 63).

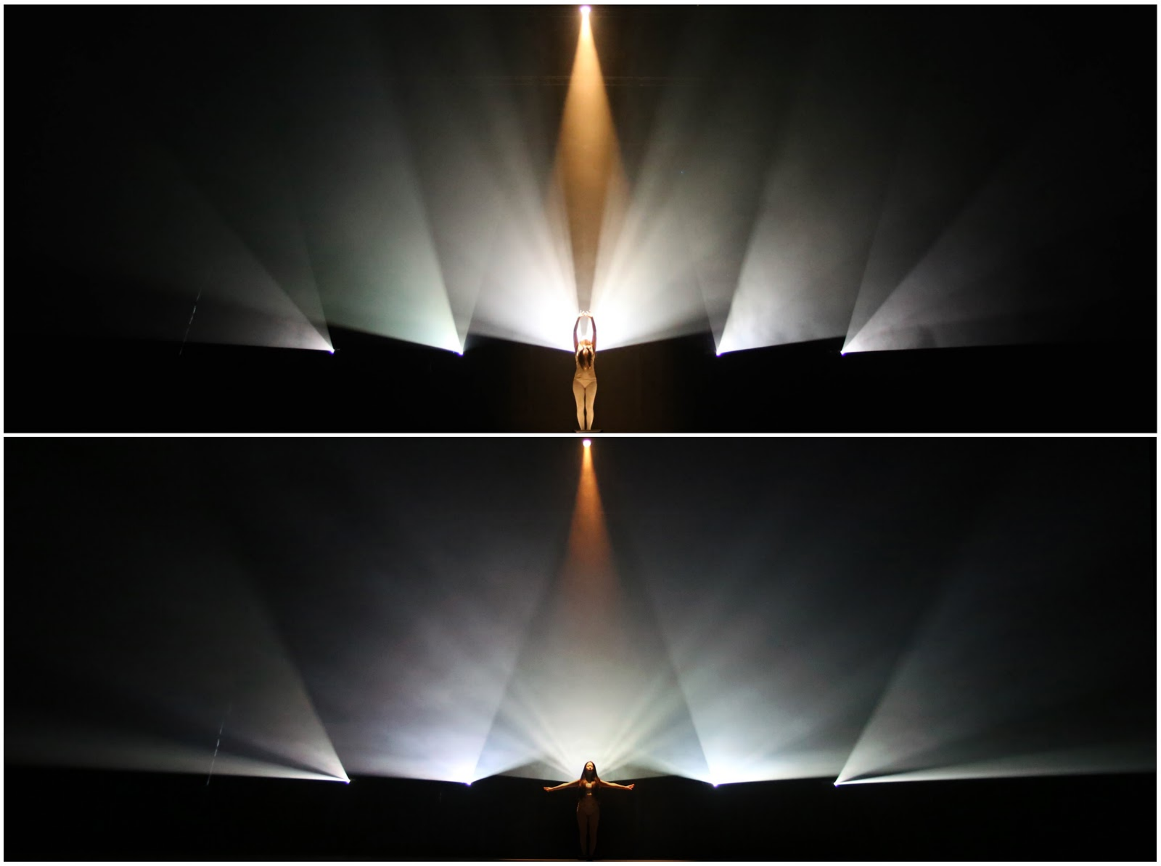

Figure 63: *Luxate [Komorebi]* dance performance climax (2015)

Luxate [Komorebi] explores interactive light beyond the screen or projection surface. By overlaying the virtual environment directly over the performer's body and the physical environment, *Luxate* creates a hybrid space and augmented spatial real-time instrument for improvisational dance performance. *Luxate* does not create holograms, but rather volumetric vector images projected onto modified midair. By making the relation between the dance performer and projected light interactive, and by projecting and overlaying the 2d virtual world directly in the dancer's body and physical space, *Luxate* investigates the qualities of embodied interactions in “holographic” augmented virtuality environments.

I conclude that this projection technique using haze is restricted to the use of bidimensional simple geometry in order to present highly immersive 3D illusions to the audiences. *Luxate [Komorebi]* successfully implemented a dynamic audiovisual enhancement and augmentation of a Butoh dance performance. By connecting the emotional and improvisational expression elements form Butoh with the physical and tangible 3D architectural projection design, *Luxate* manifested the magical and illusional dimension of embodied augmented environments. There was a collective sense of mystery in the understanding of the technology used from the audience. 3D projected light, dance, and sound merge in one multidimensional embodied augmentation.

Future Work

Future projection mapping techniques in mid-air should be based in expanding this method to overlay 3D projections with the dance performer in higher detail. Also, it will be beneficial to use of laser digital video projectors, instead of conventional DLP (digital light processing), due to the lack of focus in DLP technology. In video projectors there is a focus range of the lens. With laser video projectors, the beam is focused all the way through the air (Guttag, 2012).

Another important development and expansion will be the integration of more video projectors and haze emitter sources from multiple angles besides front and rear projection. Peyghambarian research in 3D holographic projection was able to project a complex 3D shape that can be seen from multiple angles into mid air by using a stream of water vapor and three digital video projectors. The projections are full-color 3D display viewable from all sides and without a pair of glasses. The effect is accomplished by taking advantage of the direction of light dispersed by the fog, generated by three different angles created by the video projectors. By using more cameras renders and video projector output, the team suggests the possibility of creating larger and more detailed 3D holographic imagery (Stolte, 2010).

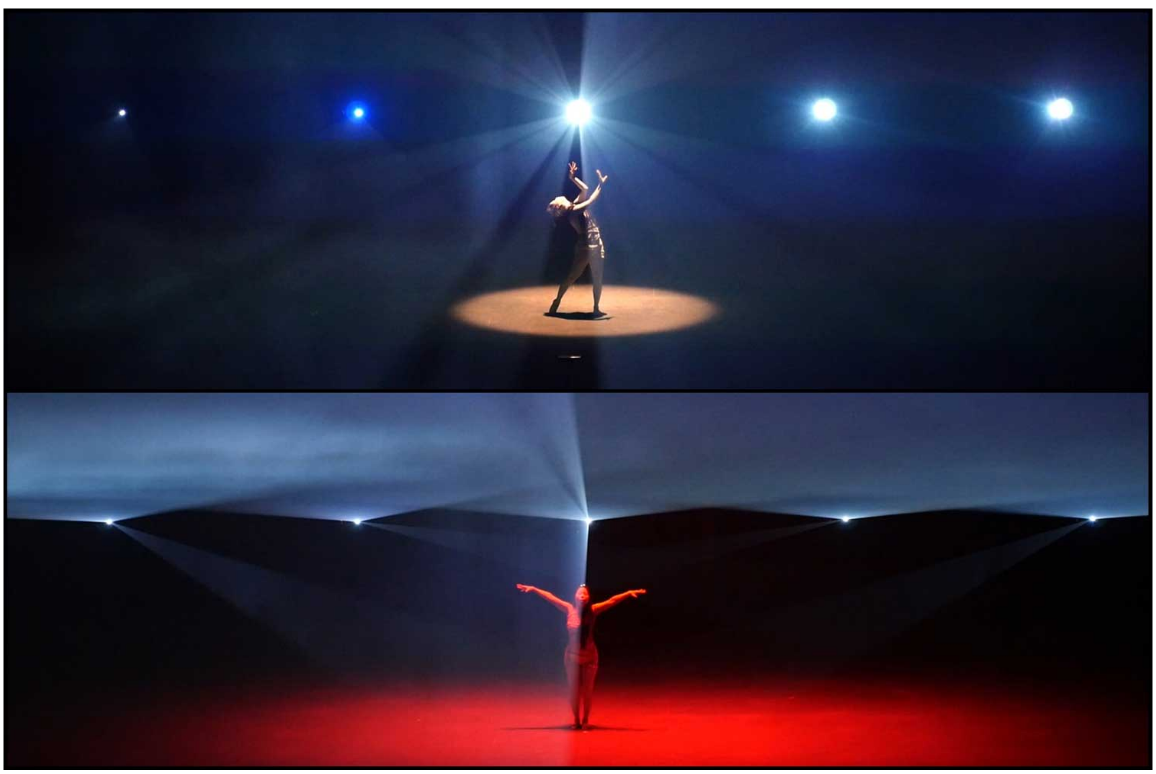

Figure 64: *Luxate [Komorebi]*: final scene (2015)

Chapter 6: *Biomediation*

OVERVIEW

Biomediation was a sensor-based audiovisual performance commissioned by the Ammerman Center for Arts and Technology at Connecticut College for the 14th Biennial Symposium on Arts and Technology on February 29th, 2014. It was collaboration between Yago de Quay and myself. The project was the culmination of an ongoing collaboration and research in the artistic exploration of audiovisual processing using natural motion-based interfaces for live performance. My work focused primarily on the visual output: the generation of real time interactive visualizations, De Quay's primarily on generating and modulating audio using the body[10].

[10] I previously presented a co-authored paper on Biomediation at the 2014 Biennale Arts and Technology Symposium at the Ammerman Center for Arts and Technology in Connecticut. See Beira, Quay (2014) Biomediation: A biofeedback audiovisual performance. Connecticut, United States.

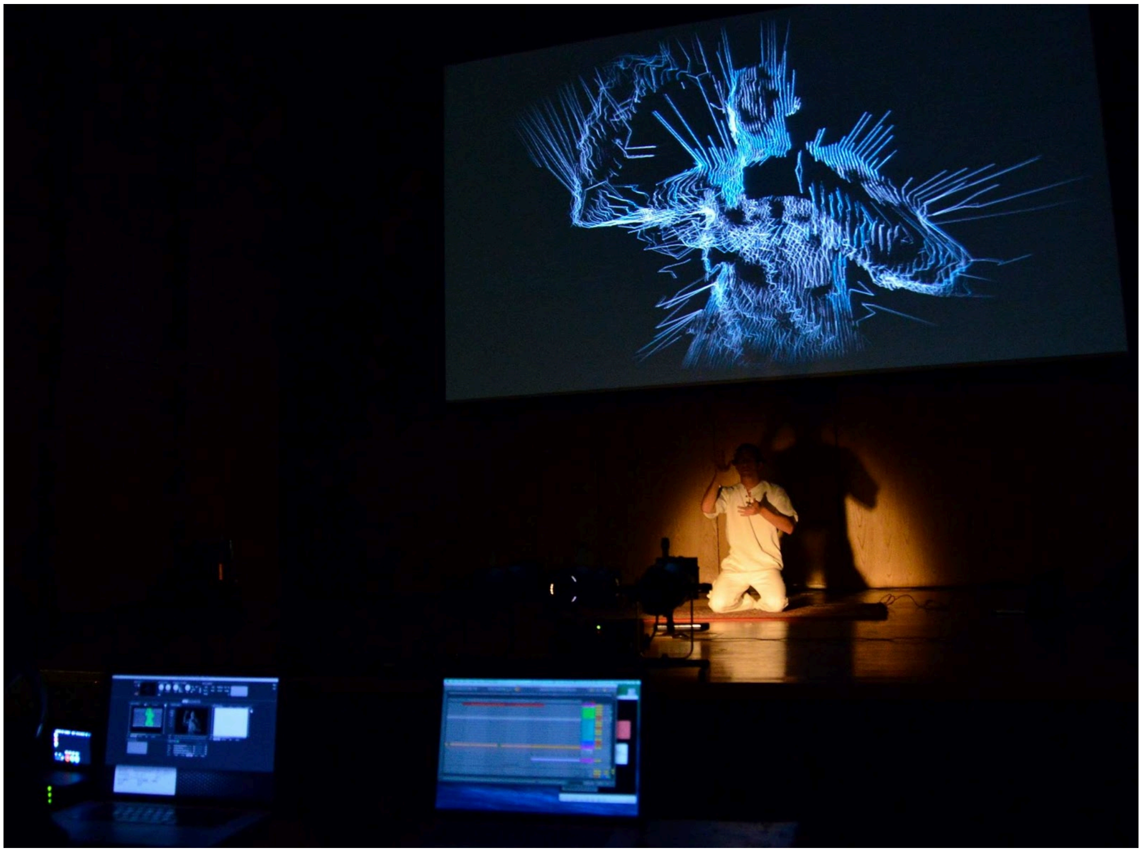

Figure 65: *Biomediation* live performance at Connecticut College for the 14th Biennial Symposium on Arts and Technology on February 29th, 2014. This was a collaboration with the musician and performer Yago de Quay designed to augment mediation using generative audiovisual signals.

In this chapter we investigate the features of an augmented reality performance created by connecting a depth sensor camera with a brain computer interface. The performer uses the practice of meditation to generate a feedback loop between him and the media.

Our system is constituted of one Microsoft Kinect depth sensor camera that digitizes the body of the performer and one brain computer interface (BCI). The BCI allows the performer to control and augment real-time visualizations of the 3D body scan parameters through brain frequencies. The cognitive and emotional experiences of the performer are translated dynamically to 3D generative graphic compositions in real time. Finally, the output video signal is projected in the performer's environment, merging the physical body with his augmented and virtual extension.

Performance improvements using neurofeedback are shown to enhance expression in performance art. Through intense and rigorous practice with neurofeedback, the performer was able to achieve the level of control to use BCI as an effective audiovisual instrument. The mapping processed was created to reinforce the role of the mind in the transformation of the physical body through tangible and clear interactions between the performer and the audiovisual feedback.

Biomediation is situated as spatial augmented reality in our theoretical framework, as it augments primarily the biological body of the live performer captured through the depth sensor camera. The brain activity is used to process this signal, but the 3D scan of the physical body is the core of the augmentation process.

From the performance, I conclude that controlling real-time audiovisual signal with BCI introduces challenging creative processes for the performer and for the audience. For the performer, the interfaces provide innovative and unconventional methods to generate feedback processes beyond the physical tangible control of the media. For the audience, BCI does not expose the nature of the interaction directly, and the interactions between the media and performer are often not understood. Still, the augmented processes between the physical and the virtual world provide unique and privileged qualities, such as intuitive and unobtrusive communication between the physical and the virtual, to generate a new layer of complex architectural embodied interactions in mixed realities environments.

CONCEPT

Meditation is usually perceived as a practice that trains the mind and induces a particular beneficial mode of consciousness. At the core of mediation there is a very defined pattern of brain activity. Several artists channeled this process through visual art. Cameron Gray painted the magical dimension of augmenting our surroundings by the use of our brain, concentration and meditation in *The Neverending Dreamer* (2006). The capacity to make this hidden mindset visible to audiences in media based performances was the conceptual trigger for *Biomediation*. The goal was to channel this unique mindset and transform it into an interactive and mixed reality performance.

Figure 66: ***The Neverending Dreamer*** **by Cameron Gray (2013)**

There is an increasing interest in developing idiosyncratic interfaces that convert physiological processes such as heartbeats, muscle contractions, brain activities, and body motion into digital media. The capacity to digitize the behavior of the human body opens communication channels to design and generate reactive feedback and augmentations to the user. In the recent past, there has been a significant development in BCI systems that use electroencephalogram (EEG) technology. These biological signals need software that converts them to audiovisual parameters because they are naturally non-digital. This transformation warrants close attention since there is virtually an unlimited number of possibilities afforded by new sensors, software and computing power.

Defining *Biomediation* as digital dance performance is challenging because dance, in many ways, plays a secondary role to the technological innovations. Varanda raises this exact problem, quoting Hayles: “Information has lost its body [1994, p. 4], is the body still an essential medium of dance?” (Varanda, 2014, p. 77).

Biomediation expands the previous framework for digital dance performance by adding a new sensing technology to the depth sensor cameras in order to generate movement beyond the use of the body. In order to create this form of augmented and virtual extension of the dancer, two new elements were introduced to our performative system. First, we used the three-dimensional volumetric visualizations generated in real time by the depth sensor camera, also referred to 3D point cloud. In previous research projects such as Super Mirror, *3D[Embodied]* and *LUXATE [Komorebi]*, we used the Kinect depth sensor camera primarily to capture the skeleton tracking joint position of the dancer. In *Biomediation*, we extend the use of the technology to generate real time three-dimensional depth visualizations of the dancer.

Instead of using the technology to capture the joint position and angle from the dancers, we also explore the creative and artistic qualities of the depth sensing technology. This allows us to generate real time computer graphics based on the live scan of the physical space.

The second element introduced was a brain computer interface, also referred as electroencephalogram (EEG), a process to record electrical activity of the brain. This particular form of interface digitizes brain activity, and creates a natural extension of the performer's behavior and emotions. These technologies and systems connected and communicating between each other, created the technological and artistic framework for *Biomediation*.

Biomediation is defined as spatial augmented reality in our mixed reality performance theoretical framework, as it augments primarily the physical body of the live performer captured through the depth sensor camera. The brain activity is used to process this signal, but the 3D scan of the physical world is the chore of the augmentation process. *Biomediation* is fundamentally different from previous performances in this research, such as *3D[Embodied]* and *Luxate [Komorebi]* because their primary source of augmentation was the 3D computer generated world created through visual programming. The primary environment to be transformed was virtual, which situated the pieces as spatial augmented virtuality. *Biomediation*, primarily augmenting the physical body and environment, is situated as spatial augmented reality.

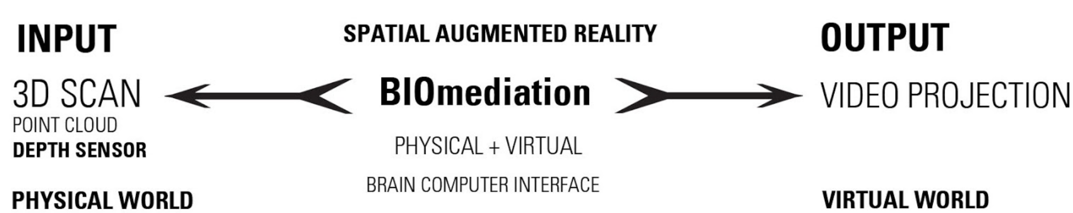

Figure 67: Conceptual framework for *3D [Embodied]* in the virtual continuum; Primary source of augmentation is the physical space: the performer's body and brain activity.

Related Work

Depth Sensor Based Visualizations

Depth sensors and point cloud visualizations expanded the research and scientific progress in photography and film developed by Eadweard Muybridge, Harold Edgerton, and Étienne-Jules Marey. Their work made the invisible visible in the study of locomotion and understanding of human movement. The introduction of depth sensor cameras in the last decade gave birth to a new image capturing paradigm and aesthetic. The Xbox Kinect depth sensor camera has an inbuilt infrared projector in order to generate a "depth image." In RGB cameras, each pixel records the color of light that reached the camera from that part of the scene. In depth sensor cameras, each pixel of the depth image records the distance of the object in that part of the scene from the camera. In the depth image, each pixel grayscale value corresponds to the depth of the image in front of the camera. The conversion of two-dimensional grayscale pixels into three-dimensional points is referred to as point cloud:

> When we look at depth images, they will look like strangely distorted black and white pictures. They look strange because the color of each part of the image indicates not how bright that object is, but how far away it is. (Borenstein, 2012, p. xi)

3D point cloud environments are defined by *x*, *y*, and *z* coordinates that represent the external surface of the captured environment, body, or object. It creates a real-time 3D representation of space, providing innovative forms of navigation in real time in the

3D virtual model using virtual cameras. The potential to use these environments for real-time applications expanded the traditional 2D filmmaking process to real time 3D interactive and dynamic experiences. By digitizing in 3D in the real physical environment, the user can navigate the virtual 3D volumetric space in real time. This process is referred in this research as the *virtual camera*.

Artist James George, one of the creators of the depthkit, an open-source suite of tools to capture and edit volumetric scans with the Kinect sensor, explains the new qualities of this new form of media as “a new emerging way to think about filmmaking for virtual reality is a technique called volumetric film making. With this technique you are actually capturing a full person that can be put in a virtual environment” (Scatter, 2015).

The aesthetic qualities of the depth image in motion graphics were introduced to a wider public in Radiohead’s *House of Cards* music video directed by James Frost and Aaron Koblin. No cameras or lights were used. Instead, 3D plotting technologies collected information about the shapes and relative distances of objects. The video was created entirely with visualizations of that data.” The project was created using Lidar, a laser light surveying technology to measure depth. The author also used sheets of acrylic glass and mirrors in front of the lasers to generate noise and distortions in the scan as a visual effect.

Figure 68: Left: *House of Cards* by James Frost and Aaron Koblin, which used 3D point cloud volumetric visualizations; Right: Depth kit mount setup, a combination of a pixel based RGB imaging with a 3D point cloud

The interactive qualities of this new media were explored in *Clouds*, one of the first interactive documentaries created for virtual reality by James George and Jonathan Minard (George, 2014). The viewer can now move freely in the 3D space, and this enables him to be immersed in a way that is impossible with screen-based recordings. The ability to navigate in real time in the 3D point cloud with multiple virtual cameras creates an unprecedented creative tool for visual artists and experimental filmmakers. Interactive artworks with point cloud aesthetics have been created in the last years using the representational qualities of this sensing visualization, such as the documentary *Ghost Cell* by Antoine Delach in 2015 and *Upending* by Downie, Eshkar and Kaiser in 2010.

The interactive and depth-based visualization qualities of this new 3D cinematic medium have provided groundbreaking work, and provided the only source of real time computer generated graphics for *Biomediation*.

Brain-Computer Interfaces and Performance Art

> "Since sensations, perceptions and emotions play the most important role in any artwork and few research efforts are exploring the potential of BCI within the art domain" (Fraga, Pichiliani & Louro, 2013, p. 642)

Real time virtual environments can be navigated, embodied, and transformed through physical movement and interactions, but also by tapping directly into the performer's brain activity—more precisely, by analyzing alpha, beta, delta, gamma, and theta frequencies. The exploration of using the brain as an interface has been adopted with success in human computer interaction (HCI) research but also for artistic expression. Exploring the connections between virtual and augmented reality, HCI and BCI is a promising research area, as it creates and merges new immersive prototypes with cerebral activity.

The need to expand physical and spatial dimension of interaction in HCI has been a growing area of research, particularly, towards the end of the 1990s. Brain-computer interface (BCI) technology created a direct communication and feedback loop channel between the human brain and the virtual environment. This is achieved through real-time analysis of electrophysiological brain signals recorded by EEG. BCIs are able to analyze and determine operative control signals from the brain and create a direct communication channel between emotional and mental activity.

In order for users to use BCI as an effective instrument for live performance the user needs to interact and practice in a process that is referred as neurofeedback.

Neurofeedback uses real-time reactive environments to teach self-regulation of brain function to the user.

> The goal of neurofeedback training is to teach the individual what specific states of cortical arousal feel like and how to activate such states voluntarily. For example, during neurofeedback training the EEG is recorded and the relevant components are extracted and fed back to the individual using an online feedback loop in the form of audio, visual or combined audio-visual information. (Vernon, 2005, p. 348)

To master the use of the brain with the digital system, the user needs to have some source of visual or audio feedback. By doing so, neurofeedback creates a learning model of real-time media processing to achieve self-regulation for the user. The clinical applications of neurofeedback have been widely researched in the field of cognition-assistive and clinical BCIs. In the last decade, several studies tested if BCIs can enhance the creative process for performance. For example, the innovations using neurofeedback in music performance are shown to enhance performance in music students (Egner, 2003). Raymond et al. tested the same principles using neurofeedback to enhance live dance performance (2005).

Research by Kamiya (1962) and Vidal (1973) on controlling and monitoring alpha activity provide solid evidence toward the application of neurofeedback. Although most of the studies using BCI focused on the passive role of the user, in the last years there is “is a growing definition for artistic brain-computer interfaces from a passive BCI perspective” (Andujar, Crawford, Nijholt, Jackson & Gilbert, 2015). This is established by generating direct actions and applications in the medium. Gürkök classified artistic BCIs into three categories with respect to the composition methods inspired by Miranda’s et al classification (2011) that highlight this active role of the brain in the augmented instrument. *Biomediation* uses the active role of the user, which Gürkök classifies as Audification/Visualisation:

> Audification (visualisation) is perceptual using the brain signals in auditory (visual) media. With basic (e.g. frequency filtering) or no processing, the brain signals are mapped onto audio signals (e.g. tones) or visual signals (e.g. lines, patterns). The resulting sounds and visualisations provide a direct representation of the brain activity. (2013, p. 828)

The relationships between immersive systems and BCIs have also been investigated, as they provide a new input for navigation. Lecuyer et al. researched the use of BCIs in virtual reality and immersive systems by creating a series of 3D models and scenes to be controlled by sensing the brain. The authors conclude that virtual reality enhances the feedback process for the user. Lécuyer et al. also researched the role of virtual reality for studying and improving BCI performance as it increases their motivation and immersion (2008). Such applications have been researched and developed for entertainment and gameplay. The potential has been demonstrated, but as Nijholt et al concludes, “to augment artistic expression new paths of experimental research must be created” (2015, p. 59).

The evolution of technology and the accessibility to new and affordable BCIs created in the last decade generated renewed interest in using the brain for interactive art installations and performances. It also gives artists the ability to introduce the brain in the creative mapping between the physical and the virtual world. For example, Canibal, a Portuguese musician, poet and performing artist created with Moura the performance *Câmara Neuronal* (Moura, Canibal, Guimarães & Branco, 2013) using an EEG headset to evoke a brain connection to the media system. This performance explored the abstract dimension of incorporating the brain in the performative audiovisual process while leaving the interpretation open to the audience. This is indeed one of the main limitations of using BCIs for live performance: it limits the capacity for the audience to decode the role of the brain in the creative process. Though, by making it simple and tangible through basic interactions between the virtual and the physical, higher levels of engagement and poetry seems to appear. For example, Park created the performance *Eunoia* using a BCI to actively transform musical composition in five individual speakers placed beneath trays of water (Figure 69). The artist uses brainwaves to transform the visualization of sound in real time, and each speaker gave a visual representation of the speed, pitch, and volume of the sound (2013).

Figure 69: Artist Lisa Park in 2015, using an EEG headset as an interface between the visualization of sound and her brain activity through the use of five metal dishes filled with water below audio speakers. This setup makes a direct relation between the brain, emotions and augmented mixed performance.

This performance was created using the four-channel NeuroSky EEG, and the artist assigned different emotion towards different speaker. This work reveals the strength of creative mapping and usage of BCIs towards performing art and augmented cyborg poetics.

The architectural mapping between the brain and mixed reality environments is a very promising field for research and development. The intersection between immersive environments, BCIs and abstract thought, such as intuition, will generate new paths and strategies for augmented interactions between the user, the physical, and the virtual world.

FRAMEWORK DESIGN AND TECHNICAL SYSTEM

Setup

The performer is located at the center of the stage using the EEG interface with a Kinect sensor camera pointed at him. The visualization of the sensor is projected in the screen in top of him, augmenting the emotional behavior to the audience through the manipulation of visual effects. The performer is facing the audience and not aware of the video projections. Instead, the performer uses audio signal and effects as a direct feedback towards the use of the EEG.

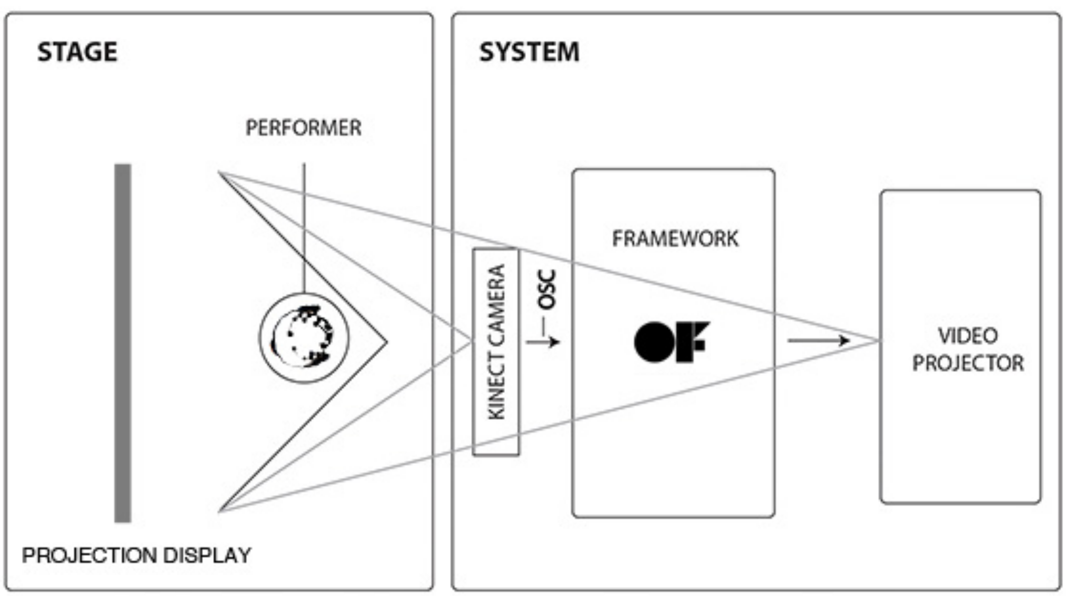

Figure 70: *Biomediation* setup: view from the top

The Emotiv EEG interface and a Kinect Xbox v1 camera establish the HCI layout and media design. Through OSC protocol, the data from this sensor is gathered in Open Frameworks for the video processing and for the audio processing we used Max Msp and Ableton Live.

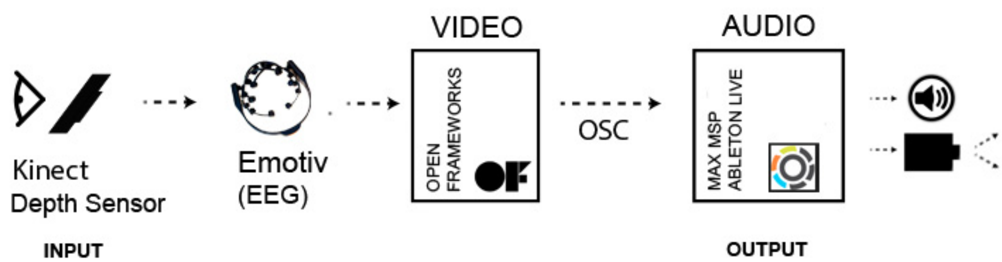

Figure 71: *Biomediation* setup:
Input by the Kinect depth sensor camera is controlled by a BCI and processed in OpenFrameworks and Max Msp for real-time generative audiovisual output.

Depth Image Visualizations

The video architecture and visual effects are generated with the support of custom based software patches. The visualization algorithm, created in Open Frameworks, establishes an interface to interact with the infrared sensor visualization. The skeleton tracking is done with the support of Open NI (Open Natural Interaction). The custom based patch from Open FrameWorks imports the Kinect signal and 3D point cloud data[12].

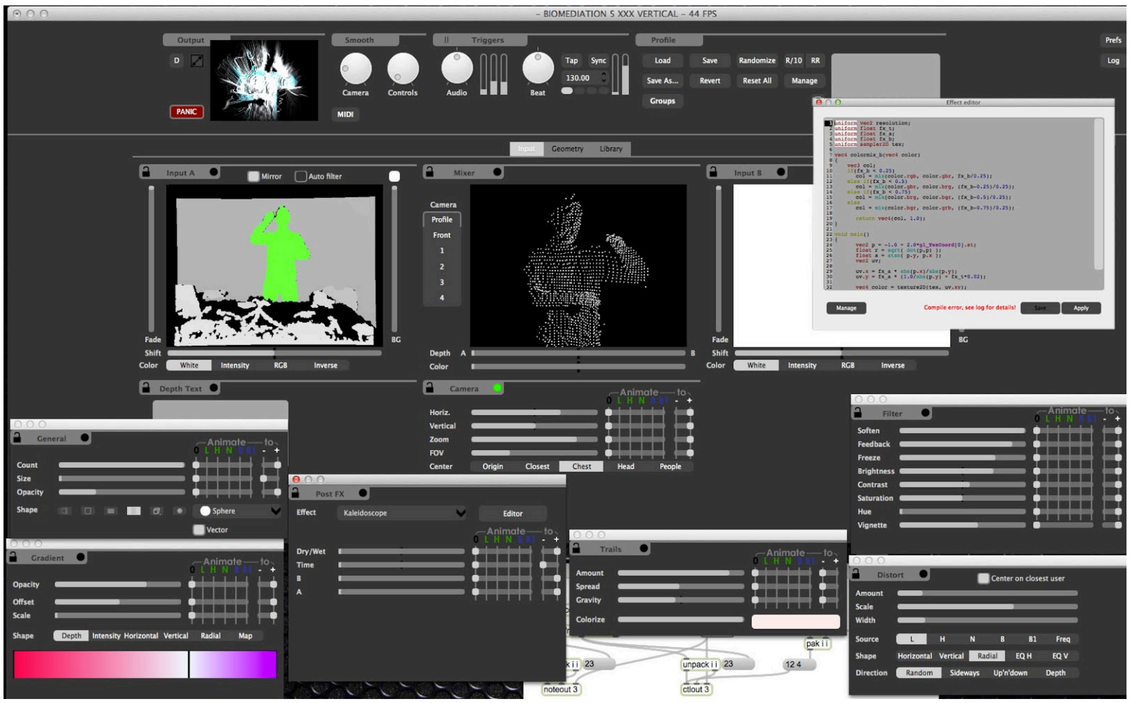

Figure 72: OpenFrameworks (OF) used to do the skeleton tracking and generate the depth visualizations of the body

Instead of using skeleton tracking to establish direct correlation between body joints and 3D geometry—such as the mapping created for *3D [Embodied]*, *Luxate [Komorebi]* and Super Mirror—in *Biomediation* we established full body recognition, which allowed us to track the body as one unit. The creative and technical qualities of using volumetric video were based in the control of virtual camera movements and depth

[12] The prototype was created by Julio Tuomisto (Delicode, Ldt) and in early 2013 I was invited by him to explore the creative application of such tool and the integration in live dance performance.

relative video effects. A 360-degree movement of the virtual camera behavior is established throughout the performance in order to generate a dynamic 3D scan of the performer's mesh.

The performer is also able to transform the multiple geometry draw modes, such as textures, lines, polygons and vectors, of the infrared point cloud. The performer is able to control visual effects such as distortion field, depth, intensity, radial, etc. GLSL shaders were used to control effects chains and some of the main mapping strategies developed for visual effects. The creation of particle trails were also added to the system in order to provide transformation control in real time to the performer of parameters such as spread, gravity, color, delay, and bleed. Multiples parameters were also pre-programmed and controlled by the BCI, such as zoom values, camera rotation, different depth effects and perspective grids deformation (Figure 73).

Figure 73: Screenshots of real-time 3D point cloud volumetric renders using our system with openFrameworks and Xbox Kinect v1 (overlay of the pixel-based RGB image with 3D point cloud).

Sensing the Brain

The interactive system *Biomediation* used oscillatory neural activity as the input signal to transform the 3D point cloud visualization. As previously described, we used an active BCI approach. The performers communicated directly with a device through consciously controlled mental activity. With basic frequency and filtering brain signals were mapped onto visual parameters of the 3D point cloud render and audio signal, providing a direct representation of the brain activity.

The interaction design model is created through process control and goal selection. The system recognizes particular voluntary mental actions or face expressions to transform the visual and audio signal. The electric signal from the brain of the performer was collected using Emovit's EPOC EEG headset with 16 electrodes to cover all four lobes in the cerebral cortex— frontal, parietal, temporal, and occipital. Through the use of a receiver in the performer's clothes, the headset communicated through Emotiv's proprietary wireless protocol with a laptop located at the front of the house. The Emotiv's software development kit (SDK) provided access to raw electrical neural activity and also classification and continuous dimension measurement.

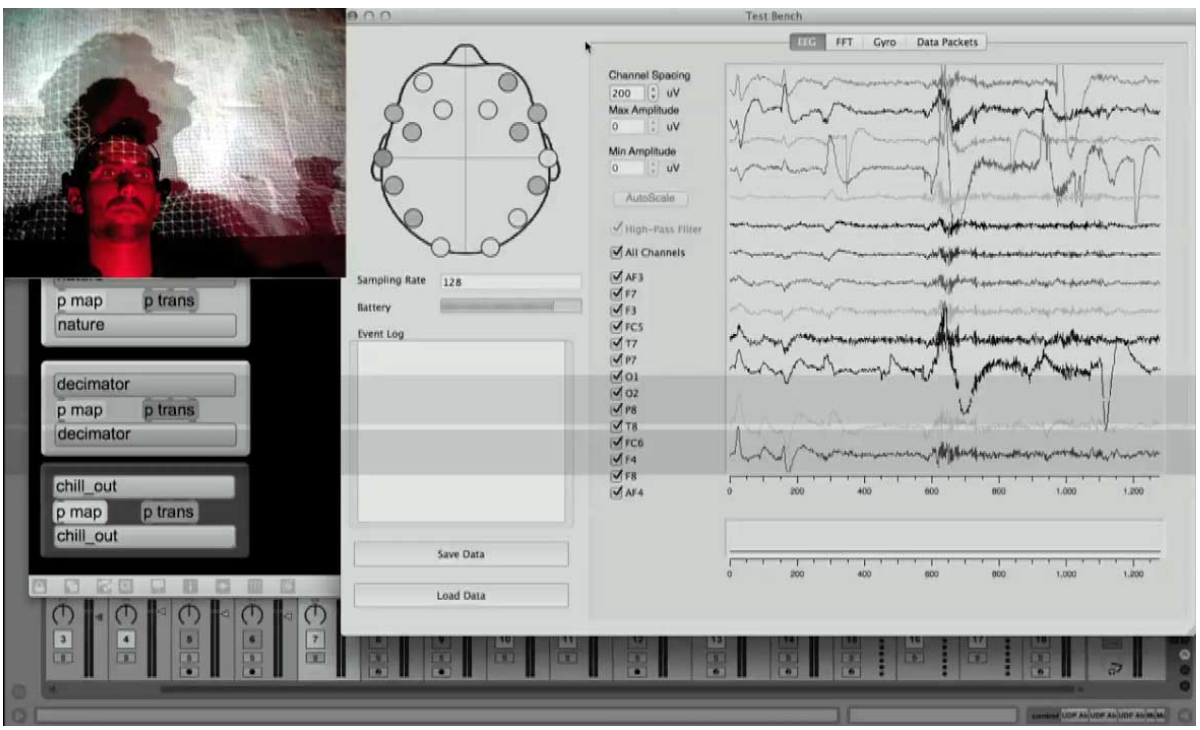

Figure 74:

Emotiv BCI SDK interface connected with *Biomediation* audiovisual real time system

The input signal from the EEG influenced the output modalities. The classification function identified particular cognitive thoughts, such as frustration, arousal, excitement, meditation and also facial expressions. The raw electric activity is used for audio processing in order to drive the parameters of a granulator. Emotiv's own benchmark of regression functions was used to measure meditation values, and this was the main classification algorithm used throughout the performance. Meditation levels, opposite from cognitive thoughts and facial expressions, are used as a continuous signal and input throughout the performance. Yago de Quay describes two mental actions used through the mapping process:

> These actions consist of imagining a liquid moving up or down. The direction of the imagined liquid produces different patterns of cerebral activity. After various training sessions the software was able to recognize quite reliably when either of these mental actions was instantiated. (2015, p. 398)

The method established by the performer was successful, as he was he was able to consciously trigger and control data processing with the BCI. These mental shortcuts and triggers were essential to successfully record and optimize the audiovisual instrument architecture and interface.

PROJECTION DESIGN

The projection design for *Biomediation* was based in the overlay of the performer and the projection using a screen behind the performer. The projection of the performers body point cloud is juxtaposed over his physical body and a background grey screen, in order to optimize the contrast levels between them. A more conservative and traditional output signal of 1920x1080 from one 10k digital video projector was then applied, along with dedicated light—in particular, the use of strobe lights to trigger the neurofeedback in the fourth section of the performance.

Figure 75:

Video projection over the performer's body with 3D volumetric scan of his body

MAPPING /INTERACTION DESIGN

The mapping between the mental states and the command in our system sets were designed to be efficient and intuitive. The interaction design was divided in four main scenes that aggregated patterns of audiovisual mapping. This allowed the audience to decode cause and effect within each section through repeated interactions. The audience gets an idea of what the performer is controlling. In a way, it educates the audience. At least, the audience becomes acquainted with the aesthetic of that section.

The OSC messages from the brain activity were mapped together at the same time for the audio and video signal. We divided this mapping process and interactive design into different sections that determined the overall flow of the performance. These sections defined the rhythm and overall structure of the performance. By mixing a constant input signal—meditation—with exploring triggers and subtle and fast flux of data the 3D virtual performer (audiovisual output) we were able to create a more dynamic behavior of the 3D augmented mesh. These association and relations between the input values and tracking and the output programming evolved throughout the performance.

Input	**Visual Output**	**Audio Output**
Meditation Level	Opacity of white light	Noise level
Mental Command	Vibration frequency Mesh direction	Tremolo frequency LP filter frequency Bit reduction
Raw EEG		Grain amplitude
Facial Expressions	Flattening of mesh	Glitch effects
Head movements		Melody volume

Figure 76: BCI input and output mapping for video and audio. Meditation levels are used as one constant input signal (Quay, 2015)

The first scene was created as a calibration tool for the performer and the system. It gave the performer a clear signal and feedback process in how the system is reacting to him. The performer was able to trigger a white circle, perceived as an aura, when he achieved high levels of concentration. It started with a black screen, while the audio was generating a grainy electronic noise. As the performer raised the meditation levels, a white circle of white light appeared behind the performer, and the noise levels fade out to silence. This introduction was also used to calibrate and test the overall system functionality in order to progress to the next scene. In the second scene, subtle alterations are applied in real time to the 3D mesh direction, and vibrations are created by intentional mental commands from the performer.

Figure 77: Top: Scene 1: A white circle is projected over the performer when he is able to achieve high meditation levels in the BCI; Bottom: Scene 2: Depth augmentations are triggered by intentional mental commands from the performer.

The goal of the mapping was to separate high-level decisions, such as meditation, with low-level manipulation, such as triggers and effects. Towards the end of the second section, there was a transition between glitchy and electronic interference triggered by the performer towards a peaceful and organic sound environment of the third section.

In the third section, the performer's mouth triggers glitch effects and flattens the mesh, and his head's quantity of movement increases the volume of a melody. The performance evolves exploring this line of commands and interactions between the performer and the system. In the fourth section and the climax of the performance we focus the mapping process towards the exploration of neurofeedback**.** By intentionally stimulating the performer's vision with violent, white light strobes pointed at him, we provoke a chaotic physical environment for the performer. This allowed us to collect data that transcended the normal and intentional behavior from the performer. The infrared tracking system was also affected by the LED strobes and was not able to run skeleton tracking and recognition. At the same time, the performer experiences an unusual and very intense emotional process that creates a dramatic effect on the augmented 3D mesh. This process generated the climax in the performance and created some of the most compelling moments of artistic expression and augmented exploration between the physical and the virtual worlds (Figure 77).

Performance Analysis and Conclusion

Biomediation takes a step further in the exploration of mixed reality environments and expressive intangible instruments by tapping directly into the performer's brain activity. It is an experimental solo dance performance in which the biological functions of the performer's body, when combined with motion, take control over the interactive audiovisual environment. Through this process, the complex data generated by the performer can be controlled by his physical movements combined with his thoughts and emotions. This method establishes an intimate and augmented link between the performer's biological body, brain activity and augmented self-expression. The integration of augmented reality with BCIs created intuitive and unobtrusive communications between the physical space, the user, and the virtual world. BCIs provide an innovative and intuitive input-sensing medium for the design and experience of mixed reality environments.

The biggest difference in *Biomediation* from previous performances in this research, such as *3D [Embodied]* and *Luxate [Komorebi]*, is that the virtual three-dimensional worlds created to juxtapose and interact within the physical space are created only by a depth sensor camera. There is no other 3D virtual environment, aside from the physical space and the performer that is scanned in real time. The primary source for the 3D virtual environment is the physical world. This defines *Biomediation* as spatial augmented reality in our theoretical framework.

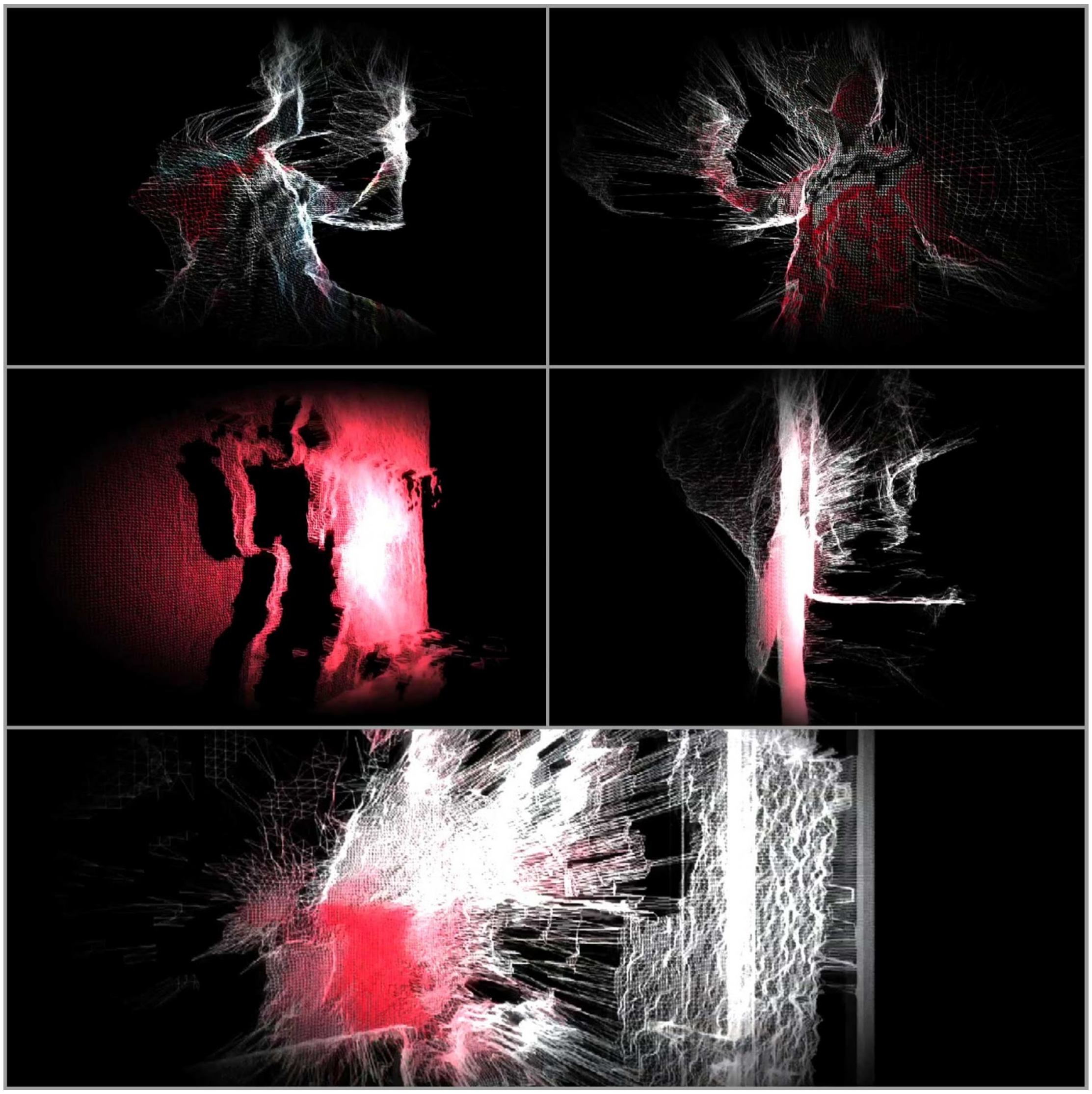

Figure 78: Live renders from the climax scene of *Biomediation*: The augmented avatar was generated by the association of the BCI and the 3D point cloud image real-time transformation.

By augmenting the physical body and agent, *Biomediation* investigated new directions for choreographic expression using brain activity transformations in mixed reality environments. The direct control of the 3D augmented digitized body with the brain allows the performer to use a different set of tools and mechanisms.

In order for the user to acquire the control skills to operate effectively the BCI several training sessions with the SDK and the headset are necessary. Yago de Quay innovated the feedback process without formal or professional training or supervision. This process was established first by controlling his own brain activity and secondly by establishing brain patterns. The first process is generated by monitoring the brain activity as raw signals and real-time changes according to different reactions. The second is referred to in computer science as machine learning and employs adaptive algorithms to detect brain patterns. This process was essential to study and record the BCI signals, create classifiers and finally establish a audiovisual feedback mechanism.

The limitations within the particular technologies created some of the most compelling opportunities to design in SAR. While conscious triggers and controlled data processing with the BCI were successful, neurofeedback provided a privileged process between the brain and the system that contributed to the artistic expression. By designing and implementing intense strobe light displays in the physical environment of the performer, we challenged the performer's emotions. The infrared technology also generated improvisational and creative expression between the physical performer, the environment and the interactive media.

Another limitation of BCI interfaces for dance performance is the limited range of movements of the user and performer. The performer is able to move freely within a specific range and limited area of motion. *Biomediation* explored this limitation to generate artistic expression beyond the physical movement of dance. Instead, the performer can use the brain activity to generate new forms and dynamics of augmented dance performance. Also, performing meditation using BCIs while exposed to audiovisual stimulation in real-time creates conflicts with the nature of meditative practice. In the end this was an opportunity, as we explored the role of neurofeedback by forcing the performer to experience a chaotic light strobe environment. We generated some of the most creative and expressive moments of the performance.

For the audience, BCI interfaces create a challenging interface because it is hidden and does not expose the nature of the interactions in real time. As opposed to other audiovisual interfaces that allow the audience to decode the nature of the interaction of the performer, such as the guitar and piano, EEG interfaces don't expose the nature of the interaction directly to the audience. They create an opaque and obscure style of art performance, in the sense that is hard to create a dialogue with the audience. The language of the biosensor's activity and interactions is not yet clear to the audience. This particular kind of art expression for live performance is still in his early infancy, and it is quite challenging to create effective narrative and cognitive experience for the audience based in this interface. The mapping between the mental states and the command sets needs to be designed for intuitive engagement from the performer and the audience. The implementation of depth image of the performer's body and environment was fundamental to creating one augmented environment that reflects this mixed reality architecture for the audience to understand the nature of such interactions and media architecture. Physical activity and facial expressions were also performed in order to emphasize the dialogue between the mindset of the performer and the extended and digitized self and avatar.

Figure 79: *Biomediation* mapping between brain activity and 3D visualization (augmented avatar): overlay of the physical body with the extended digital self and avatar

There will be several benefits to overlaying the video projection directly onto the performer. This could be accomplished by using a similar display and projection design strategy as *Luxate [Komorebi]* and adding a thin layer of mist or a translucid surface in order to create a dedicated screen imagery. By doing so, the performer and the extended avatar will be perceived as one mixed reality experience to the audience. The virtual and physical dimension will be presented as one extended and augmented environment.

Future work should focus on the overlay and integration of augmented reality displays with BCIs. Connecting the brain with the body to create a digitized and augmented self represents an innovative strategy for augmented reality design, allowing the cognitive process to automate depth cameras. Such creative strategies for media manipulation in real-time allows us to explore the idea of self-awareness systems. This means the ability of the extended agent, the software, to become increasingly “aware” of their environment and the users, and being increasingly “self-aware” of their own existence within it. Eventually, such systems will merge with artificial intelligence research and applications, in order to provide semantic segmentation and high-level visual recognition tasks. I conclude by arguing that the integration of the BCIs, biosensors, and motion tracking with augmented reality systems have the potential to generate new layers of complex architectural embodied interactions in mixed reality environments—more precisely, by using intuitive and unobtrusive communication strategies and interfaces between the physical and the virtual realities.

Chapter 7: Conclusions and Contributions

This dissertation investigates the considerations at play when designing for mixed reality environments in dance performance. The research is performative, transdisciplinary, and maps the architectural dimensions in augmented environments between the performer and virtual agents. By connecting digital information to human bodies and minds, I augment the capability to interact with our surroundings and environments and, ultimately, make the invisible visible for the audience. Using practice as research, this thesis argues that humans can reshape interactions between physical spaces and virtual spaces by adding new layers of connectivity and visual feedback through projected light. The incorporation of off-the-shelf technologies into complex interactive media architectures in live dance performance gives an experimental character to this research. The access to affordable sensing technologies such as depth sensors and BCIs, as well as digital projectors and HDM, allows artists and researchers to implement and integrate mixed reality architecture into their work.

By using the body and creative expression as the interface between the real and virtual worlds, dance performance provides research opportunities that connect the mind, body, and emotions. The integration of virtual environments and extended digital agents in dance performance creates a privileged framework to research and design interactive mixed reality environments. The juxtaposing of space and body in mixed reality environments may ultimately contribute to the broader extension of the meaning of the body in the digital age.

The research presented and analyzed in this thesis engaged the work of many artists and scientists. It also created the foundation of my personal advancement and acquisition of knowledge in the field. However, the direct interactions with collaborators, such as the choreographers, programmers, dance performers and musicians, engaged privileged and personal opportunities to acquire valuable insights based in direct experience.

The practical outputs of the research consist of four interactive dance pieces and stage performances, exhibited in public on multiple occasions, as well the technical resources (custom software and libraries) developed. The process and outcome of these performances were incorporated into the theoretical framework. At the same time, the practice also gained valuable insights from theory as the research evolved. This feedback loop between practice and theory established the direction and natural progression of the conceptual, technical and artistic elements of this research.

MAIN CONTRIBUTIONS

The goal of this document is to expand the working practices of digital artists and designers towards the possibilities of augmented architectures and performance art. Ultimately, I hope that this dissertation demonstrates techniques for creative insights that can help navigate the field of augmented art performance.

Conceptual and practical architecture principles to design and created augmented dance performance are presented. To create effective interactions between the dance performers and computer-processed imagery, a direct and implicit chain of cause and effect needs to be established. In order for the observers to decode the tangible actions, these interactions should replicate processes present in physical movement of the world, as we know using, for example, psychic forces. Properties that can be attributed simultaneously attributed to physical and digital behaviors such as volume, speed, mass, gravity and attraction create an effective augmentation between the dancer performer and the interactive visualizations, and vice versa.

TECHNICAL CONTRIBUTIONS

This dissertation presents insight on and analysis of immersive and interactive design in mixed reality from the perspective of a visual artists and interaction designer. This work creates a practical guide for conceptual and technical implementation of mixed reality dance performance. It reports creative applications and mapping strategies between sensing technologies and projection design. It also provides theoretical and critical analysis of the performances.

The first section of the study focused on approaches to using depth sensor cameras in order to make the interface invisible and non-invasive. Creative and technical insights are developed towards exploration of sensing technologies for interactive systems. The main focus is towards the use of the Kinect depth sensor for 3D motion tracking. Chapter 3, Super Mirror, conducted a comprehensive study with ballet dancers with the Kinect to perform 3D motion tracking in real time. In Chapter 6, *Biomediation*, the same technology is used but with a very different approach and exploration of the medium, exploring the sensing technology as a visualization tool using depth image and 3D point cloud. In *Biomediation* the integration of BCI were also analyzed and implemented in our workflow.

The technical resources created in the course of this study, such as custom software and libraries created in node-based visual programming software such as Touchdesigner, Quartz Composer and Open Frameworks, are distributed for free and available for download.[13] The design patterns can enable the integration and development of interactive applications and provide valuable resources for research projects and the artistic exploration of interactive systems. Super Mirror provides a system that could be useful for a large number of domains that evolve full-body movement training. It provides a simulation and real time analysis framework for body movement comparison for further analysis, such as Trajkova's research on ballet (2015).

The adoption and development of affordable and accessible DIY solutions for interactive 3D environments provides a technical contribution to other practitioners in the field.

THEORETICAL FRAMEWORK FOR MEDIATED LIVE PERFORMANCE

Using Milgram's 1994 virtuality continuum as a reference point, I adopted a theoretical framework for interactive media live performance. The virtuality continuum

[13] Software and libraries available for download at http://www.joaobeira.com/web/3d-embodied/

provided a fundamental map to organize and understand the complex connections between virtuality and reality in stage performance using projector-based augmentations. Though the identification of the primary source of augmentation either from the physical world (augmented reality) or from the virtual world (augmented virtuality), the main architectural foundations for analysis are defined and pursued. This model and framework is then mapped through the performances created in this study, covering the whole spectrum by establishing different technologies and modalities for the input and output. Each performance addresses distinct spatial relationships between the performer, the media, and the physical environment.

Mixed Reality Performance

The first performance, *Two&For* (Chapter 2), is an exploratory study that investigates the ability of computer-generated graphics to interact with dance performers without the use of automation and sensing technologies. The primary source of augmentation changed according to my focus of representation and observation. I classify the performance as mixed reality because spatial augmented virtuality and reality are juxtaposed and overlaid depending on my focus of augmentation, either from the performers movements and behavior to the 3D virtual extension. The interactive dynamics between the dancer, the media and me create a higher form of interactive design, but also limit the range and variety of the visual narrative. This performance provided a deeper understanding of the qualities of interactive and generative embodied design.

Augmented Virtuality Performance

3D [Embodied] (Chapter 4) and *Luxate [Komorebi]* (Chapter 5) are situated in spatial augmented virtuality, as their default architecture derives primarily from computation and visual programming. Augmented virtuality creates then a privileged environment for designers to implement 3D animation and perspective illusion strategies for live stage performance. The ability to transcend the laws of physics from the real world give designers the opportunity to create high-level illusion through digital simulations and to test the limits of imagination by creating new artificial worlds. These worlds come to life under the performer's control. By overlaying the physical body of the performer directly on the 3D virtual imagery, the audiences perceives a collective experience of 3D immersive environments embodied.

The interaction design between the virtual and physical is also based in the direct spatial manipulation and transformation control over the 3D objects, making the interactions intuitive and natural for the audience to assimilate. The first interactive design method of *3D [Embodied]*, which used a continuous tracking signal with computer generated graphics, provided a high level of interaction and the integration of the virtual environment with the dance performance. The same method was applied in *Luxate*. This particular method created a higher level of integration between the dancer and the interactive image by addressing the digital agent, the software, as a choreographer and partner. This method increases the nonlinear, improvisational, dynamic interactions between the performer and the media.

Even though both performances are classified as augmented virtuality, the projection design and display method had fundamental differences in the reception mode. *3D [Embodied]* created 3D illusions by adding extra spatial dimensions and notions of movement in the three static panels on stage. I created optical illusions in this form of 3D video mapping by projecting directly onto individual surfaces in order to display a high-resolution, concrete 3D image.

Luxate [Komorebi], in contrast, explores infinite 3D projector-based augmentations without the use of a screen. The display strategy is restricted to volumetric basic 3D shapes, but the image display goes beyond any object and surface, i.e., it is "holographic." Both projection systems had the same limitations and incapacity to generate an optimized illusion to all audience members, as the optimal position for the full effect of the projected illusion is position of the video projector. The integration of the physical body within the projection display at specific angles might break some of the illusion and create a displacement in the apparent position of the virtual object. This incapacity to provide the same visual experience to an audience can be addressed by adding more video projectors and positioning them with full coverage of the audience area.

Augmented Reality Performance

Biomediation is situated in the opposite extreme of the continuum as spatial augmented reality. The primary source of augmentation lies within the real environment. The design opportunities focus on the enhancement of physical phenomena by making the invisible visible. Sensing technologies plays a fundamental role in spatial augmented reality performance, as it mediates this primary augmentation. It establishes an intimate and augmented link between the performer’s biological body and the virtual media. In *Biomediation* a depth sensor camera digitizes the body of the performer onto a 3D volumetric mesh. This 3D avatar of the performer is then controlled and transformed in real time through the use of a BCI. Using brain activity to expand physical movement and expression allows the performer to use a different set of tools and mechanisms to execute mediated dance performance. The mapping between the mental states and the command sets reinforced the biological behavior of the performer, creating an intuitive architecture between the physical body and the virtual extension.

The main challenge in the integration of BCIs and biosensors in general for stage performance is the hidden interface that does not expose the nature of the interaction in real time to the audience. The integration of sensing technologies for augmented reality performance provides then an intimate link between the performer's physical movements and biological and brain activity.

Another limitation with BCIs is that they have limited range of movements due to the EEG headsets of the user. This represents an important limitation for the adoption of BCIs for dance performance. The ability of the performer to consciously trigger and control data processing using the BCI was successful. However, the exposure of the performer to audiovisual stimulation and noise in real-time interfered with his capacity to consciousness operate the virtual instrument. We found that from this apparent problem and limitation, some of the most expressive and creative moments of the performance were produced. Neurofeedback provided then a privileged process between the brain and the system that created new directions for choreographic expression.

In summary, augmented virtuality for live performance focused primarily on the 3D immersive design (output) and augmented reality focused on the sensing technologies (input). Mixed reality performance integrates and intertwines the dynamics of both AR and VR performance, providing a hybrid environment of computational dance expression between the physical body and the digital agent.

To the audience, the AV and VR performance does not define primarily the perception and quality of the work presented. The capacity to trigger the audience's imagination is the key element in the success of digital dance performance. The mysterious and magical attributes of the technologies and space, and the interactions with the live dancers, generate the core of the mediated and augmented artistic performance.

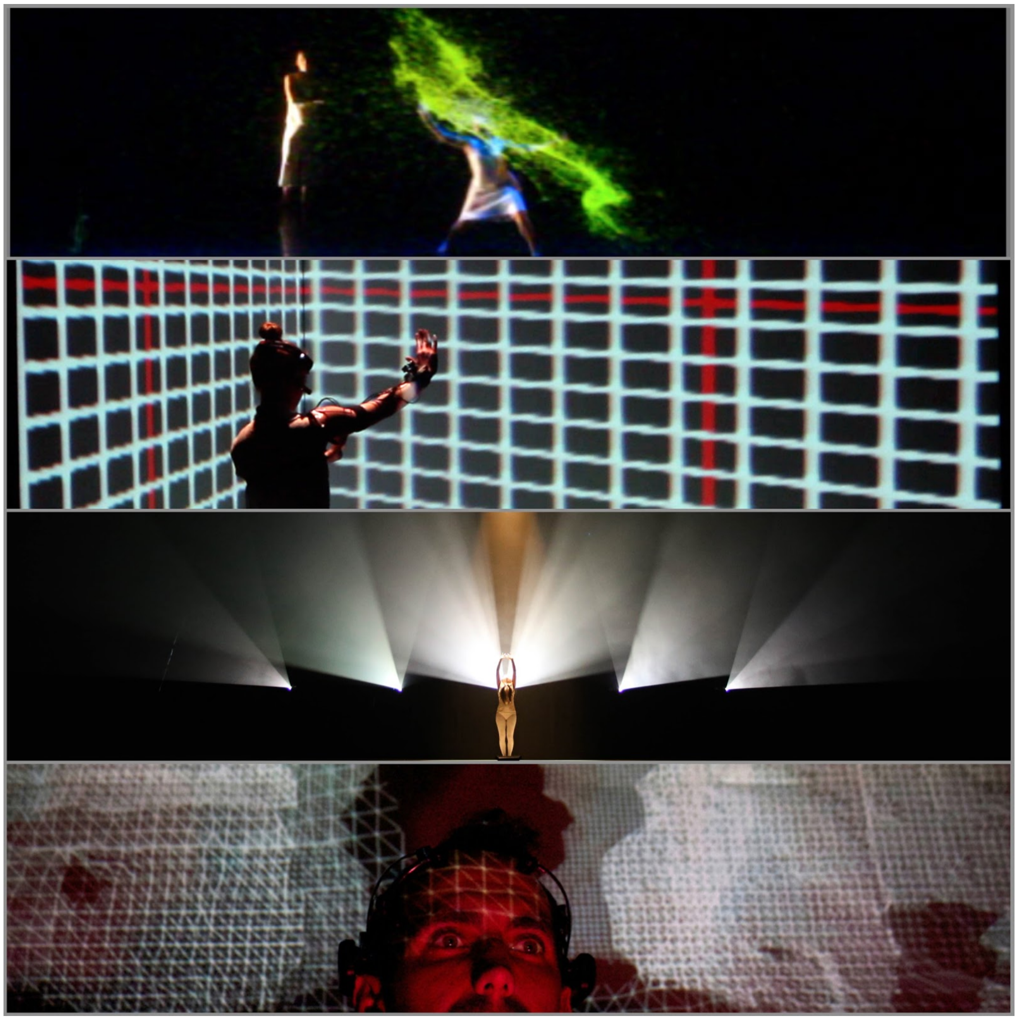

Figure 80: Live dance performances created in this performative research exploring the poetry of augmented and mixed reality architectures.
From the top to the bottom: Super Mirror (2011), *3D [Embodied]* (2013), *Luxate [Komorebi]* (2015) and *Biomediation* (2014)

Future Work

My future work will be an extension and exploration of the technical and creative contributions of augmented architectures between reality and virtuality. It is important to note that the findings and artistic achievements from the body of work presented within interactive performance have resonance and relevance beyond performance and interactive projection design.

I am particularly interested in the potential of holographic head mounted displays, such as Hololens, and the ability to integrate and mix reality and virtuality using depth of field transformations. Such visualization display creates a privileged window to integrate infinite virtual objects overlaid in the physical space, combining the immersion of virtual reality with the interactions in real world and physical spaces.

In order to take full advantage of the immersive and interactive augmented design, sensing technologies need to integrate a wide range of sensing technologies, from spatial and 3D body tracking to biosensors. Augmented reality and virtuality interfaces and architectures need to integrate the brain in order to achieve their full potential. New input channels with intuitive sensing capacities will allow designers to create innovative bridges and architectures between the user and the media.

The integration of sensing technologies such as motion tracking, BCIs, and biosensors with augmented reality has great potential to generate new layers of complex architectural embodied interactions in mixed reality environments. More precisely, this development can help use intuition and unobtrusive communication strategies between the performer and the virtual world. Such systems can promote the idea of self-awareness by allowing the system to become increasingly “aware” of the performer and further develop the concept of software as an extended agent for live performance.

Even though no commercial device or research project has developed such technology, the potential to research and explore creative communications networks using integrate cognitive commands and applications between computer generated imagery and the user is an appealing area of research for the near future. The intersection between mixed reality immersive design and intuitive interfaces might represent a paradigm shift in HCI and computational sensibility systems. The boundaries between reality and media are merging, and eventually they will disappear, creating a unified instrument for artistic expression and mixed reality exploration.

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