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From Pink to Pong: Tracing a Convergence of Art and Ludic Engineering

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Kurzfassung

Diese Dissertation geht einer Annäherung von künstlerischen und spielerisch-technischen Entwicklungsansätzen an der Schnittstelle von interaktiver Kunst und Mensch-Computer-Interaktion (HCI) nach, und zwar auf der Grundlage einer Fallstudie über den Forschungsverlauf der Kunstinstallation *Solar Pink Pong*, bei der das „Spielerische“ als erfinderisches Element im Mittelpunkt steht. Ein zentrales Anliegen dieser Arbeit ist es dabei, widersprüchliche Sichtweisen, die bei dieser Annäherung auftauchen, zu überbrücken und den operativen Wert des „Spielerischen“ (d.h. spielerisches Denken und spielerisches Verhalten) für die Erfindung von Technologien für den gelebten Körper, und unter Einbeziehung desselben, besser zu verstehen. In diesem Sinne bietet diese Dissertation eine facettenreiche Antwort auf die Fragen, welche Bedeutung *spielerische Ingenieurskunst* (d.h. *Ludic Engineering*) bei der Entwicklung neuer Technologien haben kann und wie dieser Entwicklungsansatz weiterentwickelt werden könnte.

Methodologisch verfolgt diese Arbeit einen „*research through art and design*“ Ansatz. Der Kern der Arbeit ist dabei der praktische Teil der künstlerischen Forschung. Dieser Teil wird in Form einer autoethnographisch informierten Entwicklungstudie präsentiert und dient als Fallstudie für *Ludic Engineering*. Diese Fallstudie umfasst neben *Solar Pink Pong* ein davon inspiriertes, interaktives System für integratives Spielen, *iGYM*. Beide dieser Projekte verwenden interaktive Projektionssysteme und ermöglichen neue Interaktionsmodalitäten, die den Bezug zum Körper und zur Interaktivität in der physischen Welt neu erfahrbar machen. Basierend auf einem vielschichtigen Erfahrungsbericht aus dem Blickwinkel des Autors über den Forschungsverlauf von *Solar Pink Pong* werden in der Folge die wichtigsten Ergebnisse der Fallstudie anhand der Literatur zum Konzept des *Ludic Engineering* erörtert. Dabei werden Ideen aus den Bereichen der Kunst, der Technologie, der Innovation und des Spiels zusammengeführt und in die Arbeit einbezogen. Darauf aufbauend werden, anhand der Ergebnisse der Fallstudie, die folgenden drei zentralen Aspekte des *Ludic Engineerings* identifiziert und zugleich als Forschungsbeiträge präsentiert:

- Der primäre Beitrag ist ein *Erfahrungsbeitrag*, der sich auf die „Ausdruckskraft“ von *Solar Pink Pong* als interaktive Kunstinstallation bezieht, die an verschiedenen öffentlichen Orten ausgestellt wurde und interaktive Erlebnisse stimuliert, die zu neuartigen Erfahrungen führen.
- Der sekundäre Beitrag ist ein *Technologiebeitrag*, der sich auf die „Einführung neuer Technologien“ in Form von Patentschriften bezieht, die neue, nützliche und nicht offensichtliche Anwendungen von Komponenten beschreiben, die diese Erfahrungen ermöglichen.
- Der tertiäre Beitrag ist ein *expliziter Wissensbeitrag*, der sich auf einen „Bedeutungsausweis“ für den Forschungsbereich von HCI bezieht, wobei einige Aspekte der ermöglichten interaktiven Erfahrungen isoliert und als Effekte vom *iGYM*–System validiert werden.

Aufbauend auf dieser dreifachen Unterscheidung werden in der Dissertation mögliche Zusammenhänge und Konflikte zwischen den einzelnen Beiträgen erörtert; sie werden

als Facetten von *Ludic Engineering* präsentiert, die jeweils vom „Spielerischen" als erfinderischem Element profitieren.

Um das „Spielerische" in diesem Zusammenhang als das erfinderische Element besser fassbar zu machen, wird ein spekulatives *Ludic Innovation* Rahmenmodell konstruiert. Dieses Rahmenmodell beruht im Wesentlichen auf der Annahme einer Analogie zwischen der Rolle des Spielens in der Kindesentwicklung und seiner Rolle in der Entwicklung neuer Technologien. Um in diesem Sinne *Ludic Innovation* zu fördern wird vorgeschlagen, den Wygotskischen Unterrichtsansatz zu adaptieren indem (1) individuelle Entdeckungen unterstützt durch Technologieexperten und in Zusammenarbeit mit Peers angeregt werden und (2) eine „Zone der nächsten Technologie Entwicklung" (*Zone of Proximal Technology Development or ZPTD*) durch Gedankenspiel oder „Rollenspiel" (d.h. durch Vorspiegelung oder glauben Machen) geschaffen wird. Die *ZPTD* bezieht sich dabei auf das Technologieentwicklungspotential, das durch spielerische Auseinandersetzung mit Technologie erweitert werden kann. Diese Zone und dieses Rahmenmodell werden in Form eines modifizierten Flow Diagramms dargestellt.

To Allegra and Vida

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Special thanks are due to my *Solar Pink Pong* and *Daylight Media Lab* collaborators at the University of Michigan particularly: Dr. Surat Kwanmuang, whose extensive engineering skills enabled to build *Solar Pink Pong* from scratch; Seth Ellis for playing the role of the entrepreneurial lead in the customer discovery program; Dr. Edwin Olson, Dr. Jason Corso, Dr. John Nees, Dr. Max Shtein, Dr. Zhou Li, and Dr. Gordon Krauss for their input and collaboration efforts on *Daylight Media Lab* projects; and Gunalan Nadarajan, Dean and Professor at the Stamps School of Art and Design for funding this initiative.

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Finally, I'd like to thank Andréia Rocha, who walked the entire journey with me and nudged me more than once to complete this project; and my daughters Allegra and Vida, who reminded me that for truly understanding "play," it has to be practiced every day.

Abstract

This dissertation traces a convergence of artistic and ludic (i.e., playful) engineering approaches at the intersection of interactive art and Human-Computer Interaction (HCI) in light of *Solar Pink Pong, a* case study that focuses on "play" as the inventive element. The work is driven by the need to bridge conflicting viewpoints of this convergence and better understand the operational value of "play" (i.e., playful thought and playful behavior) for inventing technologies for, and with, the lived body. As such, the dissertation provides a multifaceted answer to the questions of what "serious" roles *Ludic Engineering* can play and how it can be further conceptualized.

Following a *research through art and design* approach, the core of the dissertation is a creative practice component, which is presented using an autoethnographically informed case study research approach. This core component comprises *Solar Pink Pong*, an interactive art installation and *iGYM* an interactive system for inclusive play that was inspired by it; both use interactive projection systems and enable new interaction modalities that re-frame the body and interactivity in the physical world. Drawing from a multilayered first-person account of *Solar Pink Pong*'s research trajectory, the dissertation discusses the main outcomes of the case study through the lens of literature related to the concept of *Ludic Engineering*; this lens weaves together ideas from the domains of art, technology, innovation, and play. Based on this conceptual lens and practice-based research model, the dissertation makes three main contributions:

- This primary contribution is an *experience contribution* that refers to the "expressiveness" of *Solar Pink Pong* as an interactive art installation exhibited at various public venues provoking novel interactive experiences.
- The secondary contribution is a *technology contribution* that refers to "bringing new technology into being" in the form of utility patents that describe new, useful, and non-obvious applications of components that enable those experiences.
- The tertiary contribution is an *explicit knowledge contribution* that refers to "stating meaning" in the research field of HCI with the *iGYM* system by isolating and validating some effects of the enabled interactive experiences.

Using this threefold distinction, the dissertation discusses the conceptual underpinnings and potential connections between each contribution; it presents them as facets of *Ludic Engineering* that each benefit from play as the inventive element.

Finally, to conceptualize play as the inventive element, the dissertation presents a speculative *Ludic Innovation Framework*. This framework draws an analogy between playfulness concerns in early childhood development and the development of emerging technologies. It proposes to adapt a Vygotskian classroom approach and cultivate *Ludic Innovation* by (1) assisted discovery with technology experts and peer collaboration and (2) creating a *Zone of Proximal Technology Development (ZPTD)* through imaginative or make-believe play. The latter zone refers to the technology development potential that can be expanded through play or playful engagement with technology; this zone and the framework is illustrated in form of a modified (i.e., "ludically engineered") flow diagram.

Table of Contents

List of Figures

List of Tables

1 Introduction

The introduction states (1) my personal motivation to conduct a practice-based dissertation as a media artist and designer using one of my interactive art installations, Solar Pink Pong*, as a case study. Further, it introduces: (2) the related problem, research questions, and topic of* Ludic Engineering*; (3) the context and significance of the topic; (4) the research approach; (5) the main outcomes; and (6) the author's role in this dissertation.*

1.1 Preamble

Framing and disseminating one of my interactive art installations, *Solar Pink Pong*, through a dissertation using the lens of *Ludic Engineering* is motivated mostly by three reasons: first, much of my work over the past 20 years has been research orientated and driven by a ludic (i.e., playful) technology engagement and engineering approach. However, it has never been published beyond short project descriptions or studied in this context before. Second, as a practicing media artist and designer based at a large research university, I experience how problem framing equals funding and collaboration opportunities. In other words, learning how to appropriately re-frame, for example, arts-based inquiry through another lens such as human-computer interaction (HCI) based research can significantly impact funding opportunities. As a result, the research team and available resources can increase drastically. Third, framing as an act of interdisciplinary self-reflection (not self-defense) can trigger a process of renewal and the emergence of something new. As an architect and designer by training and an artist and engineer by heart, the emergence of something new is perhaps the most important motivation. It is the main driver behind the dissertation's strategic goal to recalibrate the often low "currency" of art on paper compared to, in my case, engineering. Such concerns of disciplinary equity are also part of the strategic reason why I will use the term *ludic engineering* (Rogers et al., 2002) and not *ludic design* (Gaver et al., 2004) in this dissertation, since design, next to engineering, is often understood as a field concerned with shaping the fruits of engineering and not contributing to their conception.

Motivated by these reasons, I present *Solar Pink Pong* as a *Ludic Engineering* case study to further articulate this term and approach as an emerging line of research and practice at the intersection of interactive art and HCI (i.e., interaction design in particular).

1.2 The Problem and Research Questions

Ludic Engineering is not an established term or practice yet. However, the basic need for exploring a *ludic* (i.e., playful) engineering approach has already been expressed by Myron Krueger, a pioneer of interactive art, long before today's ubiquity of computational technologies:

To fully explore and enjoy what we are about to create will take more than practical problem solving. To truly master our tools we will have to use them for aesthetic expression, whimsy, and play. We must do this if we are to discover what it is, that what we have made, makes us. (Krueger, 1983, p. 245)

Krueger's (1983) early call to action for exploring alternative, more whimsy and playful, engineering approaches was the conclusion of his visionary book on the future of responsive environments titled *Artificial Reality* in 1983[1] – coincidently the same year as the term *Human-computer Interaction (HCI)* was first popularized (Card et al., 1983) and with it a new interdisciplinary field of study.

Three decades later, Krueger's vision has become a reality at the growing intersection between interactive art and human-computer interaction, particularly its related field of interaction design. This new reality and interdisciplinary intersection has been demarcated most notably by approaches termed as *ludic engineering* (Rogers et al., 2002) or *ludic design* (Gaver et al., 2004). Both approaches highlight playfulness and aesthetic appreciation as key elements regarding the engagement with novel technologies as well as our learning through it. Further, both approaches originate from established HCI scholars, although only *ludic design* has been popularized and is widely recognized as a term, today. In addition, there are other related approaches and terms that have emerged at this intersection including, for example, *speculative design* (Dunne & Raby, 2013), *critical design* (Dunne, 1999/2006), and *discursive design* (Tharp & Tharp, 2018). However, each of these terms emphasize, as their adjectives suggests, a different orientation of practicing design rather than re-framing engineering.

To reframe engineering at the intersection of interactive art and HCI in light of the *Solar Pink Pong* case study, I built primarily on Yvonne Roger et al.'s (2002) lesser known term of *ludic engineering*. I further conceptualized this particular approach and term, because it went beyond the scope of, for example, *ludic design* which aimed to enable ludic activities primarily for pleasure rather than external goals or utilitarian values. While supporting ludic activities are also implicit in Roger's *ludic engineering* approach, the latter was initially discussed as part of a larger technology-inspired innovation approach or "research aesthetics." This approach made explicit references to innovation techniques in art such as experimenting with combinations and juxtapositions of elements seeking to promote creativity and generate new experiences in return. Building on this particular orientation of a ludic and technology-inspired innovation approach, I explored and articulated *Ludic Engineering* with respect to the following three research questions:

- **RQ1:** *How can art (in a broader sense including architecture and design) and human-computer interaction (HCI) work together under one roof?*
- **RQ2:** *How can* Ludic Engineering *be further articulated as an emerging line of research and practice between interactive art and human-computer interaction?*
- **RQ3:** *What "serious" roles can* Ludic Engineering *play in the innovation process of technologies for the lived body?*

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[1] Krueger's book *Artificial Reality* is based on his PhD titled *Computer Controlled Responsive Environments* in which the statement quoted above was already included and published in 1976.

The first question (RQ1) addresses the larger problem space and context of this dissertation and serves as a starting point for the literature review. The second (RQ2) and third (RQ3) question guides the critical reflection on the research trajectory and outcomes of the *Solar Pink Pong* case study. I selected *Solar Pink Pong*, one of my interactive artworks, for this case study, because it was at the core of a *research through art and design* project that, like Roger et al.'s (2002) *ludic engineering*, sought to inspire learning and innovation through novel and playful visions of technology. Further, *Solar Pink Pong* as an artwork and research artifact traversed the entire epistemological spectrum from arts-based research to HCI-based research in a multiple yearlong research trajectory. By reflecting on *Solar Pink Pong* through the lens of *Ludic Engineering*, I further articulate the approach and concept for my own practice and for creative practitioners and scholars working at a similar intersection.

1.3 The Context

The investigation and further development of *Ludic Engineering* as an emerging concept and alternative technology innovation approach is timely, because over the past two decades, there have been increasing signs of a sometimes conflicted convergence of Art and HCI (Sengers & Csikszentmihályi, 2003) – with *ludic engineering* (or *ludic design*) as friction points right at its intersection. These signs of a convergence have been equally visible in practice, research, and education, for example:

In practice, HCI researchers have been exhibiting alongside with artists at venues such as the Ars Electronica or the International Symposium on Electronic Art (ISEA). Likewise, HCI conferences such as SIGGRAPH (International conference devoted to computer graphics and human-computer interaction) or TEI (International Conference on Tangible, Embedded and Embodied Interactions) have been organizing art tracks or art galleries to showcase digital art and interactive installations.

In research, conference articles, books, and special interest groups have started to address topics such as "music" (Holland et al., 2013), "socially engaged art" (Clarke et al., 2014), "digital art" (Leong et al., 2011; Fantauzzacoffin et al., 2012; Mendes et al., 2012; Villafuerte & Malinverni, 2014), and "interactive art" (Jacobs et al., 2015) – all in the context of HCI. A frequent topic that has come up in this context is the role that evaluating the "user" and "experience" should play in digital or interactive art. Likewise debates have been addressing the use and value of critical theory and aesthetics for HCI (Bardzell, 2009). Discussions have also focused on the role of the artifact and creative practice itself vis-à-vis the research process and knowledge contribution in HCI (Gaver, 2012).

In education, HCI's recent turn to aesthetics and focus on creative practice has led established schools of informatics (e.g., the University of Michigan School of Information) offer courses in graphic design, web design, interaction design, as well as in "unorthodox research methods" or "play and technology," on one side. While on the other side, many Art & Design schools have been striving to renew or increase their academic authority on campus by, for example, developing PhD programs that adopt research methods and methodologies that make their domain appear more solid and less unorthodox.

Historically, and in broader terms, the above described signs of a convergence can also be traced back to at least Walter Gropius's motto for the Bauhaus in Weimer: "Art and Technology: A New Unity." In fact, the rise of digital media at the end of the 20th century and the resulting opportunity for art and technology to come together under one roof in this context has also been referred to as "Digital Bauhaus" (Ehn, 1998; Binder et al., 2008;). The Digital Bauhaus discussion has also been echoed in the STEM versus STEAM debate regarding the integration of art in a 21st century school curriculum. In that sense, the convergence of art and HCI explored in this dissertation could also be referred to as an *HCIA amalgam* (i.e., Human-Computer Interaction Art).

However, the problem and premise of today's convergence to a "Digital Bauhaus" or *HCIA amalgam* seems quite different. In contrast to the historic Bauhaus, in which art (or architecture) played the dominant role as the intellectual "host" for the field of technology, it seems that today technology (or computer science) has, or might soon, become the "host" for the field of art – at least for digital art or interactive art in the context of a research university. This change of ownership or leadership from art expert to technology expert brings with it also a significant cultural shift from "Art as Experience" (Dewey, 1934/2005) to "Technology as Experience" (McCarthy & Wright, 2004) — and with this shift arise new opportunities (i.e. cross-pollination of knowledge, methods, skills, etc.) and problems (i.e. appropriation, misinterpretation, loss or oversimplification of worldviews and epistemologies, etc.). In the field of HCI, the consequences of this cultural shift or collision of two often conflicting frames of reference have been referred to as the dilemma of doing either art or computing well; the latter often leads to "good computing and dubious art" (Bardzell, 2009).

The underlying problems of this cultural shift are part of the bigger picture that this dissertation addresses by tracing a convergence of Art and *Ludic Engineering*. *Ludic Engineering* serves as the focal point specific to the intersection of interactive art and interaction design in this picture. To contribute to the discourse that describes similar meeting points or approaches related to art or HCI, I focus particularly on *Ludic Engineering's* innovation potential regarding novel technologies for the lived body as well as the role of the researcher's body as an instrument in the research process.

1.4 The Research Approach

The basic research approach with which I explore and further articulate *Ludic Engineering* as a concept and practice is twofold:

First, to explore the innovation potential of *Ludic Engineering* as a media artist and designer, I followed a practice-based research model. This model regards the process of creative practice and the resulting research artifacts as an integral part of its research method and knowledge contribution (Candy & Edmonds, 2018). In HCI this method has also been popularized as research through design (RtD) referring to the knowledge generated through the design process (Zimmerman et al., 2007). Following this model, I collaborated with engineers to create *Solar Pink Pong*, an interactive art installation. With this installation, I explored novel interaction modalities for the lived body in a multiyear long research project which transitioned from arts-based research in the wild (i.e., casual observations and conversations with passersby during exhibitions of the artwork) to HCI-based research in the lab (i.e., user studies with recruited participants in a controlled study environment).

Second, to further articulate *Ludic Engineering* as a concept at the intersection of interactive art and HCI for researchers and creative practitioners, I adopted an autoethnographically (Bartleet, 2013) informed case study research approach (Papachroni & Lochrie, 2015). I compiled a multilayered first-person account of *Solar Pink Pong*'s research trajectory that is both chronologically and thematically organized in order to reflect on patterns and emic issues that defined my creative process and shed light on the research questions. To provide sufficient background for my summative reflection, I described the project's entire research trajectory from its epistemologically and value-based foundation (i.e., *Pink Prints* and other foundation work with the artist collective Assocreation), its inspiration (i.e., colorful sunlight reflection), its implementation as an interactive artwork (i.e., Pong-like street video game console), to its re-evaluation for inclusive play and HCI research (i.e., *iGYM* augmented reality system). For the reader, I triangulated my direct and subjective interpretation of the creative process and its outcomes with external evaluation steps and milestones including patent applications, juried exhibitions, awards, grant applications, publications, research and teaching collaborations, a customer discovery program, and user studies. The goal of the triangulation was not to validate my interpretation, but to stimulate further reflection by optimizing readers' opportunities to learn (Stake, 1995).

In brief, this twofold research approach built on the knowledge that resides in *Solar Pink Pong* as an interactive artwork and research artifact, the knowledge generated through it, and the summative reflection on the creative process underlying it.

1.5 The Outcomes

The primary outcome of the dissertation is the creative practice component of the case study, which includes the interactive artwork *Solar Pink Pong* and the *iGYM* system for inclusive play that was inspired by it. Both are "ludically engineered" systems that enable novel interaction modalities and provoke new interactive experiences. As such these systems can best be examined by directly engaging with them in person or, alternatively, by watching a video documentation of people interacting with it (see e.g., www.solarpinkpong.com and www.igym.solutions). The interaction modalities themselves can briefly be described as follows: *Solar Pink Pong* enables passersby to interact with a pink sunlight reflection on the street using their bodies and shadows. *iGYM* enables physical play among people with different abilities in a projected augmented reality gym environment. What both modalities have in common is that they use interactive projection systems to re-frame the body and interactivity in the physical world.

Based on this creative practice component, I make four contributions. The first three are structured insights into *Solar Pink Pong* as a *Ludic Engineering* case study that I refer to as *experience contribution, technology contribution,* and *explicit knowledge contribution*; these structured insights are in response to the research question (RQ3) that aims to explore the "serious" roles that *Ludic Engineering* can play in the innovation process of technologies for the lived body. These first three contributions align with the most tangible and best documented results of the research though art and design process;

they each illustrate different facets of *Ludic Engineering* as a playfulness-oriented research and technology-inspired creative practice at the intersection of art and HCI:

- *Experience contribution* is the primary contribution of the case study. It refers to the "expressiveness" (Dewey, 1934/2005, p. 90) of *Solar Pink Pong* as an interactive installation exhibited at different venues ranging from art gallery and museum spaces to academic conferences and public spaces in the USA, UAE, Brazil, Japan, and Belgium; this contribution was also documented by two international awards from the media art community. Exhibitions in this context provided not just a dissemination opportunity, but also a critical learning opportunity in which the multifaceted nature of the artifact's expressiveness could be studied in different settings and based on open ended critique formats. As such, I articulate this contribution through the lens of Dewey's (1934/2005) *Art as Experience* and McCarthy and Wright's (2004) *Technology as Experience*.
- *Technology contribution* is the secondary contribution. It refers to "bringing new technology into being" (Schön, 1967, p. 1) in form of utility patents related to *Solar Pink Pong* and *iGYM* as interactive systems. Exploring the operational value of those systems through the process and criteria of a utility patent application (i.e., new, useful, non-obvious or surprising) is largely compatible with creative work and its evaluation. It helped to analyze and further conceptualize the design space related to both *Solar Pink Pong* and *iGYM* as an interactive artwork and system. Finally, acquiring utility patents was a step towards a *knowledge contribution* in a Deweyan sense of stating new meanings (e.g., describing new applications of technical components in this context) versus expressing them.
- *Explicit knowledge contribution* is the tertiary contribution. It refers to "stating meaning" in the field of HCI in form of two studies and publications that described and validated some effects and implications of *iGYM* as an augmented reality system for inclusive play and exercise. The key challenge was to find a way to isolate the effects of the system and make the study documentation "talk" in a way that doesn't cut short its "expressiveness" (e.g., the range of enabled interaction modalities and provoked experiences). In that sense, designing the study posed similar "wicked problems" (Rittel & Webber, 1973) and required similar "expert creativity" (Helfand et al., 2016) than the design of the interactive system itself. This contribution resulted from the shift from arts-based research to HCI-based research at the end of the *Solar Pink Pong* case study.

The fourth and final contribution is the *Ludic Innovation Framework*. This contribution is not a scholarly argument, but – like *Solar Pink Pong* – a "ludically engineered" construct. The framework builds on speculative reasoning in form of diagrams and images similar to alternative pictorials paper formats at HCI conferences. It is based on a summative reflection on the case study's underlying creative process through the lens of the literature reviewed for *Ludic Engineering* in chapter 2; it draws an analogy between playfulness concerns in childhood and technology development in response to the research question (RQ2) that aims to further conceptualize *Ludic Engineering*. The framework proposes to reflect on the benefits of play in childhood development (i.e. the ability to creatively adapt to, survive, thrive in and shape social and physical environments even in unpredictable or stressful situations) using it as a lens for emerging technology development vis-à-vis uncertain future scenarios. To achieve this, I designed a diagram that illustrates the process of *Ludic Innovation* based on a modified flow diagram.

1.6 The Author's Role

The work and case study research presented in this dissertation represents my own perspective as the artist and principal investigator leading the design and development of *Solar Pink Pong* including the related *iGYM* project and user studies. However, much of my perspective is grounded on prior work with the artist collective *Assocreation* and driven by a collaborative creative research approach. Outside this dissertation, *Solar Pink Pong* has often been exhibited and publicized under my artist collective's name *Assocreation*, in which I and other members typically operate anonymously.

Further, the HCI-oriented user studies and publication effort (i.e., CHI Play paper) described at the end of the case study was leveraged by the expertise of my research collaborators in engineering and HCI. Although I conducted the entire literature review and led the study design and manuscript writing, conducting the studies and analyzing the data involved a team of researchers and research assistants (i.e., graduate students). It built particularly on the feedback and input of my HCI and Engineering collaborators, Michael Nebeling, Assistant Professor in the School of Information, and Hun Seok Kim, Assistant Professor in Electrical Engineering and Computer Science. Nebeling made contributions particularly to study design and procedure and Kim to developing the arithmetic model used for player balancing. Finally, whenever other people were involved as experts, researchers, students, or assistants in the research or technical development of the project, it is mentioned as part of the respective case study description or in the related publication.

In addition, to clarify the author's writing perspective, the dissertation is mostly written from a first-person perspective, because it this perspective is best aligned with the autoethnographically informed case study research approach. I mostly use the authorial "we" for viewpoints that are part of the HCI-based user study in order to be consistent with the narrative form of already published ideas of this dissertation.

2 State of the Art Review

The state of the art review is divided into two parts: The first part reviews artworks, artists, and researchers related to the initial conception of Solar Pink Pong *as an interactive art installation. This part contextualizes* Solar Pink Pong*'s arts-based research trajectory prior to its examination as a* Ludic Engineering *case study for this dissertation. The second part reviews literature related to the notion of* Ludic Engineering *itself. This part contextualizes* Ludic Engineering *as an emerging form of playfulness-oriented research and technology-inspired creative practice at the intersection of interactive art (i.e., art-related domain) and interaction design (i.e., HCI-related domain). It provides the lens through which I explore the results of* Solar Pink Pong*'s research through art and design process as a* Ludic Engineering *case study in chapter 6.*

2.1 Solar Pink Pong: Precedents

This section provides a brief overview of the key art and technology precedents related to the conception of *Solar Pink Pong* as an interactive art installation. It includes: Nam June Paik's early video art; Myron Krueger's *Video Place*; VALIE EXPORT's *Ping Pong*; the *Light and Space* movement; the *Light Walks* and *Pixel Sonne* project; *Sixth Sense* and *Projection-based Augmented Reality*; and, the concept of *Next Nature* as well as *Ephemeral User Interfaces*.

2.1.1 Nam June Paik

Nam June Paik (1932-2006) was a pioneer of video art and an influential figure in the international Fluxus art community. Paik is an important historic precedent for many media artists today. He helps to contextualize *Solar Pink Pong*'s conception as an artwork, because of his dual interest in understanding the emerging technologies of his time – Video and Television – and transforming them through art. Unlike many of his peers and also some media artists today, Paik saw technology as well as his work in general as constructive and empowering (Hanhardt, 2014). For example, in *Magnet TV* (1965), Paik placed a large horseshoe magnet on top of a television set to manually distort and generate an electronic image on its screen. A simple but effective manipulation that turned a TV screen into a new canvas for art. A few years later, with the help of his engineering collaborator Shuya Abe, he created the *Paik-Abe Video Synthesizer* (1969), which was an interactive device that enabled gallery visitors to manipulate and play with their own footage displayed on a screen. With the video-synthesizer, Paik created both an artwork and functional tool. These are just two examples that highlight his interest in developing both new forms of art and technology. Paik's dual interest in shaping art and technology as well as his recognition of light as the primary medium of mass communication, which he emphasized in *Candle T.V.* (1975), is also shared in *Solar Pink Pong*'s conception as an interactive art work.

Paik's work is often characterized as experimental, playful, and visionary. By his own account, he didn't create work based on theories but was driven by instincts followed by practical methods (Zurbrugg, 1990). His approach towards technology and art making, however, was strongly influenced by two ideas: first, he was interested in humanizing technology, an idea that he adopted from the mathematician and scientist Norbert Wiener (Zurbrugg, 1990). As part of this interest, he explored video and television and their interplay with the human body in various forms including sculptures, installations, and performances – sometimes even building bodies with electronics or television sets such as for his *Family of Robot* (1986). Second, he was interested to blur the boundaries between ecology and technology. This idea is particularly visible in his first large-scale installation *TV Garden* (1974), in which forty TV sets were lying on the floor amidst tropical plants. The TV's were tilted upwards playing Global Groove, a video with colorful, synthesized imagery from commercial television programming. Paik considered this work to be particularly successful, because it puts the TV on the ground in a new and unusual position. It liberated the viewers from the typical TV position and prompted them to look around. Further, the colorful light from the TV's that flickered through the leaves and blended with their shades of green, prompted the viewers to lean back and talk to their neighbors instead of being fixated on a screen. As such, Paik's considerations describe early social concerns regarding screen-based interactions and the desire to break conventions that limit technology development and use. Taken as a whole, Paik's playful exploration of electronic media focusing on the interplay of light, the body, and the environment is an important reference for *Solar Pink Pong*. It is mirrored in its conception as a completely sun-powered artifact that provokes playful body interactions and that blends the built and natural environments.

2.1.2 Myron Krueger

Myron Krueger is a pioneer of interactive art and first-generation augmented reality researcher. Krueger is the primary reference point for this practice-based dissertation for two reasons: first, he developed *Video Place* (1974), an interactive art installation that uses similar body and shadow interaction modalities like *Solar Pink Pong*; and second, he wrote a dissertation related to *Video Place* titled *Computer Controlled Responsive Environments* (Krueger, 1976) in which he already expressed the need for a playful technology development approach, which I further conceptualize as *Ludic Engineering*.

Krueger's approach to interactive art took shape early in his career at a similar intersection like this project yet long before HCI was established as a field. In 1969, Krueger participated as a computer science graduate student in the development of *Glowflow*, a computer controlled, responsive light-sound environment conceived by artists and scientists for a university gallery exhibition. It was in the context of this exhibition that the term interactive art was first used (Kwastek, 2008, p. 19). Krueger (1983) himself, however, considered *Glowflow* a "kinetic environmental sculpture" (p. 17) rather than a responsive environment or interactive art installation. Seeking to develop more responsive forms of interactive art, he started his own career. Like Nam June Paik, who created the *Paik-Abe Video Synthesizer* in the same year, Krueger was interested in humanizing technology. He recognized technology as an important part of human nature. However, as a trained computer scientist, Krueger was interested in pushing the interactive capabilities of video and computer technology further by combining sensory and display systems. His goal was to build computer controlled responsive environments that engage people and their bodies in playful explorations of future interaction possibilities by "making technology both palpable and palatable" (p. xiv). Krueger saw his work as an art form that "is the composed interaction between human and machine, mediated by the artist" (p. xiii). Further, he saw the relationship between action and response as a dynamic composition that can change one's awareness of the body. Interactive art, for Krueger, provided a way to comment on experience at a philosophical level (p. 51).

Krueger's *Video Place* (1974) embodies his ideas on interactive art that he developed in his thesis and that he later also published as a book entitled *Artificial Reality* (Krueger, 1983) similar to the way that *Solar Pink Pong* embodies the ideas of *Ludic Engineering*. *Video Place* is an interactive installation in which the silhouettes of participants appear on a rear-projected wall as they enter a room. Using their silhouettes, they can interact with other participants in other locations and/or manipulate virtual objects displayed on this wall. Hence, *Video Place* creates a third, virtual place or what Krueger also calls an *artificial reality* in which participants can interact separate from the existing physical space. Krueger discovered this simple yet intuitive interaction modality by accident as he tried to troubleshoot another project with a friend by pointing two cameras at remote locations at the same display creating a composite image showing both of their hands interact with each other. This effect, according to Krueger, created a sense of touching each other and with it a new kind of social and spatial situation, which he explored extensively in various configurations. The interaction modalities in *Video Place* build on body silhouette movements like *Solar Pink Pong*'s body and shadow play, except that they are generated by artificial light on a wall instead of sunlight on the ground. However, Krueger also speculated about the potential use of *Video Place* for many other applications including physical therapy or "video sports" in which people with disabilities can join those without disabilities (p. 183). The latter scenario, although brief and without much details, outlines a striking parallel to *Solar Pink Pong* that actually inspired the iGYM system for inclusive play at the end of this case study.

2.1.3 VALIE EXPORT's Ping Pong

VALIE EXPORT is a pioneer of media art and performance art who has been particularly influential on my generation of artists growing up in Austria interested in exploring emerging intersections of new media with the body. One of her early key projects, the minimalistic film installation *Ping Pong* (1968), is an important reference for *Solar Pink Pong*'s underlying ideological motivation. In this installation, a black-and-white film is projected on a screen from the back of a dimly lit room showing large black dots appearing and disappearing in an alternating, predetermined rhythm. Right in front of the screen is half of a Ping Pong table. As the viewers approach the table they walk into the light of the projector and their shadows appears on the screen. The installation invites the viewers to pick up a paddle and ball and play Ping-Pong against the projected dots on the same screen, which gives the impression of playing against an imaginary opponent. The viewers' shadows, however, interfere with the game as they try to hit the dots on the screen. As a result, this installation doesn't enable the participant to successfully play the game. Instead, it draws attention to the relationship between their body and screen.

With *Ping Pong* (1968), EXPORT critically explored the spatial and political conditions of screen-mediated experiences vis-a-vis the human body. Unlike Paik and Krueger, who focused on interactions enabled by video technology, EXPORT explored the interactive dimensions of filmic experiences, which has also been defined as *interactive Expanded Cinema* in regards to her work (Mueller, 1994, p. 9). In other words, EXPORT was interested in the space in front of the screen and concerned with the ideological implications of the consumers' tendency to focus on the information "inside" the screen (Mondloch, 2010, p. 76).

> *(…) Ping Pong renders visible ideological relationships of domination. The viewer and the screen are partners in a game whose rules are dictated by the director, whose demand is that of making screen and viewer into a single unit of trade. To this extent, the consumer reacts actively. Nothing illustrates the dominant character of the screen more clearly as a medium to be manipulated by the director than this; no matter how much the viewer also enters into the game and plays with the screen, his status as a consumer is altered very little. (Export, 1968/2003)*

EXPORT also described *Ping Pong* (1968) as "Ein Film zum Spielen, ein Spielfilm" *(A Film to [Be] Play[ed])* (Mondloch, 2010, p. 65). Yet it is neither a conventional film to watch nor a functional game to play. It is an installation that draws attention to the space between the body and the screen. It is important to note that for EXPORT, this installation was not a critique of interactive game environments, but a critique of cinematic spectatorship. As such it also won the award for the most political film at the Viennese Film Festival in 1986 (p. 69). In the context of this research project, however, *Ping Pong* (1968) is also a visionary precedent for *Solar Pink Pong*. It shares its minimalistic aesthetic and playful shadow engagement of the viewer or player for the purpose of the critical reflection of the space between the viewer or player and the screen as well as the space between the viewers or players themselves – the latter highlights a qualitative difference of *Solar Pink Pong* which responds to player interactions in a sense as Krueger defines interactive art. Although less explicitly politically motivated than *Ping Pong*, *Solar Pink Pong* is driven by the same interest to move beyond a fixation on the screen and concerned with the societal implications of consumers being limited to, or conditioned by, its boundaries.

2.1.4 Light and Space Movement

What is often referred to as Light and Space movement started in the mid-1960's in Southern California as a small cluster of artists, who turned their focus away from producing art objects and focused on light and creating spatial, sensory experiences for the viewer instead (Butterfield, 1993, p. 8). Two prominent proponents of this movement, James Turrell and Robert Irwin, set important art historical precedents for *Solar Pink Pong*'s phenomenological interest in manipulating daylight in the built environment. Both artists have been particular interested in the visual impact of light and the nature of perception. Both were also part of the initial Art & Technology program of the Los Angeles County Museum of Art from 1967–1971. In this program, they collaborated with scientists and explored among others the effects of sensory deprivation. In a related report on this collaboration, they highlighted their joint interest to make people "aware of their perceptions" and "conscious of their consciousness"; simply put, for Irwin and Turrell, the experience, not the art object, was the "thing" (Weschler, 2008, p. 131). Driven by this phenomenological interest, they each created many immersive experiences that built on the interplay of light and space in various forms over the course of their careers.

Turrell's work is an important precedent for *Solar Pink Pong* as it draws particular attention to the space-making abilities of light as a medium. Turrell understands light is a thing. He also refers to the "thingness" of light; he sees light as an optical material that he molds and forms in his work (King, 2002). To achieve this, he mostly operates in dimly lit spaces that require the viewer to slow down and the pupils to dilate. He uses both natural and artificial light, sometimes combining them. For example, in his *Projection Pieces* a beam of light creates the illusion of a three-dimensional object floating in a corner of a dimly lit room; in *Skyspaces* a hole in the ceiling framed with artificial lighting create an effect that makes the sky appear closer and more tangible; and in *Ganzfeld*, a large enclosed space with programmed artificial lighting creates a disorienting effect that makes the viewer unable to distinguish between internally and externally generated visual sensations and see clouds or fog as a result. Unlike Turrell's immersive spare light experiences, however, *Solar Pink Pong* creates immersive experiences in bright outdoor environments. As a result, the pupils constrict and the "thingness" of light changes; there are no volumetric light effects. Instead, *Solar Pink Pong*'s sunlight reflection manipulated by virtue of a computer-controlled dichroic color mirror resembles fluorescent paint or color pigments on the ground. In other words, *Solar Pink Pong* explores daylight as a medium at the other end of the phenomenological spectrum. Space-making refers here to the transformation of a street into an immersive, interactive environment by engaging the viewer with bright, animated light effects similar to those on a computer screen.

Irwin is also interested in the articulation of space through light (Welschler, 2008, p. 197). His work is an important precedent for *Solar Pink Pong* insofar as it draws attention to the site, the richness of perception, and the spectacle that can be experienced every day, which he also referred to as "visual Disneyland" (p. 215).

> *The point is to get people to peel those visors off their faces, to remove the goggles, to abandon the screens. Those screens whose very purpose is to screen the actual world out. Who cares about virtuality when there's all this reality – this incredible, inexhaustible, insatiable, astonishing reality – present all around! (Irwin as cited in Welschler, 2008, p. 292)*

Irwin wants the viewer to "get rid of the window and just experience the world" (p. 271). The latter statement sums up the approach with which he transformed a room overlooking the pacific coast at the La Jolla branch of the Museum of Contemporary Art San Diego in 1997. In this room, Irwin cut out squares of glass in the middle of tinted windows framing the view of the museum. By cutting "squares of empty daylight" as he said, he created a frame within a frame that put the landscape outside into a new focus as if it was a painting. In addition to this pictorial framing, he added further experiential dimensions to the viewing experience by allowing the sound and wind from the outside to come in. Irwin referred to this intervention as a "truly four-dimensional, (…) site-conditioned piece" (pp. 270-271). *Solar Pink Pong* as well as much of my prior work with *Assocreation*, shares Irwin's focus on the site, the multiple layers of perception, and his concern with the potential of screens "to screen the actual world out" (p. 292). In *Solar Pink Pong*'s case, however, the primary focus is on enhancing the perception of the physical world to change the viewers interaction with it by manipulating daylight through the integration of digital technologies as opposed to getting rid of it.

2.1.5 Light Walks and Pixel Sonne

Bob Miller's *Light Walks* (1975) help to explain the particular nature of sunlight that had to be considered in *Solar Pink Pong*'s initial design; Johann Gielen's *Pixel Sonne* (2010) illustrates a concept of animating a sunlight reflection with a computer-controlled mirror similar to *Solar Pink Pong*. Both projects were inspired by observing the intricacies of sunlight reflections on the street like *Solar Pink Pong*.

Bob Miller (1935-2007) was an author of many museum exhibitions about light, color and shadow at the Exploratorium, a museum of science, technology, and arts in San Francisco (San Francisco Public Library, 2014). *Light Walks* was one of his key projects that he started to develop in 1975 and that has become an attraction for many Exploratorium visitors since then ("Light Walk," n.d.). In this project, Miller took visitors for a walk to explain light and shadow phenomena that can be observed every day. In these walks, he highlighted a particular aspect of sunlight that I also encountered in the early development stages of *Solar Pink Pong*. He demonstrated how sunlight creates a round spot of light no matter what shape the mirror it reflects from, or hole it passes through, and that this round spot of light is in fact an image of the sun. He showed how the same "pinhole camera" effect can be observed when sunlight light shines through the gaps between the leaves of a tree or the fingers of his hands when he crossed them. In each case, with enough distance between the projection surface and the holes, or the mirror, as well the right angle (i.e., perpendicular to the rays of the sun), all sunlight eventually turns into a round spot of light (i.e., showing a round image of the sun). This aspect of sunlight, related to the size and shape of the sun, is one of the reasons why *Solar Pink Pong*'s mirror design is oval. Further, it is the reason why sunlight cannot simply be used like a conventional, artificial point light source in an optical system, which I also explored (see chapter 5).

Johann Gielen is a lighting designer and urban planner, who presented *Pixel Sonne* as a concept of using sunlight for a low-resolution display system at the Media Architecture Biennale 2010 (Gielen, 2010). A colleague made me aware of this concept, which is unfortunately not documented in the exhibition catalogue, after I shared a video of *Solar Pink Pong*, because of the similarity with which sunlight is animated with a moving mirror. Gielen's concept illustrations show a computer-controlled mirror array system for urban spaces. The system uses square mirrors that are supposed to create pixelated sunlight reflections on building facades or city squares to animate public spaces with natural light as opposed to conventional media facades. Gielen also built first mock-ups of this system. Interestingly, however, he illustrated the resulting sunlight reflections incorrectly as squares (i.e., pixels), which cannot be achieved by square mirrors in the proposed way over longer projection distances for reasons described in Miller's *Light Walks* above. Nevertheless, *Pixel Sonne* is a precedent that captures the basic idea of animating sunlight with automated mirrors. In *Solar Pink Pong*, however, this idea is technically and conceptually taken further. Two of the main differences are that in *Solar Pink Pong*, the sunlight is manipulated with a custom designed, oval dichroic color mirror that changes the perception of sunlight to make it largely indistinguishable from artificial light (e.g., the light of a video projector). Further, it uses sensor technology to animate this artificial light effect and explore new interactions possibilities that comment on screen-based video game culture as supposed to media facades in architecture.

2.1.6 Projection-based Augmented Reality and Sixth Sense

Projection-based Augmented Reality and Sixth Sense are two concepts that marked *Solar Pink Pong*'s technical development and inspired the way it mediates the playful interaction with the physical world through novel sensing and display technologies. Projection-based augmented reality is sometimes also referred to as *spatial augmented reality* (Bimber & Raskar, 2005). It refers to the concept of overlaying the physical world with digital images or visual cues to enhance the way users can interact with it. This information overlay can be achieved through combining sensing and projection technologies such as cameras and video projectors or in the case of *Solar Pink Pong* a computer-controlled color mirror that reflects sunlight. Projection-based augmented reality represents one of many *Mixed Reality* technologies that range from augmenting the real environment to replacing it with a virtual environment (Milgram et al., 1995). The former is often referred to as Augmented Reality (AR) and the latter as Virtual Reality (VR). In Milgram's (1995) *Reality-Virtuality* framework they are both situated at opposing ends of the same continuum blending, to different degrees, the information visible in the real environment with virtual content and vice versa. *Solar Pink Pong* explored the boundaries at the extreme end of this continuum, where projection-based augmented reality technologies blend with the natural surroundings and the built environment. Instead of projecting artificial light to display digital information that augments the real environment, it uses sunlight to display computer-generated information (i.e., an animated pink sunlight reflection on the ground). Further, it augments the participants' natural gesture feedback and "virtual representation" provided by the sun. In other words, it makes their shadow silhouettes interactive boundaries with which they can manipulate the overlay of computer-generated information (i.e., the animated pink spot) on the same surface and in the same environment.

Sixth Sense is a term related to projection-based augmented reality that was popularized by Pranav Mistry (2009) as an MIT graduate student in his TEDIndia talk in 2009. It refers to the idea of augmenting the five human senses with a metaphorical sixth sense, a wearable, interactive projection system that scans the environment and overlays surfaces or physical objects in front of the user with digital information that can be controlled by gestures. A similar system had been developed earlier by Steve Mann (2000), who also worked at the MIT and who initially coined *Sixth Sense* as a term (2001). In his TED talk, Mistry showed many potential applications of this wearable, gesture-based system that seek to make interacting with digital information more intuitive and akin to interacting with the physical world – from projecting additional content or context information on newspapers, books, or airline tickets to drawing or modifying virtual photos directly on walls. One application of this technology was a particular inspiration for the development of *Solar Pink Pong* as an interactive game and installation. It shows passengers playing a pong game inside a subway train kicking a small projected virtual target with their feet on the ground. This adaptation of Atari's 1972 Pong game showed a playful interaction modality with a virtual target that takes Myron Kueger's idea of responsive environments that he explored in *Video Place* (1974) further outside the gallery into an everyday environment. Mistry's *SixthSense* technology in this respect also builds on Kueger's (1983) *Artificial Reality* concept. *Solar Pink Pong* combines interaction ideas from both, Krueger's shadow interaction and Mistry's feet or gesture-based manipulation of virtual targets. However, *Solar Pink Pong* is not a wearable system like the latter. It is a device that is installed at specific sites (e.g., on light poles, building facades, or trees) based on the course of the sun to augment its natural surroundings and social settings.

2.1.7 Next Nature and Ephemeral User Interfaces

Next Nature and Ephemeral User Interfaces are two concepts that contextualize *Solar Pink Pong*'s motivation as an interactive artwork that seeks to blur the boundaries between natural and artificial light – interactive media and daylight as medium. I used these concepts both for *Solar Pink Pong* and the related *Daylight Media Lab* research to articulate the need for novel, sun-powered, interactive outdoor experiences.

Next Nature is a concept that was proposed by the Dutch artist and researcher Koert van Mensvoort and the graphic designer Hendrik-Jan Grievink in a same-titled publication illustrated by many thought-provoking images (e.g., an embryo holding a cell phone) (Mensvoort & Grievink, 2012). With this publication, they countered the dominant nature-technology dichotomy of the western industrialized world that distinguishes between human-made and non-human made or born – a distinction that can be traced back to the ancient Greeks (Schiemann, 2004). Mensvoort and Grievink (2012) articulated nature as a dynamic concept that changes along with cultural and technological advances. Simply put, they argued that technologies that shape today's culture may become tomorrow's next nature (i.e., perceived as natural or indistinguishable from nature). Mensvoort illustrated this argument in the book with many examples ranging from the soil where he was born, the Netherlands, where much of today's landscape is a product of earlier human ingenuity and water management technology to computer viruses that behave like nature in the way they function autonomously outside of human control. In other words, Mensvoort proposed to draw boundaries between culture and nature by distinguishing between controllable and autonomous elements in addition to human-made versus born. A related two-by-two matrix based on these distinctions shows the sun in a quadrant labeled as "old nature" that is "born and beyond our control" and a lightbulb in an opposing quadrant labeled as "culture" which is "made and in our control" (Mensvoort & Grievink, 2012, p. 13). These distinctions between natural light as old nature and artificial light as culture are exactly the lines that *Solar Pink Pong* seeks to blur by manipulating sunlight with a computer-controlled dichroic mirror; the resulting new experiences may qualify as next nature in this view.

Ephemeral user interface is a concept that fits into the above described next nature framework and marks the intersection between art and HCI that I will further review in the literature review for *Ludic Engineering* in the next section. It was proposed by HCI researchers to describe the potential of unusual, natural materials (e.g., water, ice, fog, air, light, etc.) for the design of digital interfaces (Döring et al., 2013). This concept resonates on multiple levels with *Solar Pink Pong* and the focus of this dissertation on tracing the convergence of art and *Ludic Engineering*. First, the idea to consider materials with a transient quality for user interfaces was, as Döring et al. (2013) themselves stated, inspired by the way the notion of material is typically framed in contemporary art (see e.g., the earlier mentioned artist James Turrell referring to light as an optical material that he molds and forms). According to Döring et al., the benefit of this more loose and metaphorical notion of material is that it opens up a design space that enables new aesthetic experiences and reality-based interaction possibilities. Reality-based interaction is another HCI concept that was introduced by researchers to characterize natural interaction styles that, similar to interactions with the physical world, build on the users' awareness and skills related to their bodies and social and environmental surroundings (Jacob et al., 2008). Second, and related to natural interaction styles, Döring et al. (2013) highlight the potential of ephemeral materials to stimulate multisensory perception that engages the whole body and provokes playful explorations of multiple interaction possibilities. This playful exploration of new and unconventional media is also at the center of the innovation potential that I propose to further explore with the concept of *Ludic Engineering*.

2.2 Ludic Engineering: Contextual Literature Review

> *Figuring out the exact connections between play, creativity, innovation, culture, art, science, beauty, and humour may not ultimately be as interesting as simply considering these notions together, or playing with them. (Stenros, 2015, p. 90)*

This section provides the lens through which I explore *Solar Pink Pong* as a *Ludic Engineering* case study. It positions *Ludic Engineering* as an emerging form of playfulness-oriented research, and technology-inspired creative practice, at the intersection of interactive art (i.e., an art-related domain) and interaction design (i.e., an HCI-related domain). To further articulate *Ludic Engineering* vis-à-vis related concepts and practices, I look at the initial emergence of the term "ludic" and the art inspiration behind it. Further, I weave together ideas from different domains – art, technology, innovation, and play – by focusing on their connections related to interaction, experience, change, and creativity (see Figure 1). The resulting lens is an interpretation of different literature and related concepts for the summative reflection on the *Solar Pink Pong* case study in chapter 6. However, it does not provide an all-encompassing rationale for a definition of *Ludic Engineering* that goes much beyond this case study. Instead, it is reminiscent of a situationist dérive, or rapid drift, through different terrains that involves making playful and subjective interpretations rather than following predetermined paths alongside established categorizations. The former tactic of drifting also characterizes part of the initial inspiration for the notion of "ludic" in the context of engineering.

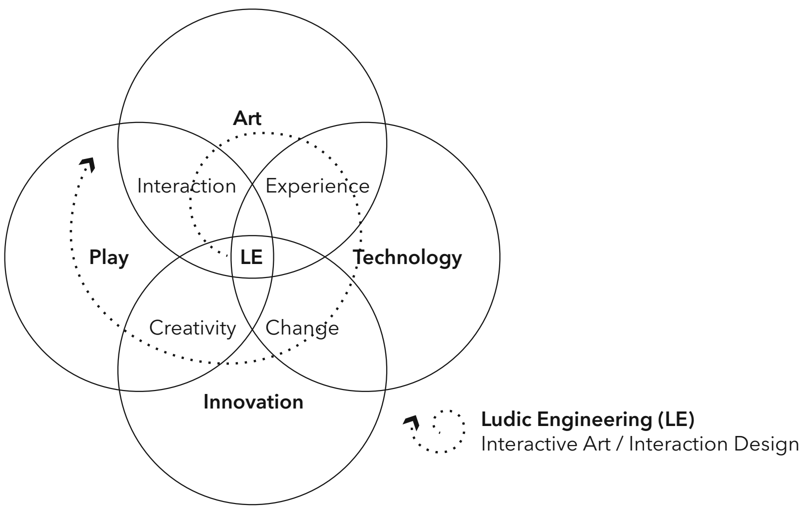

Figure 1: *Ludic Engineering* Venn diagram with a spiral indicating the way I articulate the term by weaving together (or drifting through) the domains of art, technology, innovation, and play through focusing on their intersections related to interaction, experience, change, and creativity.

2.2.1 Related Terms and Practices

> *Engineering [is] Most simply, the art of directing the great sources of power in nature for the use and the convenience of humans. In its modern form engineering involves people, money, materials, machines, and energy. It is differentiated from science because it is primarily concerned with how to direct to useful and economical ends the natural phenomena which scientists discover and formulate into acceptable theories. Engineering therefore requires above all the creative imagination to innovate useful applications of natural phenomena. (Barker, 2005, p. 288)*

To position *Ludic Engineering*, it seems appropriate to start by addressing the root of the term: the profession of engineering. Today, the engineering profession encompasses many specialized fields. In 2018, the American Society for Engineering Education alone listed more than 20 different engineering disciplines (Roy, 2018), each with distinct emphasis areas related to specific knowledge applications and technology innovations – ranging from "A" like aerospace engineering to "P" like petroleum engineering. Why add another emphasis area like *Ludic Engineering* to this list? The need for a more whimsy and playful engineering approach was not just supported by the visionary work of the artist and computer scientist Myron Krueger (1983) or the HCI researchers Yvonne Rogers et. al (2002) and Bill Gaver et al. (1999, 2002) that I discuss in the following; it is also supported by a vision statement from the above mentioned engineering community which characterized the "Grand Challenges for Engineering in the 21st Century" as: "Continuation of life on the planet, making our world more sustainable, secure, healthy and joyful" (American Society for Engineering Education, 2019). This broad vision is clearly counter to an image of engineering as an austere and narrow-minded profession. It sets the tone and expresses the spirit with which I seek to further articulate *Ludic Engineering* as a playfulness-oriented research and development approach at the intersection of interactive art and interaction design.

Ludic Engineering is not an established term yet. However, it has already been used at least once by Rogers et al. (2002) to comment on the practice of interaction design in the context of a human-computer Interaction (HCI), when the latter was still referred to as "usability engineering" (Rex Hartson, 1998). HCI has indeed strong roots in engineering; it was initially a convergence of software engineering and human factors engineering before it was popularized as a multidisciplinary field starting to integrate perspectives from social psychology, anthropology, and sociology in the 1980's (Carroll, 2003, p. 2-4). Rogers et al. (2002), however, use the term "ludic engineering" with a different goal in mind. They use it to describe the future-oriented technology development approach with which their team (i.e., a large group of designers, technologist, artists, psychologists etc.) created a mixed reality game for children. Their approach focused on exploring the capabilities of novel technologies instead of usability concerns related to existing fields of games, products, or commercial toys. More specifically, they mention "ludic engineering" as one part of a so-called "research aesthetics" seeking "to promote learning through novel, playful visions of technology"; the other part focuses on "technology-inspired" development through creative experimentation and new combinations of technologies (Rogers et al., 2002). The result of their work was a new interactive experience in the form of an adventure game that combined RFID tags, various sensor technologies, handheld computers, and video projectors, etc. The goal was to playfully engage children in new ways of thinking about technologies particularly related to the intersections of physical and virtual experiences. This playful way of technology arrangement was directly linked to innovation techniques in art that involve experimentations with new combinations or juxtapositions to provoke audience responses. In fact, Rogers et al. (2002), go so far as to draw parallels with Marcel Duchamp's readymades and the surrealist movement of Paris in the 1920's as examples following similar aims. This analogy and first mention of "ludic engineering," although very brief, is an important foundation for the further articulation of *Ludic Engineering* at the intersection of art and HCI or interactive art and interaction design in this project. It highlights the potential of artistic strategies to inform new ways of thinking in HCI particularly those that go beyond the mainstream of "usability engineering" (Rex Hartson, 1998) and address novel technologies for which applications have yet to be defined.

Ludic design is another related and better known interaction design approach that was formulated around the same time by the designer and HCI researcher William Gaver in his manifesto "Designing for Homo Ludens" (Gaver, 2002). Gaver actually used the term "ludic design" not until a few years later (Gaver et al., 2004); and he revisited it (Gaver, 2009) when it had already gained some popularity among designers, who shared the perspective that "technologies and the methods used to develop them need to embrace more open-ended forms of exploration and recognize wider ranges of human experience" (2009, p. 177). Gaver's *ludic design* perspective was illustrated and popularized by many artifacts including, among others: *The Pillow* by Tony Dunne (Dunne & Gaver, 1997), a pillow made out of translucent plastic, that shows changing light patterns in response to ambient electromagnetic radiation; the *Drift Table* (Gaver et al., 2004), an electronic coffee table, that displays slowly moving aerial photography controlled by the distribution of weight on its surface; and *The Prayer Companion* (Gaver et al., 2010), a small device with an integrated display, designed for a group of cloistered nuns that suggests possible topics for prayer sourced from RSS news feeds and social networking sites. All these examples highlight Gaver's (2002) emphasis on interaction designers as "playful creatures" as opposed to just practical problem solvers. To support the need for this emphasis, Gaver references Johan Huizinga's (1938/2016) influential book *Homo Ludens – A Study of the Play Element in Culture* that elevates the role of play for culture to the same level as making (i.e., Homo Faber) or reasoning (i.e., Homo Sapiens). Using Huizinga's work as a reference, Gaver (2002) highlights the importance of more open-ended interaction design methodologies that better capture the full spectrum of people's lives as opposed to just their work. In a related diagram he positions ludic design amidst the fields of art, entertainment, tools, information, toys, and communication (Gaver et al., 2004). Further, he outlines three related methodological implications: first, the need for scientific approaches to be complemented by more subjective, idiosyncratic ones that use the personal experiences of designers as sounding boards; second, the need to provide room for people to appropriate technologies by suggesting opportunities for ludic activities and employing ambiguity in all phases of the design process; and third, the consideration that "pleasure comes before performance, and engagement before clarity" and that designers need to be "provocateurs, seeking out new possibilities for play and crafting technologies that entice people to explore them" (Gaver, 2002).

This more idiosyncratic "artist-designer" or "artist-provocateur" (Gaver et al., 1999) approach that characterizes *ludic design* is particularly relevant for tracing the art inspiration behind the term "ludic" in this research project. It was described in more detail by Gaver et al. (1999) when they coined the term *Cultural Probes* for a related ludic design research approach that employs carefully designed artifacts (e.g., maps, postcards, etc.) to gather "inspirational data" about people's lives. In this context, Gaver et al. (1999) also drew parallels with artistic strategies much in the way Rogers et al. (2002) did with the notion of "ludic engineering." In their case, however, the researchers made even more explicit the intersection of their work with artistic strategies. To conceptualize the *Cultural Probes*, Gaver et al. (1999) took cues from the psychographical maps of the situationists. They referred to the situationist practice of dérive, or drift, that prompted participants to go on a journey though the city and take notice of their state of mind to find reasons for movement other than those for which the environment was designed (Plant, 1992, p. 59). They also pointed out the situationists' ideological motivation behind such disorientation practices as a way to explore new cultural possibilities that liberate people from being consumers of fabricated experiences, including their own, in a capitalist society. This practice and ideological motivation informed the ludic approach of Gaver et al. (1999) which was looking for new ways of appreciating social, urban, and natural environments. It also aligns with the researchers' emphasis to approach new technologies by focusing less on precise analyses and more on aesthetic control and the cultural implications of their designs. Overall, it seems evident that much of this ludic design approach was informed by conceptual and ideological concerns of the situationists whose theories on drifting themselves built on Huizinga's work and were motivated by a "passion for play" (Debord, 1955). This art-inspired spirit of ludic design has been explored in various forms since the 90's. It has been particularly popularized by one of Gavers co-authors, Anthony Dunne, under different terms such as critical design (Dunne, 1999/2006) or speculative design (Dunne & Raby, 2013). In fact, critical design and speculative design are far more widespread terms today than ludic design. Dunne, a trained industrial designer, also explored how designers can use fine-art means to probe the aesthetic potential of new technology and question the way they shape people's lives (Dunne, 1999/2006, p. ix). Both Dunne and Gaver (1997) insist, however, that their work is design and not art. Anthony Dunne and his design studio partner Fiona Raby further elaborate on this position in respect to critical design emphasizing:

> *It is definitely not art. It might borrow heavily from art in terms of methods and approaches but that's it. We expect art to be shocking and extreme. Critical Design needs to be closer to the everyday, that's where its power to disturb comes from. Too weird and it will be dismissed as art, too normal and it will be effortlessly assimilated. If it is regarded as art it is easier to deal with, but if it remains as design it is more disturbing, it suggests that the everyday as we know it could be different, that things could change. (Dunne & Raby, n.d.)*

In addition, there are many other related terms and design practices. Dunne and Raby (n.d.) highlight, for example, *conceptual design, design fiction, interrogative design* as some of the main "relatives" of *critical design*. "Critical" in this context refers to the focus on exploring "the ideological nature of design" in electronic products that shape everyday experiences (Dunne, 2006, p. xv). It goes beyond the concerns of "usability engineering" (Rex Hartson, 1998) and focuses instead on an "aesthetics of use" (Dunne, 2006, p.17) or "functional aesthetics" (Gaver et al., 1999) – both are related terms that reframe the value of aesthetics next to usability or function. The former term was in fact first proposed by Dunne to describe the expanded notion of "design aesthetics," which in his view included "the aesthetics of the social, psychological and cultural experiences" that are mediated by the interactive nature of digital products (1999/2006, pp. xv-17). Bruce and Stephanie Tharp (2018), who have most recently surveyed *critical design* practices proposed yet another term, *discursive design,* that also emphasized the potential of design to spark new ways of critical thinking. This list of related terms and practices is certainly not comprehensive, but it shows the multimodal ways with which the art-inspired, critical and ludic design spirit has already manifested itself.

However, the concept of *Ludic Engineering* that I propose for the *Solar Pink Pong* case study has a different orientation. It focuses less on the discursive quality or "functional aesthetics" (Gaver et al., 1999) of artifacts and more on exploring the operational value of playfulness in the process of engineering interactive systems. In this context, having the word "ludic" in front of "engineering" is conceptually both an important and intentionally provocative signal. It signals that in *Ludic Engineering*, playfulness is not positioned somewhere downstream the development process to shape cosmetic details of its outcomes like human factors in the beginnings of HCI (Carroll, 2003, p. 2). It is also not de-coupled from engineering to merely provide inspiration for it like critical or speculative design (Dunne & Raby, 2019). In the notion of *Ludic Engineering* that I explore, playing and making co-exist as activities at the same level as in Huizinga's (1938/2016) work *Homo Ludens* and *Homo Faber*. Further, in *Ludic Engineering*, interactive art is a closer inspiration for ludic forms of interaction design than early forms of conceptual art (see e.g. Rogers et al.) or the work of the situationists (see e.g. Gaver et al.). In fact, interactive art with its origins in participatory art and cybernetic art (Kwastek, 2008), is more than an inspiration in this context, because it is the field where the *Solar Pink Pong* case study and much of my work as a media artist with the collective Assocreation started (see Chapter 4). Therefore, in lieu of outlining a brief history of new media art – an umbrella term for different forms of art with interactive or time-based orientation (see e.g., Paul, 2008; 2015) – I have reviewed in the previous section the precedents specific to the conception of *Solar Pink Pong* and its notion of interactive art.

2.2.2 (Interactive Art + Interaction Design): Interactivity

Key for situating *Ludic Engineering* at the intersection of interactive art and interaction design (as a domain of human-computer *interaction*) is their common denominator: their shared interest in the notion of "interactivity."

The term "interactivity" has been discussed extensively particularly in the 1990's when it was a "buzzword" in the media community (Jensen, 1998). It is certainly no coincidence that both interactive art and interaction design gained popularity in the 90's even though their concepts were coined much earlier. Interactive art was coined in 1969, when Krueger participated in the development of the *Glowflow* exhibition that I discussed earlier; and interaction design was coined in the mid 1980's by Bill Moggridge and Bill Verplank, two industrial designers (Cooper et al., 2014, p. xx). In the late 90's, the term "interactivity" was already considered to be a *multi-discursive* concept that is difficult to define (Jensen, 1998), because it is closely related to the term "interaction" that has various connotations in different disciplines. For example, in sociology it can refer to the reciprocal relationship between two or more people; in informatics or HCI it can refer to the relationship between people and machines; and in communication studies it can refer to, among other things, the relationship between the text and the reader or to reciprocal human actions and communication associated with the use of media, etc. (Jensen, 1998). "Interactivity" and "interaction" are often used synonymously in this context. Further, it has been argued that it is debatable whether the meaning of "interactivity" is the same as "interaction" (Quiring & Schweiger, 2008), which complicates making conceptual distinctions.

Three basic distinctions or conceptualizations, however, help to clarify the notion of "interactivity" for the *Solar Pink Pong* case study. First, there is an older consensus among researchers in media studies and informatics that "interaction is a style of control and interactive systems exhibit that style" (Guedj, 1980). This view helps to clarify the basic relation between both terms in *Solar Pink Pong* as an interactive system that enables and displays a novel interaction modality or style of control. Second, there is the conception of "interactivity" that views it "solely as a process of inter-human communication via technical means" that is "the result of a complex interplay between action, situational evaluation [by the user], and the exchange of meaning" (Quiring & Schweiger, 2008). This three-fold conception of interactivity helps to differentiate, for example, the actions that can be observed (e.g., bodily play), the situational sensations (e.g., playfulness, connectedness, etc.) that can be experienced, and the meaning that can be exchanged through engaging with *Solar Pink Pong* as an interactive artwork. In fact, the latter two parts of this conception could be extended, because *Solar Pink Pong* also allows people to interact with the environment (e.g., sunlight) and not just with each other. Further, meaning is not just exchanged between participants, but also evoked (e.g., environmental awareness, technology criticism, etc.) by the system and the way "interactivity" can be evaluated in this situation. Third, there is the distinction between ideological and instrumental concerns with which interactivity or interactive media (Kwastek, 2008) can be addressed. This distinction is more one of degree than of kind as "meanings and uses" of technology are intertwined particularity in ludic forms of engagement with interactive media (Lister, 2009, p. 253) as in the case of *Solar Pink Pong*. However, this third distinction helps to explain why the discourses in interactive art or media studies on one side, and interaction design or HCI on the other side, have largely been disconnected despite their shared interest in the notion of "interactivity" — with the former being in general more charged with ideological concerns and the later more focused on instrumental concerns.

The goal of *Ludic Engineering,* as it relates to interactivity, is to address both instrumental and ideological concerns that have shaped the work of artists and technologists as a joint field of study. This joint field of study and the historic context behind the convergence of art and technology concerns are further explored in the next section which focuses on another common denominator: the notion of "experience."

2.2.3 Art and Technology as Experience: A Convergence with History

The traditions of thought that *Ludic Engineering* draws from are marked by the convergence of two influential frameworks: John Dewey's *Art as Experience* (1934/2005) and John McCarthy and Peter Wright's *Technology as Experience* (2004). Key to both frameworks — of which the first, a reflection on aesthetics and arts informed 70 years later a reflection on technology — is their shared interest in the notion of "experience." This shared phenomenological interest has also given rise, over the past few decades, to a growing discourse at the intersection of interactive art and interaction design. In the field of HCI, some scholars have framed this emerging interest as the third of three intellectual waves (Bødker, 2006) or paradigmatic shifts (Harrison et al., 2007); each of those shifts or waves has built on different metaphors of interaction: the first paradigm focused on "interaction as man-machine coupling"; the second paradigm shifted the focus to include "interaction as information communication"; and the third paradigm further shifted the focus to include "interaction as phenomenologically situated" (Harrison et al., 2007). The third paradigm has also been described as "phenomenological matrix" (2007) and later as "situated perspectives" (Harrison et al., 2011). The central characteristic of this third paradigm is the integration of many different critiques and approaches ranging from embodied interaction to critical and value-sensitive design into a single epistemological framework. This framework "treats interaction as a form of embodied meaning-making in which the artifact, its context, and its study are mutually defining and subject to multiple interpretations" (2011). *Ludic Engineering* builds on the inclusive orientation of this epistemological framework and focuses on further exploring its intellectual commitment with a particular focus on the development of technologies for the lived body.

Dewey's (1934/2005) influential ideas as a pragmatist philosopher in *Art as Experience* have often been criticized and defended from many perspectives (see e.g., Leddy, 2016) many of which would fit in the "phenomenological matrix" of the third paradigm. In this project, Dewey's ideas are embraced on many levels. They particularly help to articulate the notion of "experience" as an aesthetic quality from the position of a pragmatist, art-oriented worldview that also shaped the development of *Solar Pink Pong* as an interactive artwork and system. The aesthetic quality in this Deweyan sense can be addressed from at least two different perspectives: first, from a "consumer" (i.e., participant, user, etc.) perspective engaging or living with technology; and second, from a "producer" (i.e., artist, engineer, etc.) perspective developing or manipulating it. The quality that is in play in both perspectives can be illuminated by Dewey's (1934/2005) concept of *an experience* and his related theory of expressive acts that are both described in *Art as Experience*. First, to understand Dewey's concept of *an experience*, it is important to note that for Dewey "every experience is the result of interaction between a live creature and some aspect of the world" (p. 45) in which the creature lives; and this interaction can lead to a continuous adaptation process in which the creature does something (e.g., lift a stone) and in return undergoes something (e.g., feel the weight or texture of the stone) and so forth. However, this does not automatically constitute *an experience* in a Deweyan sense. To have *an experience*, the process of "doing and undergoing" needs a pattern and structure that allows every part of the experience to flow freely until the creature and object are mutually adapted and the total experience ends with felt harmony (pp. 37, 45). For Dewey, perceiving the distinct structure of such *an experience* and enjoying its aesthetic quality as a consumer is related to the experience of making as a producer. Both require training and are active, intelligent forms of engagement. Yet he emphasizes that the unity of "undergoing and doing" that characterizes "*an* experience" and its aesthetic quality as distinct from other, inchoate experiences is more difficult to grasp for a consumer than a producer. Second, and related to the producer perspective, within Dewey's theory of expressive acts there is a framework for creativity or "creative production" (p. 76) that, as he states, is not only relevant for aesthetics and arts, but for all modes of production.

> *In an imperfect society—and no society will ever be perfect—fine art will be to some extend an escape from, or an adventitious decoration of, the main activities of*

living. But in a better-ordered society than that we live in, an infinitely greater happiness than is now the case would attend all modes of production. (…) there is an immense amount of organization, but it is an external organization, not one of the ordering of a growing experience, one that involves, moreover, the whole of the live creature, toward fulfilling conclusion. (Dewey, 1934/2005, p. 84).

Dewey's (1934/2005) framework for creative production builds on the idea that every experience begins with an "impulsion," that is a drive or movement of the whole organism (i.e., including all elements and tools necessary) towards fulfilling a need; this "impulsion" is distinct from mere "impulses" that are supplemental to it like the reactions of tongue and lips are supplemental to the craving of the living creature for food (pp. 60-61). To fulfill this need, obstacles and conditions that are encountered have to be converted in favor of this need. This encounter of obstacles and conditions can trigger a process of thoughtful action in which the present "impulsion" assimilates with meanings from past experiences. In other words, the present "impulsion" takes shape and solidifies while the material from the past is revived and given new life. As a result, something that is first encountered as an obstruction can, in light of past experiences, become a mean or medium for expression (p. 63). The same process of thoughtful action can convert a raw material (e.g., movements of a dancer, pigments of a painter, etc.) into works of expressive art (p. 65). For Dewey, such an expressive act is a union of something stored from past experiences with present conditions; it is a construction in time, a process in which inner material (e.g., feelings, ideas, etc.) and outer material (e.g., pigments, words, etc.) have to be ordered and connected in an organic way to qualify as creative (pp. 74, 78). Creative production in that sense is always an act of re-creation that builds on prior work and experiences and the subconscious maturation of ideas; it is "the remaking of the material of experience in the act of expression" (p. 84). This is in a nutshell Dewey's conception of creative production. Taken as a whole, Dewey's concept of "*an* experience" and his theory of expressive acts can be used to articulate the intrinsic relationship between creative production and aesthetic enjoyment; they help to articulate aesthetics and creative performance for *Ludic Engineering* on an experiential basis that is consistent with the emphasis of the third HCI paradigm on embodied meaning-making.

In *Technology as Experience,* the HCI scholars John McCarthy and Peter Wright (2004), build directly on Dewey's concept of "*an* experience" to propose a framework for people's felt experience with technology; they see Dewey's pragmatism, as well as the work of literary critic Mikhail Bakhtin, who they place in a pragmatist thought tradition, as an analytical tool for the aesthetic quality of the felt experience of people *living* with technology (pp. ix, 17, 19). McCarthy and Wright's framework was one of the first and most important milestones leading to the third paradigm in HCI. McCarthy and Wright argue that HCI is not accustomed to dealing with experience beyond usability concerns and advocate for an "aesthetic turn" to better explore the full scope of *human experience* with technology as opposed to just the *user experience*. To achieve this, they suggest the need for a stronger art-related approach to HCI using, among others, the art-inspired technology explorations by Dunne and Gaver that I reviewed earlier as examples. Like Dunne with "aesthetics of use" and Gaver et al. with "functional aesthetics," McCarthy and Wright were also concerned with re-conceptualizing aesthetics to better capture, and critically reflect upon, the multifaceted experience of living with technology. The key position in their framework, however, goes beyond merely expanding the notion of aesthetics vis-à-vis usability concerns. Inspired by Dewey's pragmatism, McCarthy and

Wright proposed to radically reformulate the relation between means and ends, usability and enjoyability by viewing "interactive technology in general as an experience." Likewise, they viewed the relationship between people and technology as one that is open like an experience and that can be shaped by creativity and dialogue (p. 68). In this respect, they propose the concept of "situated creativity" as "the process of making something out of what is given" (p. 68). This concept builds directly on pragmatist ideas of creative action such as Dewey's framework for creative production. To illustrate this pragmatist inspired concept of creativity as situated in each action and moment, McCarthy and Wright also draw parallels to play activities. For example, they argue that children engaged in the process of painting might equally enjoy the act of creating pictures as they enjoy feeling the texture of paint on their fingers. Related to this analogy, McCarthy and Wright (2004, p. 194) also refer to the design process as putting something into the world of experience through play by referring to Gadamer's (1975) characterization of "being in play." This play analogy used to describe the intrinsic relation of means and ends in the process of creative action is particularly relevant in the context of *Ludic Engineering* as playfulness-oriented form of research. However, within the domain of the domain of play itself the analogy was not further explored in this context.

Dewey's *Art as Experience* (1934/2005) and McCarthy and Wright's *Technology as Experience* (2004) stake out the field for many related concepts and tactics that mark the convergence of art and HCI as a joint field of study. Particularly relevant to describe *Solar Pink Pong* as a *Ludic Engineering* case study are the following signs of a convergence that are briefly outlined here:

- *Somaesthetics* is a reconceptualization of aesthetics as an interdisciplinary field of study that explores the role of the body in aesthetic experience. It was proposed by one of the most influential proponents of Dewey's ideas on art and aesthetics, the pragmatist Philosopher Richard Shusterman (1996/1999). Key for *somaesthetics* is Shusterman's distinction between aesthetic potential that is external (i.e., the sensory perceptions of an object grasped by the bodies' external senses) and internal (i.e., the experience of one's body from within, for example, when breathing deeply). Shusterman (2012) also characterized the somaesthetic approach as "thinking through the body." This approach has been inherent in many forms of artmaking particularly those that address the body in some way, which is why Dewey referred to art as a model for aesthetic experience in the first place. Somaesthetics has also been adopted in HCI from a "consumer" and "producer" perspective in a Deweyan sense; it has been explored for designing interfaces that make people more aware of their felt bodily experiences and for training designers to gain more skills and awareness related to their own body as an instrument in the design process (Höök et al., 2016).
- *Interaction gestalt* is a concept proposed by HCI scholars (Lim et al., 2007) to describe the aesthetic aspects of the relationship between user experience and interactive artifacts. This concept builds on an earlier similar idea that draws parallels between gestalt principles in visual thinking and kinesthetic thinking (Svanæs, 1997). *Interaction gestalt* is also informed by Shusterman's somaesthetics, though it doesn't focus on aesthetics beyond usability concerns. Most important for *Solar Pink Pong* is the fact that this concept views the tacit knowledge of traditional design disciplines as a model of cultivating an ability to work with gestalt principles. However, "gestalt"

in this context is only defined by a dictionary definition of the term instead of, for example, the work of Rudolf Arnheim (1969/2004a; 1974/2004b), who coined the term "visual thinking" and explained gestalt principles for many generations of artists and designers. The dictionary definition also seems problematic, because it appears to be a wrong translation of gestalt in the context of gestalt psychology in which "the whole is *something else* than the sum of the parts" and not "*greater*" than it – a small, but meaningful difference that Kurt Koffka, who coined the phrase, pointed out repeatedly (Townsend & Wenger, 2015, p. 949).

- *Embodied interaction* is an approach to technological practice defined as "the creation, manipulation, and sharing of meaning through engaged interaction with artifacts" (Dourish, 2001, p. 126). The key position behind this approach sees "embodied practical action in the world as the foundation for our conscious experience" (p. ix). This position shares many similarities with McCarthy and Wright's *Technology as Experience* framework (2004). However, *embodied interaction* was primarily inspired by the phenomenology of Husserl, Heidegger, Schütz, and Merleau-Ponty and not Dewey's ideas on aesthetics – although the similarities between Dewey's phenomenological thinking and particularity Merleau-Ponty's philosophy seem to be considerable (Leddy, 2020). Most interesting for *Ludic Engineering* in this context is Merleau-Ponty's concept of the lived body, which is an active body that, similar to Dewey's notion of live creature, rejects a body-mind dualism. Inspired by this concept of the lived body, Svanæs (2013) proposes the concept of *kinesthetic creativity* as "the body's ability to relate in a direct and creative fashion with the 'feel' dimension of interactive products during the design process." Savanaes also argues that "the best way to design for the lived body is to design with the lived body." The latter qualifies as a motto for *Ludic Engineering* and its focus on the development of technologies for the lived body.
- *Research in the wild* is an umbrella term for a range of "situated perspectives" (Harrison et al., 2011) that have been used to explore people's lived experiences with technology in a real-world context as opposed to a controlled lab setting; the term was inspired by the work of anthropologists Lucy Suchman (1987), Jean Lave (1988), and Ed Hutchins (1995), who first wrote about cognition "in the wild" (Rogers & Marshall, 2017). *Research in the wild* also describes a terrain that many artists are used to dealing with when they engage with the public outside the confines of their studio or gallery spaces. Perhaps not surprisingly, HCI researchers (Rogers & Marshall, 2017), including Rogers, who first coined the term *Ludic Engineering*, included art-inspired "provocative approaches" in a framework that brings together different *in-the-wild* approaches. These "provocative approaches" involve the deployment of novel technologies in settings that are unusual for, or not yet familiar with, them (p. 23). Examples mentioned for these approaches are also referred to as: "breaching experiments" (Crabtree, 2004), a re-conceptualization of an interactive art intervention as HCI research that draws from Garfinkel's (1964) breaching procedure, which was designed as a sociological demonstration that disrupts ordinary action to reveal the social structures of everyday activities; or as "technology probes" (Hutchinson et al., 2003). The latter shares similarities with the cultural probes of Gaver et al. (2004). However, "probes" in the latter case refer to a co-design method that deploys simple technologies in the wild to study and inspire the design of novel technologies. Both examples are provocative in a sense as they seek to disrupt or probe into the everyday to make visible and reflect on future possibilities, which was also a goal of *Solar Pink Pong*.

- *Interaction criticism* is one of the latest and perhaps most conflicted signs of a convergence of art and HCI; it was initially proposed as a term that is related but distinct from the intellectual tradition of *aesthetics* to connect HCI with practices of "expert judgement" or "disciplined speculative reasoning" that are key to aesthetics and critical theory; *criticism* was seen as complementary to scientific reasoning and essential to critically reflecting on how knowledge is constructed in HCI (Bardzell, 2009). *Interaction Criticism* also meant to address the problem of doing both computing and art well by providing an alternative approach that doesn't reduce "culture and cultural theory to bullet lists" (Bardzell, 2009). A related, more comprehensive approach to embrace criticality in HCI has recently been introduced under the umbrella of "critical theory" (Bardzell et al., 2018). Critical theory with its origins in the Frankfurter School, that defines critical as "emancipatory" and "liberating" (Bohman, 2019), is also, in a broader sense, the dominant worldview of Western contemporary art (Euron, 2019). Further, *criticism* in the sense of a disciplined, but non-standardized critique process has a long tradition particularly in art practice (Buster & Crawford, 2010). That being said *criticism* or critical theory, which are center stage in art, are still at the margins of HCI, perhaps similar to scientific thinking that remains at the fringes of art. The critical orientation of art can also be exemplified by the notion of *critical aesthetics* that brings together critical discourse and aesthetics in a broader cultural context (Crowther, 1996); this longstanding critical orientation of art, however, is outside the scope of this project. It is too remote from the art and HCI intersection that I explore with *Ludic Engineering*.

These are some signs of a convergence and their conceptual underpinnings that I build upon to further articulate *Ludic Engineering* as a lens for the *Solar Pink Pong* case study. The question that could be asked at this point is why do I commit to the third HCI paradigm when other researchers (see e.g., Frauenberger, 2019) are discussing the next wave in HCI that proposes yet another shift towards *posthumanism* or *new materialism*? The answer to this question is three-fold: first, I am committed to the "phenomenological matrix" of the third paradigm, because it is already receptive to arts-based traditions of thought and supports the focus of *Ludic Engineering* on developing technologies *for the lived body with the lived body*; further, its conceptual underpinnings related to Dewey's pragmatism or Merleau-Ponty's phenomenology have not lost their currency yet even for scholars interested in the recent turn towards materiality; in fact, they can be seen as a resource, for example, when new feminist perspectives on embodiment are discussed (Fischer & Dolezal, 2018). Second, although the third paradigm and its art and HCI intersections have been discussed for many years, it remains unclear what impact they have actually had on research, practice, and education on an operational or administrative level; shifting the epistemological perspective in HCI from human-centered to posthuman or in the case of media art from digital to post-digital would imply that the current intellectual wave's impact on the ground is sufficiently well understood; in case of the latter, it might bear the risk to reflect on digital technologies with "a false distance" as was recently pointed out by a new media scholar (Paul, 2018) at a conference that explored the notion of "becoming digital" as an ontological state. Finally, I am drawn to this "phenomenological matrix" for practical reasons. As an artist and designer who has ventured into the field of HCI scholarship only recently, I am certainly better trained to have fun with – much like some of the situationists – trying to change the world through playful action rather than helping to change it by playing with new epistemological frameworks.

2.2.4 Innovation and Technological Change

Key to distinguishing *Ludic Engineering* from other forms of playfulness-oriented research is its focus on "bringing new technology into being" and, if appropriate and possible, "bringing invention into use"; the first defines the process of invention and the second the process of innovation in the words of Donald Schön (1967, p. 1) that I adopt to set the stage for further addressing the ideological and instrumental concerns of *Ludic Engineering*. Both definitions fit well in the "phenomenological matrix" described above and connect with Dewey's pragmatism. In fact, Schön is one of the most prominent proponents of pragmatist principles in design (Dalsgaard, 2014) particularly due to his influential work *The Reflective Practitioner* (Schön, 1983), which builds on Dewey's work. Much less known, but equally relevant in this context, is Schön's characterization of invention as "a nonrational process" that often works backwards "from observation of a phenomenon to exploration of a use for it" in *Technology and Change* (Schön, 1967, p. 11) – which is exactly what happened in *Solar Pink Pong*'s development process (see Chapter 5). Schön contrasted this characterization with that of a rational view that saw invention as "the conversation of knowledge to technology" in the form of a structured corporate activity like sales or accounting for example (pp. 3-5). These polarizing characterizations were informed by Schön's decade long work as a research consultant directly involved in technological innovation and studies of technological change for government and industry. Schön used these characterizations to advocate for a new model of corporate culture as well as an "ethic of change" that embraces experimentation as a way of constant adaptation that favors "process, contribution and discovery" over "the stable states of success or failure" (pp. 212, 215). Schön's "ethic of change" advocated against an instrumental view of technological change that sees human action occur against a stable background. Schön saw technological and social change as intertwined and human actions embedded in a background that is always fleeting; he also referred to Heraclitus's analogy of life to a river and the larger context of child development to illustrate his worldview or "ethic of change" (pp. xii-xiv).

> *Children growing up today face a future without a Promised Land. If they are to develop a sense of themselves and of their own worth, they will have to develop an ethic of change. They will have to accept, as continuing, the changes in technology, in situations and objectives which have outmoded the Technological Program; they will have to identify themselves instead as those who trust themselves to the here-and-now, who start from where they are, who experiment, who seek the metaphor for the future inherent in their traditions, who permit freedom to change, seek new visions and become. (Schön, 1967, p. 218)*

At the time, Schön's *Technology and Change* received mixed reviews and was described, for example, as "a manual for R & D innovation in American corporation" and the work of an "amateur philosopher" (Kranzberg, 1967). In this project, however, Schön helps to further explicate Dewey's idea of "creative production" in respect to the process of invention, which Schön linked to the process of artistic creation and discovery. For Schön, both require the attention to the immediate experience and the passion for uncovering something hidden, which he saw as akin to enjoying an aesthetic experience (p. 207).

Schön also used explicit refences to Gestalt theory (i.e., illustrated by two cow head images, one a more stylized, simplified version of the other), which are only implicit in Dewey's work, as an analogy for sensemaking and coping mechanisms vis-à-vis the uncertainty and ambiguity of unclear situations that he saw inherent in technical innovation (p. 22). In the context of *Ludic Engineering*, Schön's reflections on technological change draw attention to the need for a holistic perception of technological change that is based on direct experiences similar to Dewey's "creative production."

To render this perspective on technological change and innovation more concrete regarding the *Solar Pink Pong* case study, I bring together two frameworks that discuss the innovation of electric light as technology and medium. These frameworks help to contextualize *Solar Pink Pong*'s instrumental and ideological concerns as a ludically engineered artifact. The first framework is Marshal McLuhan and Eric McLuhan's (1988) "laws" of media, which was conceived from a very particular, art-inspired cultural theory and media studies standpoint; the second framework is Eugene Shteyn and Max Shtein's (2013) system approach to innovation, which was conceived from an engineering and entrepreneurship standpoint. Both frameworks help to raise awareness from different perspectives about aspects of technological change that are often overlooked or hidden in the background of innovation processes.

The McLuhans (1988) framed their "laws" of media as a "tetrad", a group of four questions, meant to reveal and explain the dynamics of innovation processes; they asked what does any technology or human artifact, any extension of the body or mind (1) "enhance or intensify?," (2) "render obsolete or displace?," (3) "retrieve that was previously obsolesced?," and (4) "produce or become when pressed to an extreme?" (pp. 7, 105). To understand this framework and its motivation, it is important to note that it resulted from a collaboration of McLuhan with his son Eric and was posthumously published by his son in *Laws of Media: The New Science*; it *was* an attempt to revise McLuhan's earlier ideas in *Understanding Media* and make them more falsifiable in a Popperian sense in response to criticism that often disqualified his work as not "scientific" (p. viii). The McLuhanian "tetrad" in that sense, however, was only a "heuristic device" (1988, p. 7) and a poetic interpretation of the logical square of opposition (Theall & Carpenter, 2001, p. 71); it presented the effects of technologies and artifacts in tetrad form not as a sequential process, but rather as four simultaneous ones (1988, p. 99). For the McLuhans (1988) – as well as for the goal of *Ludic Engineering* – key for understanding the four media effects (i.e., enhancement, obsolescence, retrieval, and reversal) is the careful observation of the artifact in relation to its ground (p. 7); artifact is synonymous with the term medium in their analysis (p. 3). In other words, McLuhan's earlier approach to understanding media most famously expressed in the phrase "The Medium is the Message" (1964, p. 7) was re-framed in *Laws of Media* through the lens of art and visual perception using a figure and ground analogy.

> *In the order of things, ground comes first and the figures emerge later. 'Coming events cast their shadows before them.' The ground of any technology or artefact is both the situation that gives rise to it and the whole environment (medium) of services and disservices that it brings into play. These environmental side-effects impose themselves willy-nilly as a new form of culture. 'The medium is the*

message'. Once the old ground becomes content of a new situation it appears to ordinary attention it appears to ordinary attention as aesthetic figure. (1988, p. 5)

With this analogy, the McLuhans emphasized that in understanding media, as in visual perception, there is an area of attention (i.e., figure) and larger areas of inattention (i.e., ground); yet it is the ground that provides the structure or terms by which a figure is perceived. (1988, p. 9). The McLuhans saw artists in that sense as especially equipped to see the shadows of coming events earlier than others, because of their training and sensibility to study the ground "on its own terms" and their ability to create "anti-environments" (1988, p. 5). The latter referred to McLuhan's concept of art as the dialectical counterpart to technology, a way to "correct the bias of technological media" (McLuhan as cited in Rae, 2008, p. 160). For McLuhan (1964), not having the ability to see a medium in that sense, for example, not noticing electric light as a medium unless it "is used to spell out some brand name" (p. 9) was indicative of people failing to study media.

Electric light played a particular prominent role in McLuhan's (1964) illustrations of his approach to understanding media. McLuhan saw electric light as a "medium that shapes and controls the scale and form of human association and action" (p. 9). The "content" of electric light or the kind of activities that it enables or mediates, be it brain surgery or night baseball, was secondary for understanding light as a medium in McLuhan's sense; the key message of electric light was "like the message of electric power in industry, totally radical, pervasive, and decentralized (…) [it] eliminate[s] time and space factors in human association exactly as do radio, telegraph, telephone, and TV, creating involvement in depth" (pp. 8-9). In the McLuhans' (1988) later framework, their "laws" of media approach, electric light simultaneously (in parenthesis are glosses that the McLuhans added to each of their four "laws"):

- *enhances* "space as visual figure and turns it into ground" ("without Edison, we'd be watching TV by candlelight")
- *obsolesces* "the non-visual" ("limitation by night and day"; "candles, lamps, oil and gas")
- *retrieves* "daytime activities: night baseball, etc." ("puts outer (sun)light inside"; "enabling, e.g., brain surgery")
- *reverses into* "blinding: outer light to inner, seer" ("organized ignorance surfaces as figure revealing hidden ground"; "blinding light vs. organized ignorance"; "after such knowledge, what forgiveness?"; "specialist knowledge as flashlight in the face"; "Homer and Holton"; "Figure and ground merge – inner trip") (p. 194)

Although the McLuhans heuristic framework was not acknowledged as meeting the scientific standards that it was initially designed for, it was as recognized as "a powerful tool for training awareness" (Fekete, 1989). As such, it can be playfully applied to any artifact or medium as the McLuhans and many others, who have been inspired by it, demonstrated extensively. Particularly useful for any practice like *Ludic Engineering* is the last "law" that addresses the reversal effects of media, which helps to speculate about the effects of future technologies would they become mainstream.

Eugene Shteyn and Max Shtein's (2013) system approach to innovation was developed for a different audience of readers; it was proposed as a guide for inventors, entrepreneurs, and IP professionals meant to "improve the quality of idea generation and the timing of innovation commercialization"; their approach views innovation as "a systematic process, where problems and solutions don't come up randomly, but rather though a series of emerging patterns of interactions between system elements." (p. xii). Despite the different orientation of this approach compared to the McLuhanian vision, it pays similar attention to aspects that are often overlooked in the background of innovation. In this context, however, it focuses particularly on the less noticeable elements that "bring an invention into use" (Schön, 1967, p. 1). To understand the goal of this system approach, it is important to note that it addresses the notion of "disruptive innovation" popularized by Clayton Christensen (2011) in *The Innovator's Dilemma*, as opposed to incremental, low-risk technological improvements. Shteyn and Shtein refer to that notion from their perspective as inventors and engineers, but suggest a terminological shift from "disruptive," which they see as inherent in any successful innovation that makes the old or existing institution or practice obsolete, to what they called "breakthrough" innovations; the latter is meant to make the focus on "finding new paths and creating new worlds" more explicit (Shteyn & Shtein, 2013, p. xiii). This subtle shift to "creating new worlds" is also important for the authors' identification of key barriers to "breakthrough" innovations, which they locate in formal education. They emphasize a lack of creativity and problem-solving ability due to habits of thought adopted as early as in kindergarten, for example, when the term *problem* is equated with a *puzzle* with a predetermined answer. As a result, returning a system to its previous state (e.g. a completed jigsaw puzzle) is seen as the norm and deviating from an established process that represents the norm (i.e., the one way to solve the puzzle) is seen as a problem; this, in return, hampers according to Shteyn and Shtein the learning of innovation skills that rely on abandoning established state of affairs to create new systems or "breakthrough" innovations (pp. xii-xiii).

To explain their system model vis-à-vis the notion of "breakthrough" innovations, Shteyn and Shtein (2013) make an "exercise in artistic imagination" (p. 8) that is in the above described spirit of early trial and error problem solving. They use their model to expand on a scenario depicted in *Invention*, a children's poem and drawing by Shel Silverstein (1974). In this poem a child has the breakthrough idea to plug a light bulb into the sun only to find out that "The cord ain't long enough" (Silverstein, 1974). Expanding on this trivial yet, according to Shteyn and Shtein (2013), often overlooked insight, they identify five key elements that help to unpack the dynamics of any invention or patent claim. The first element is the *Tool* that is equivalent with the light bulb in Silverstein's poem that serves the desired function to illuminate a dark room. The second element is the *Source* that is equivalent with the sun without which the *Tool* couldn't operate; other sources of energy in this model could be batteries, solar panels, or power plants. The third element is the *Distribution*, which refers to the cord in the poem; other instances for *Distribution* could be fiber-optic cables or a satellite with mirrors. The forth element is *Packaged Payload*, which refers to the specific form of energy that flows through the cord or distribution channel; it is typically hidden in the system and often overlooked by inventors; without the right *Packaged Payl*oad (e.g., the right electric current) a technical solution is ineffective or can even be damaged; common types of *Packaged Payl*oad are energy, mass, and information. The fifth element is the *Control*, that is, the functional element necessary for "setting up and orchestrating interactions between various Sources, Tools, Distributions, and Packaged Payloads" (p. 7). This element is missing in the poem. It is added in the form of a light switch to complete the model. The switch represents the critical control element that is often overlooked by inventors, who might, for example, focus on solving the issue with the cord (i.e., the *Distribution*), while others might invent and patent a control mechanism. As a result, those who own the patent for the *Control* element might prevent the former to implement their *Distribution* system and build their own instead. The latter control element description is one of many examples that the authors use to explain the interplay of innovation with intellectual property rights in their system model.

Shteyn and Shtein (2013) use this imaginary innovation scenario to draw attention to the system as a whole as opposed to focusing on individual elements such as the *Tool,* which is especially visible and attractive particularly in consumer-oriented markets (p. 13); like the McLuhans, they also refer to Gestalt theory, for example, by emphasizing that "When the elements work together as a system, the system becomes greater than the sum of its parts." (p. 7). Further, and related to *Solar Pink Pong*, they use their system approach to reveal common misconceptions about inventions most notably that of Edison's lightbulb, which is often presented as a symbol for creativity and innovation – which the authors contribute to the influence of a thirty-five-year advertising campaign by General Electric that described Edison's light bulb as the sun's only rival (pp. 38, 39). In brief, they point out that Edison's main creative effort was not directed towards the light bulb (i.e., the *Tool*), which had been invented before, but the invention of a large-scale eclectic system with all its components (i.e., the other four system elements described above). They describe in detail how Edison's company developed a house lighting system for his main business supporter, J. P. Morgan, in Manhattan (p. 8.) by strategically addressing all elements discussed above – starting with the location of the coal-fired steam engine (i.e., *Source*) that Edison placed at the edge of the property away from the home of his business supporter to not draw unwanted attention to the air and noise pollution it caused. Most relevant to understand Edison's invention of electric light according to this system model is the fact that he developed a parallel electric grid (i.e., *Distribution*) with low-current DC (i.e., *Packaged Payload*) (p. 11). Further, he made improvements to the electric meters (i.e., *Control*), which were protected by multiple patents and helped him to introduce a new business model. (p. 11). Shteyn and Shtein also point out that while other elements in this system have changed including the lightbulb itself, the screw-in socket that Edison invented in 1890 (i.e., the critical interface between the *Tool* and the *Distribution*), remained largely unchanged; yet, as they point out, few think of this socket as Edison's greatest invention (p. 38).

In the context of *Ludic Engineering*, this system approach connects well with the entrepreneurship and intellectual property perspectives that dominated the ecosystem that I explored with *Solar Pink Pong* as part of the customer discovery program; further, it helps to contextualize from a historic and technological system perspective, the juxtaposition or rivalry between sunlight and electric light that was central to *Solar Pink Pong* and my *Daylight Media Lab* research (see Chapter 5). In addition, it draws attention to the role of creativity and problem solving as fundamental skill for any innovation effort that can be learned or un-learned in kindergarten already. Taken as a whole, this system model of innovation can be used as an awareness raising tool in a similar fashion as the McLuhans' "tetrad" of media effects. Its main focus in this case, however, is to discover "patterns of interactions between system elements" and to "take advantage of them to create breakthrough opportunities" (Shteyn & Shtein, 2013, p. xiii).

The challenge of "breakthrough" innovation that is a key concern of *Ludic Engineering* has also been acknowledged in the field of HCI, where the term *Ludic Engineering* first appeared. In this context, the problem of innovation has been attributed to, for example, a misalignment of goals and cultures in research and practice (Norman, 2010) or the lack of awareness of business models and technical infrastructure (Frohlich & Sarvas, 2011). Norman and Verganti (2014) have illustrated the problem of "breakthrough" innovations particularly well from a design-driven research perspective with a hill climbing analogy that distinguishes "incremental innovation" from "radical innovation" ("radical" is a synonym for "breakthrough" in this context). In this analogy, "incremental" refers to the small steps necessary to climb a hill (e.g., to improve the quality of an existing product) and "radical" refers to moving or jumping to the next potentially higher hill (e.g., to create a new product); both are equally important in their view, but radical innovation is less studied and understood. They see radical innovation not as the result of a detailed analyses of existing user needs – a view that is also shared, for example, by the artistic approach of vision-driven design research in HCI that Ishii et al. (2015) advocated for. Instead, Norman and Verganti (2014) see radical innovation driven by either a "change of technology" (e.g., technical advances in computer chips) or a "change of meaning" (e.g., new applications of technical components). As a result, they use both change strategies as axes to map out different development paths of products including game consoles, which are in a similar design space as *Solar Pink Pong* in the case study. To illustrate their view, they mapped out how Microsoft, for example, focused on faster processors and better displays to radically improve existing game experiences that led to the *Xbox* (i.e., technology change). In contrast, Nintendo focused on applying less advanced, but never-before-used, components for gaming such as accelerometers and infrared sensors that led to *Nintendo Wii* (i.e., meaning change). As a result, Nintendo's strategy of "meaning change," enabled a new platform for a radically different type of whole-body games. Microsoft eventually moved into the same solution space (i.e., imitated the meaning change) and responded to Nintendo's success with another technology advance, the *Kinect*, that enabled similar whole-body game experiences yet without the need for any hand-held devices. When comparing these two strategies, Norman and Verganti offer the following perspective: they see radical innovations driven by technology typically as the result of dreams or explorations of innovators or engineers, who follow an inner vision that can capture a perceived need but don't rely on formal studies or analyses; hence in their view this type of radical innovation doesn't benefit much from market research or other forms of design-driven research. In contrast, radical innovation driven by meaning change could, in their view, also be design-driven as it benefits from a better and more general understanding of socio-cultural changes and potential patterns of meanings through research and observation; further, for this type of innovation they suggest human-centered design processes could be modified to include the simultaneous development of multiple ideas and prototypes to increase the chance that a new design space emerges. Norman and Verganti describe the goal of design research in this context as the building of "a new hill" (i.e., a complete change of frame or solution space) following "a vision that comes from a deep re-interpretation of the meaning of a product."

Ludic Engineering shares this goal of building "new hills" or prototyping new design spaces particularly by re-interpreting the meaning or purposes of existing technologies as Norman and Verganti suggested above. In fact, *Solar Pink Pong*'s development path (see Chapter 5) shared many similarities with their suggested development approach of exploring multiple prototypes simultaneously while searching for new patterns of meaning. However, *Ludic Engineering* differs in the range of frameworks that it draws from to reveal patterns of meaning or use (e.g., see McLuhan or Shteyn & Shtein). Further, it sees innovation approaches that are driven by inner vision or dreams versus those driven by formal analyses or study less as separate paths and more as two components of the same path. Further, it deviates from Norman and Verganti's (2014) view that sees "tinkering" and "creativity" in the context of radical innovation as playful activities and random qualities that can lead to brilliant insights, but only by accident, because the former lacks goals and a deeper understanding and the latter falls short of interpreting meaning. Such characterizations of playfulness and creativity as a "shotgun" strategy (Norman & Verganti 2014) that emphasize their nonrational or complete random quality are not uncommon. However, they risk hampering – like being taught to view problems as puzzles in kindergarten (Shteyn & Shtein, 2013) – a better understanding of their operational value in innovation processes particularly those that draw from the lived experience like *Ludic Engineering*. In other words, they don't capture the interplay of "inner materials" and "outer materials" in a "creative production" in a Deweyan sense (Dewey 1934/2005, pp. 74, 78) or the nature of "situated creativity" in McCarthy and Wright's sense (McCarthy and Wright, 2004, p. 194). In the last section of this situationist drift through related literature, I therefore focus on further articulating the "nonrational" aspects of the invention process (Schön, 1967, p. 11); I look for meaningful connections between playfulness and creativity that have potential to better explain breakthrough innovations in the context of *Solar Pink Pong* as a *Ludic Engineering* case study.

2.2.5 The Play Element in Creative Work and Innovation

Key to better understanding the operational value of *Ludic Engineering* in this project is to further articulate the "nonrational" (Schön, 1967, p. 11) aspects of the invention process through the lens of creativity and play. Invention and innovation as such have already been defined above for this purpose. Creativity and play also came up earlier, but have not yet been explicitly addressed as research topics or terms. To provide more clarity and limit the scope, I start therefore by providing specific definitions and distinctions related to creativity and play that seem most relevant in the context of *Ludic Engineering* and the topics discussed so far:

(1) *creativity* is the ability to generate ideas that are *novel, useful, and surprising*; this definition is an adaptation of the US Patent Office evaluation criteria (i.e., *new, useful, nonobvious*); the last criterion is not included in most creativity definitions that typically focus on some versions of the first two criteria; however, *surprise* is a key criterion for characterizing breakthrough ideas in this definition that I adopt (Simonton, 2012); further, creativity in this project refers mostly to "expert creativity" (i.e., "Pro-c") as opposed to "everyday creativity" (i.e., "little-c") or "genius creativity" (i.e., "Big-c") following the rationale of the *Four-C Model* of creativity (Helfand et al., 2016); finally, the adopted view underlying this definition sees creativity twofold: first, as a domain-specific *skill* as opposed to a domain-general *factor;* according to this view *expertise* is a better metaphor for creativity than *intelligence* (Baer, 2016); and second, as socially constructed and not the result of the mental process of an isolated individual. According to this view:

(…) creativity results from the interaction of a system composed of three elements: a culture that contains symbolic rules, a person [or group] who brings novelty into the symbolic domain, and a field of experts who recognize and validate the innovation. All three are necessary for a creative idea, product, or discovery to take place. (Csikszentmihalyi, 1996, p. 6).

(2) *play* is an observable manifestation of *playfulness*. This reverse definition of *play* emphasizes *playfulness* as a more important consideration than *play* following Dewey's (1910/2017, p. 110) distinction in *How We Think* that I adopt. Further, it separates observable play behavior from the underlying mood state, which is a key driver for creativity. The latter, when positive, facilitates *playful play,* a term proposed by two behavioral biologists, Bateson and Martin (2013, pp. 1, 3), who saw this kind of play as a tool and mountain climbing mechanism for creativity and innovation that helps to abandon local optima to discover higher peaks (p. 31). Its core mechanism of "playfully rearranging disparate ideas into novel combinations" (p. 45) is also related to *combinatory play*, which Einstein (1954/1995, pp. 25-26) proposed as an essential feature of "productive thought" ("*organisches Begreifen*") in reference to Wertheimer's (1945/2020) *Productive Thinking*. The underlying view of this definition focuses primarily on the developmental function or benefits of play and less on immediate intrinsic rewards or pleasure; according to this view, there can be a time gap of months or even years between play experience and beneficial outcomes:

This temporal disjunction between [play] experience and later performance has proved important in interpreting apparently insightful solutions to problems, when the individual seemingly plumps instantly for the right answer without testing the alternatives. The experience that enabled it to respond promptly to the new challenge occurred earlier in its life, when playing. (Bateson & Martin, 2013, p. 6)

With these perspectives of these definitions in mind, the following review looks at connections between play and creativity that can help to articulate aspects of an invention process that are typically characterized as "non-rational." As such, this review is the last step of my situationist drift through related literature which started by addressing the profession of engineering as the root of the term *Ludic Engineering* and which concludes in the following by looking at the main driver or engine of *it*: the play element in creative work and innovation.

Emphasizing the play element in this form is, at least initially, a reference to the ideas of the Dutch historian Johan Huizinga (1938/2016) in *Homo Ludens – A Study of the Play Element in Culture* that was mentioned earlier. In this book, Huizinga describes the broader implications of play as a cultural phenomenon. In fact, he saw play as an element *of* culture and not *in* culture, which is an important detail for his view of play "being older than culture" (p. 1). Huizinga sees play first of all as a free and voluntary activity that is "standing consciously outside 'ordinary' life as being 'not serious', but at the same time absorbing the players intensely and utterly"; he later also refers to "[t]he function of play" in the same spirit as a "*stepping out of* common reality into a higher order" (p. 13). Huizinga's ideas that address the larger concept of play have been very influential for many artists and researchers including the situationists and HCI researchers I mentioned earlier. Beyond that, Huizinga's work is often discussed in combination with the related ideas of the French writer and philosopher Roger Caillois in *Man, Play and Games*

(Caillois, 1958/2001); together, they are the starting point of many reviews of play literature related to, for example, design practice (Ham, 2016), game studies (Stenros, 2015; Tekinbaş & Zimmerman, 2004), and experience of interactive art (Costello, 2009). Both views fit together well, because Caillois builds directly on Huizinga's work, crediting him for defining the essence of play and clarifying the role of play present in, or animating aspects of, all culture ranging from art, philosophy to even "the etiquette of war" (Caillois, 1958/2001, p. 3). At the same time, Caillois criticizes Huizinga's definition of play for, among other reasons, as being both "too broad and too narrow" (p. 4). He expands it with an often-cited typology of play that classifies four characteristics of games[2]: *agōn* (competition), *alea* (chance), *mimicry* (simulation) and *ilinx* (verigo). Most interesting for *Ludic Engineering*, however, is Caillois' distinction that games can evolve or manifest themselves on a continuum between two different conditions: the first one is *paidia*, which is an "unruly" condition or "spontaneous manifestation of the play instinct" (p. 28), for example, a cat entangled in a ball of wool or an infant laughing at a rattle; the second one is *ludus,* which is a rule-bound condition that refines, enriches, or disciplines *paidia* or the "play instinct" by virtue of conventions, techniques, and tools. According to this view, the more refined the "play instinct" (i.e., the closer games are to the *ludus* condition) the more the character of a game becomes visible including any related problem-solving activities that can be pursued for their own sake or personal satisfaction; further, according to this view, it is the rule-bound *ludus* condition that facilitates the discovery of solutions to conventional problems (p. 29). Caillois does not focus on creative problem solving and therefore he does not explore the inversion of his argument (i.e., the type of problems that can be solved in the *paidia* condition), which would be more interesting in the context of *Ludic Engineering*. However, his characterization of the play instinct as the "primary power of improvisation and joy" and the term *paidia* (ancient Greek for *childish play, amusement*) that he chose for it (p. 27) clearly has implications for creativity. Precisely these implications have been addressed earlier and in more detail by the psychiatrist and psychoanalyst Carl Gustav Jung, who described the play instinct as follows:

> *If play expires in itself without creating anything durable and vital, it is only play, but in the other case it is called creative work. Out of a playful movement of elements whose interrelations are not immediately apparent, patters arise which an observant and critical intellect can only evaluate afterwards. The creation of something new is not accomplished by the intellect but by the play instinct acting from inner necessity. The creative mind plays with the objects it loves. (Jung, 1921/1976, pp. 122-123)*

Jung's characterization of the play instinct is probably the most concise description of the intricate or ambiguous relationship of play and creative work in this dissertation. Jung's paragraph often appears in abbreviated form as an inspirational quote reduced to the last two sentences to highlight playfulness as a key to creativity. In such form it was used, for example, by musician, computer artist, and psychologist Stephen Nachmanovitch (1990, p. 42) in his practical and spiritual account of the value of play in the broader context of art and life. Nachmanovitch's account saw play as free improvisation or the "free play of consciousness" (p. 9); in fact, he saw the "play-consciousness" of the inner

[2] Games are a subset of play in Caillois' view.

child in adults as the key source of "full-blown artistic creativity" (p. 47). This notion of "play-consciousness" is most certainly also informed by Nachmanovitch's academic background, as he earned his Ph.D. in the history of consciousness (Nachmanovitch, n.d.). Nachmanovitch's view of play, which is close to the conception of playfulness in this dissertation, has been described as a typical romantic account that idealizes the benefits of children's free play without factoring in the societal reasons for limiting that freedom; at the same time, it was also put in close relationship with Bateson and Martin's (2013) functional view of *playfulness* that emphasizes the evolutionary and developmental benefits of play vis-à-vis creativity and innovation (Stenros, 2015, p. 83).

Put in the context of *Ludic Engineering*, Jung's characterization is not just an eloquent description of the intricate play-creativity relationship that defines the "play-consciousness," it is historically probably the most suitable starting point for the discussion of the "nonrational" play element in *Ludic Engineering*. The reason for the paragraph's historic significance is that it originates from Jung's analysis of the play instinct as it was first proposed as a concept by Friedrich Schiller (1795/2004) in his *Aesthetic Letters (Über die ästhetische Erziehung des Menschen in einer Reihe von Briefen)* published in 1795. To better understand the historic context, it is important to note that Schiller proposed the "play instinct" (*Spieltrieb*), as part of a larger criticism of his contemporary culture in response to his political disillusionment with the French revolution and concerns with the Enlightenment's over-emphasis on reason. In brief, he saw the play instinct as a liberating element that can reconcile the tension between sensation and thinking and allow humans to fulfill their nature: "man only plays when he is in the fullest sense of the word a human being, and he is only fully a human being when he plays" (Schiller, 1975/2004, p. 80). As such, Schiller's larger view of play also shares striking similarities with Huizinga's view of play as a pioneer of culture (Grossmann, 1968). Huizinga actually discusses Schiller's "play-instinct" as a "cultural factor" at the end of his book, but interestingly he sees its relevance only limited to the domain of "plastic art" (Huizinga 1938/2016, p. 168). Further, he interprets it not as a mediating function between sensation and thinking like Jung (1920/1976, pp. 122-123), who analyzed Schiller's ideas closer to their original meaning as I discuss in the following. Instead, Huizinga (1938/2016) interprets Schiller's play instinct reduced to a "play-function of lower order akin to the child's playing in the first years of its life" incapable of producing "plastic art." In fact, he sees the play element necessary to create artistic work less associated with individual artists and more with the condition of their environments. He suggests that the creation of art of higher order is always the result of some sort of competition and that the competition as such *is* the play-function (pp. 170, 172). Huizinga's view as a historian, who saw "expert creativity" merely as an externalized function of competition is in fact not far from Csikszentmihalyi's (1996) view as a prominent creativity scholar, who also saw it most critical to ask "*where* creativity is" as opposed to "*what* creativity is" (p. 23). However, this view doesn't help to further articulate *playfulness* as an attitude and internal driver of creativity vis-à-vis the two opposites of sensation and thinking that Schiller referred to and that are both necessary to bring "novelty into the symbolic domain" (p. 6). Better aligned for this task is Jung's (1920/1976) analysis of Schiller's play instinct in *Psychological* Types that was motivated by Jung's interest to better understand "the relation of the symbol to consciousness" (p. 126).

Jung's (1921/1976) *Psychological Types* can be considered as one of the first postmodern presentations of the human psyche (Cambray & Carter, 2004, p. 2); in this book, Jung proposes four functions of consciousness – two non-rational (i.e., *sensation* and *intuition)* and two rational (i.e., *thinking* and *feeling*) – that are each modified by two main psychological attitudes: introversion and extroversion. This book is typically not reviewed by creativity scholars in this form. In the context of *Ludic Engineering*, however, it helps to unpack precisely the notion of "play-consciousness" (Nachmanovitch, 1990, p. 43) and "nonrational" (Schön, 1967, p. 11) that shaped the process of creativity and invention in the *Solar Pink Pong* case study. In fact, for *Ludic Engineering,* Jung's type theory that takes up the way consciousness is structured (Beebe, 2004, p. 84) has a similar relevance as Dewey's analyses of the structure of *an experience* as the following shows. In *Psychological Types,* Jung (1921/1976) acknowledged Schiller's profound psychological insights and devoted more than 70 pages to a detailed analysis of Schiller's ideas that shared similarities with two of his main types (i.e., extroversion and introversion); at the same time, Jung criticized Schiller, among others, because of his "illusory picture of an earlier, more perfect type of man" and his idealization of "the beauties of antiquity" that are typical for German classicists (pp. 82, 83). Most relevant to unpack the play element in *Ludic Engineering* is Jung analysis of the tension that Schiller (1795) felt between "sensation and thought" or "matter and form," which Schiller saw as two opposing energies (*Kräfte*) that define human nature. As such, this twofold conception of "Man as sensuousness and reason" was directly informed by Kant's *Critique of Judgement* that had been published only a few years earlier in 1790 (Snell, 2004, p. 8). Schiller called these two energies sensuous instinct (*Sinntrieb*) and formal instinct (*Formtrieb*); the play instinct (*Spieltrieb*) was in fact proposed as a third instinct to describe the position in between in which both opposing instincts can work together to fulfill the human nature (Schiller, 1975/2016, pp. 34-48); Schiller also referred to this third mediating position as "aesthetic mood" (*ästhetische Stimmung*) (p. 84).

Jung (1921/1976) reviewed these ideas closely and analyzed both Schiller's thinking patterns and the role he attributed to the play instinct from a psychological point of view drawing from his type theory. Analysis in that sense was not meant to be an objective evaluation, but an intentionally "one-sided presentation" of Schiller's ideas; Jung's goal was not to diminish the validity of the problem Schiller described, but to "make room for other formulations" of the problem (pp. 68-89). In reference to his type theory, Jung identified Schiller as an *introvert thinking* type, who approached the problem of opposing instincts mostly from the perspective of his own inner experience. Schiller referred to the sensuous instinct, therefore, as sensation and not as active, sensuous desire, which would have been more typical for an extrovert type; hence, Schiller excluded sensuousness from the concept and scope of the "person" (i.e., ego) and assigned this instinct more the character of reactiveness or affectivity. As a result, sensuousness was set apart and seen as an inferior function from the intellect as a superior function – which expressed the bias underlying Schiller's view of the conflict inherent in human nature. Likewise, Schiller didn't "discriminate sufficiently between feeling and sensation" (pp. 97, 98), which have different meanings (i.e., functions) in Jung's type theory (i.e., sensation has perceptive functions; feeling has evaluative functions). These are only a few examples that Jung analyzes as factors that contributed to Schiller's psychological perspective. Jung also identifies several contradictions in Schiller's argument that resulted from his inconsistent use of terms and two conflicting viewpoints with which Schiller often addresses the same problem as a poet and a philosopher:

> *The quarrel between the poet and the thinker could surly be composed if the thinker took the words of the poet not literally but symbolically, which is how the tongue of the poet desires to be understood. (Jung, 1921/1976, p. 85)*

The core of Jung's (1921/1976) critique and further articulation of Schiller's play instinct can be summarized as follows: first, sensation and thinking are not opposing *instincts*, but are sensuous (i.e., irrational) and rational *functions* of consciousness; second, the mediating role of the play instinct between those functions is that of a *symbol-creating function* or *creative fantasy*. In other words, Jung reframes the mediating role of Schiller's *play instinct* as a *creative fantasy* and assigned it a *transcendent function* that combines conscious and unconscious elements within his proposed view of consciousness. Playing in that sense can be interpreted as a *symbol forming activity*; it "alone has the power to supply the will with a content of such a nature that it can unite the opposites" (Jung, 1921/1976, p. 115). According to Jung, Schiller (the poet) intuitively grasped this symbol forming function of the play instinct and the union of conscious and unconscious in which sensation and thinking are simultaneously active to produce "something positive" (p. 128); however, Schiller (the thinker) could not rationalize this function within his framework of opposing instincts and his idealization of the play instinct as an aesthetic function (that equated aesthetic with "pure beauty") without reverting to the intellect (i.e., prioritizing only one instincts) (pp. 116, 117). In brief, to resolve the tension between sensation and thinking and find a more suitable middle ground than "beauty," Jung saw it critical to replace the notion of *aesthetic* with *symbol*. A *symbol* in Jung's view has the capacity to unite opposite elements within its nature; it "unites the antithesis between real and unreal, because on the one hand it is a psychic reality (on account of its efficacy), while in the other it corresponds to no physical reality. It is *reality* and *appearance* at once." (pp. 128, 129). According to Jung, it would therefore be "pointless to call upon consciousness to decide the conflict between [Schiller's] instincts" (p. 112), that is, between sensation and thought. Jung, who based his psychological view primarily on his clinical work experience, observed:

> *In practice, opposites can only be united in the form of a compromise, or irrationally, some new thing arising between them which, although different from both, yet has the power to take up their energies in equal measure as an expression of both and of neither. Such an expression cannot be contrived by reason, it can only be created through living. (Jung, 1921/1976, p. 105)*

Jung suggests, therefore, solving the conflict between sensation and thought at a deeper level of consciousness in which primordial instinctivity is still preserved. For Jung, this deeper level is the unconscious, which he also refers to as the neutral region of the psyche. The unconscious, in his view, lacks of differentiation due to almost direct association of all the brain centers with each other and the relatively weak energetic value of the unconscious elements in that region. It is here where different psychic functions (i.e., including sensation and thinking) are indistinguishably merged in the original activity of the psyche. As a result, every element that is divided and antagonistic in consciousness flows together into groupings and configurations in the unconscious (pp. 112-113). According to Jung, any unconscious element that rises above the threshold of consciousness by virtue of added energy can become a "lucky idea" or "hunch" (p. 112). In this context, he also refers to the unconscious as "that maternal womb of creative fantasy, which is able at any time to fashion symbols in the natural process of elementary psychic activity, symbols that can serve to determine the mediating will" (p. 113). Jung's view of consciousness taken as a whole suggests that playing in this "maternal womb of creative fantasy" is both an irrational and instinctive function yet one with a serious purpose:

> *It is not, of course, a matter of wanting to play, but of having to play; a playful manifestation of fantasy from inner necessity, without the compulsion of circumstance, without even the compulsion of the will. It is serious play. And yet it is certainly play in its outward aspect, as seen from the standpoint of consciousness and collective opinion. That is the ambiguous quality which clings to everything creative. (Jung, 1921/1976, p. 122)*

This ambiguous quality of creativity and play in between the opposites of nature and reason is precisely what Jung refers to in the paragraph I highlighted at the beginning as an inspirational quote for playfulness. My brief summary of Jung's ideas provides more context to this quote, but it is also a crude simplification or "one-sided" presentation of a much more nuanced argument for the purpose for *Ludic Engineering*. Outlining the full scope of Jung's view of consciousness would require a different dissertation format. For the purpose of *Ludic Engineering*, I focus on Jung's ideas about the play-creativity relationship and don't address, for example, his concept of creativity as one of five instinctive factors (i.e., hunger, sexuality, activity, reflection, and creativity) that he proposed later (Jung 1931/1969, p. 118). Key, however, to better understand Jung's ideas is the premise underlying his "non-pathological view of the multiplicity of consciousness" (Cambray & Carter, 2004, p. 2); "non-pathological" is important to highlight, because it emphasizes the intent behind the type theory which was to allow for "different formulations" of viewing the world as opposed to categorizing people. Jung's premise in this context was to see the psyche as the starting point of all human experience. He viewed consciousness primarily as "an organ of orientation in a world of outer and inner facts" (pp. 123, 125). Most importantly, this premise and view also make clear how closely Jung's view intersects with Dewey's pragmatism that is central to this dissertation: both focus on the human experience and the interplay of inner and other facts (Jung) or inner and outer materials (Dewey) while rejecting a body/mind dualism; Jung did so by focusing on the structure of the consciousness and Dewey by focusing on the structure of the experience. Further, Jung's view of play or creative fantasy as a serious, symbol-forming function intersects with Dewey's (1910) view of play particularly in respect to the intellectual development of children where play has historically been seen as "the child's work" (Isaacs, 1929/1970):

> *(…) when children play horse, play store, play house or making calls, they are subordinating the physically present to the ideally signified. In this way, a world of meanings, a store of concepts (so fundamental to all intellectual achievements), is defined and build up. Moreover, not only do meanings thus become familiar acquaintances, but they are organized, arranges in groups, made to cohere in connected ways. (Dewey, 1910, p. 110)*

To sum up, the discussed views about play and creative work, particularly Jung's interpretation of the play instinct, have many implications for the concept and operational value of *Ludic Engineering*. In the context of my situationist drift through related literature, these views provide the basis to further articulate the play-element in at least three ways:

First, they help to further articulate "ludic" (i.e., playfulness) as the main driver of *Ludic Engineering's* invention process, which is often characterized as "non-rational." Jung's ideas offer a theoretical basis for an alternative interpretation of this "nonrational" character that resists simply equating it with "mindless," "blind," or "random"; Jung's view helps to conceptualize a type of playfulness or "playing" – that is otherwise often used only as a metaphor for the creative process (Medina, 2006) – as a serious "symbol-forming function" that is neither completely rational nor irrational; instead, it can only operate in between both of those oppositions slightly below the threshold of consciousness, that is, the "neutral zone of creative fantasy,"[3] where literal and symbolic thinking merge together with other psychic functions. This articulation of "playing" or playfulness aligns well, for example, with studies on divergent thinking that suggest "unconscious thought is more 'liberal' than conscious thought and leads to the generation of items or ideas that are less obvious, less accessible and more creative" (Dijksterhuis & Meurs, 2006). In other words, playfulness in that sense is key for providing the content that satisfies the third criterion of creativity according to the patent law definition (i.e., *non-obviousness* or *surprise*) that I outlined at the beginning that is also central to breakthrough innovations.

Second, they help to unpack the inner workings of playfulness as they relate to creative work or invention. Although Jung's view is not the only basis on which the formation of creative ideas that meet the criteria of a utility patent can be articulated, it offers a more robust pragmatist foundation for Ludic Engineering than, for example, Koestler's (1969) concept of bisociation. The latter describes "the act of creation" as the intersection of two incompatible frames of reference; it suggests creative thinking operates in "a double-minded, transitory state" (pp. 35-36), but doesn't provide the same analytical distictions and psycological insights to describe that state. Closer related to Jung's view of playing as "symbol-forming" is Einstein's (1954/1995) notion of *combinatory play* which he coined to describe his thought process in response to a psychological survey. Einstein described *combinatory play* as a "rather vague play" with "psychical entities" that operate like signs or "less clear images which can be voluntarily reproduced and combined"; he referred to it as a form of visual and kinesthetic operation that has to be established before it can be rationalized with words or signs (pp. 25-26). In regards to understanding those combinations as opposed to only producing them, Einstein referred to the gestalt-theoretical approach in psychology that Wertheimer (1945/1959) outlined in *Productive Thinking*. This explicit reference to Wertheimer is particularly relevant for *Ludic Engineering*; it shows that *combinatory play,* as outlined by a mathematician, builds on the same premise as Arnheim's (2004) *Visual Thinking* that I mentioned earlier and which has been implied by the frameworks of many scholars that I have reviewed (e.g., the McLuhans; Schön; Shteyn and Shtein). Both refer to the view of Gestalt psychology for which thinking is a lot like perception and problems are considered "as a disturbed Gestalt that 'asks for' being transformed into a good Gestalt" (Öllinger & Knoblich, 2009). Restructuring in that sense is a "grouping and reorganization" and is seen as essential to

[3] To promote a more neutral interpretation, I replace the phrase "maternal womb of creative fantasy" with "neutral zone of creative fantasy" in the context of *Ludic Engineering*.

solving problems with "insight" as opposed to "traditional logic" or "school drill"; the latter is seen as "blind", because it focuses on the "piecemeal" nature of thought processes as opposed to "whole-characteristics." As such, Gestalt Psychology is key to better understanding the innerworkings of *Ludic Engineering* and also remains relevant for the future study of creativity (Sarris, 2020). From a psychological perspective addressing creativity and neuroaesthetics, combinatory play has also been described as "the conscious and unconscious cognitive playful manipulation of two or more ideas, feelings, sensory experiences, images, sounds, words, or objects" (Stevens, 2014). However, Jung's or Wertheimer's ideas that seem particularly relevant to conceptualize the inner workings of the play-element in *Ludic Engineering* have not been discussed yet in this context.

Finally, the discussed views imply that the key to better understanding the operational value of the play-element in *Ludic Engineering* is to look particularly at its mid or long-term developmental benefits rather than its immediate effects. Child's play or child development, in this case, as referred to by the authors discussed in this review including the engineers Shteyn and Shtein (2013) in their system approach to innovation is not used as a metaphor romanticizing free play and creativity, as it otherwise often happens. Instead, it is used to describe certain functional and developmental benefits. In the context of *Ludic Engineering*, play can therefore better be described as a metaphor for serious work and prerequisite of innovation that draws from human experience in the course of action over the lifetime of individuals. In fact, play or *playful play* in that sense has been argued to facilitate creativity and innovation in both human and non-human animals. It can affect the biological evolution, for example, by enabling organisms to rapidly adapt to novel environments; further, play experience can transfer to other activities that are not in considered to be forms of play (Bateson & Martin, 2013, pp. 1-8). In these different perspectives ranging from biology to engineering, which are far from romanticizing child's play, the need to better understand and cultivate the play experience starting at early childhood has been seen as critical. This need is also supported, for example, by various studies that suggest that pretend-play or make-believe play in young children can be indicators of their creative potential in adult years (Russ & Doernberg, 2019, pp. 608-609). As such, this need to better understand the benefit and implications of the play experience from a developmental perspective marks the end of my situationist drift through literature related to *Ludic Engineering*; it is the basis for a speculative framework and analogy between childhood and technology development that brings together both Jung's and Dewey's view on human experience in light of the *Solar Pink Pong* case study in the summative reflection in chapter 6.

3 Methodology

This chapter describes the overall worldview and practice-based research model of this dissertation, which are both dedicated at exploring and articulating Ludic Engineering*'s technology innovation potential for the lived body. It clarifies the entire research and development process including the dissertation's formal start (i.e., framing* Solar Pink Pong *as a* Ludic Engineering *case study) and key turning points from arts-based research to HCI-based research. It distinguishes this process into four project phases. Further, it outlines the different research methods used throughout these project phases ranging from casual playtests in the wild, controlled user studies in the lab, to autoethnography for a summative reflection on the entire process and outcomes; in addition, it describes the context and motivation for selecting these research and development methods.*

3.1 Worldview and Research Model

The overall world view or basic belief system that guided this research project builds on the pragmatist thought tradition, particularly the work of Dewey that is also key for the art and technology convergence discussed in chapter 2 (Section 2.2.3). As such, pragmatism is typically seen as a worldview that arises out of actions, situations, and consequences; it is concerned with what works to solve problems; it gives researchers the freedom to choose the research methods, techniques, and procedures that best meet their needs and purposes (Creswell & Creswell, 2018, pp. 10-11). In a world of change in which the context and meaning of actions is evolving, this worldview has also been described as "dynamic and open and accommodating of the emergence of radically new ways of thinking and acting" (McCarthy & Wright, 2004, p. 71). The selection of methodologies and methods within this worldview, however, was not always a clear path and was often a subjective decision challenged by balancing academic habits of thought (Ascott, 2011) with those of a practitioner (i.e., my habits as an artist and designer). This challenge was further complicated by the iterative research and development process that moved from arts-based research to HCI-based research. As a result, the selected methodologies and methods evolved as much as the ideas that were developed in the course of this research project; this evolution will be further described in the next section.

> *The challenge always confronting art research is how to untie the Newtonian knot that binds us uncritically to academic habits of thoughts and to develop methodologies that can, whenever needed, put subject before object, process before system, behavior before form, intuition before reason and mind before matter. (Ascott, 2011, p. vi)*

The general format of this dissertation follows a practice-based research model (Candy & Edmonds, 2018). In its broadest definition, this model is characterized by the researcher being both practitioner in a particular field and researcher carrying out inquiry relevant to the same field. In my case, the research has been heavily intertwined with my practice as a media artist and designer. The potential advantage in this case is that my insider role can lend my research credibility in the eyes of my peers. The potential disadvantage is that it can be clouded by preconceptions exactly because of my insider role (Gray & Malins, 2004, p. 23). This outsider/insider distinction is also known as the etic/emic dilemma in qualitative research in general; it refers to etic (outsider) theory that may have little or no meaning to the emic (insider) view of studied individuals or groups in a specific context (Guba & Lincoln, 1994).

> *(…) the advantages of the practitioner-researcher role are compelling: your 'insider' knowledge, experience and status usually lends your research credibility and trustworthiness in the eyes of your peers, that is, you are not an 'external' researcher. (Gray & Malins, 2004, p. 23).*

The advantage of my insider role as a practitioner (i.e., my "street credibility" as a media artist and designer) has been evidenced, for example, by international awards, exhibitions, and patents that resulted from *Solar Pink Pong*. The disadvantage of my insider role as a researcher, however, has equally been evidenced, particularly by my first unsuccessful attempts to adequately frame *Solar Pink Pong* and the resulting *iGYM* research project for external reviewers at academic conferences. Further, these challenges to see beyond my insider role and articulate my work for external researchers have been part of the reason why most of my prior research and potential knowledge contributions had been hidden in the tacit dimension (Polanyi, 1966/2009). The role of knowledge in this dimension is an ongoing theme in art and design research (see e.g., Mäkelä et al., 2011; Mareis, 2012). It is also at the center of theory-practice divide (Sanders, 2017) or research-practice barrier (Zimmerman et al., 2007), which continues to remain one of the most prevalent issues to be addressed particularly in the field of art and design and HCI. Choosing a practice-based research model was a response to address this barrier and make a step towards bridging the theory-practice divide in this context. In addition, choosing a practice-based model was a step towards bridging yet another divide: one between art and science. Some of the main tenets of this art-science divide can be characterized across the three dimensions of qualitative research (i.e., numbers, data discovery, measurements, etc.), qualitative research (i.e., words, data collection, meaning, etc.), and arts-based research (i.e., stories, images, sounds, scenes, sensory; data and content generation; evocation, etc.) (Gide, 2015). I highlight this particular characterization, because it shows that the idea of art as a form of knowledge, which stood at the beginning of this dissertation's research trajectory, still doesn't fit in contemporary philosophical thought (Eisner, 2008). Following this characterization makes clear that the research contribution of art as it has resulted from most of my practice prior to this dissertation (as well as the practice of many of my peers), lies outside the established cannons of quantitative or qualitative research and their respective research methods.

To sum up, choosing a practice-based research model was a response to deal with some of the challenges of both the theory-practice divide and the art-science divide. It allowed to build on the tacit knowledge (Polanyi, 1966/2009) and evocative capacity (Eisner, 2008) that I had developed earlier as a practicing artist and designer, which would otherwise not fully be recognized as part of the dissertation. Further, to mitigate potential adverse effects due to my insider role using this practice-based model, I have made the research process and the evolution of research methods transparent for the reader and "external" researcher. The next section gives a brief overview of this research process and evolution of research methods leading towards and throughout this dissertation.

3.2 Summary of the Research Process

The whole research process leading towards and throughout this dissertation progressed mainly in four phases as outlined in table 1. These phases can, with some caution, be associated with Wallas' (1926/1931) pioneering model of the four stages of creativity that divides the creative process in: (1) preparation, (2) incubation, (3) illumination, and (4) verification phases. Caution is necessary, because Wallas' original distinction focused primarily on clarifying psychological thought processes around the

	Main Actions	Methods	Outcomes
Phase 1 Intellectual foundation of the dissertation	Earlier, related artwork creations: *Windows, Bump, Common Ground* and *Pink Prints*, and *Rolling Shadows* (Ch. 4)	Art practice, studio critiques and visits, casual observations and reflections individually and collectively (as part of my artist group *Assocreation*)	Re-framing the body and interactivity in the built environment by ludic technology development and public engagement
Phase 2 Incubation of the dissertation's central idea (i.e., *Solar Pink Pong*)	Lived experiences, idea incubation and simulations (Ch. 5)	Photo and video documentation, material and idea explorations using combinatory play and bisociation	Ideas for ludic, whole body interaction modalities leading towards *Solar Pink Pong*
Phase 3 Research through Art and Design	Artifact creation: *Solar Pink Pong* (Ch. 5)	Sketching and prototyping	Novel body and shadow interaction modalities. Exhibitions, awards, invention reports and patents. Re-evaluation of *Solar Pink Pong* for inclusive play
		Technology expert consultations	
	Evaluation of *Solar Pink Pong*	Casual playtests, observations, interviews; reflective video documentations	
		Customer discovery workshop; casual interviews	
	Artifact creation: *iGYM* (Ch. 5)	Sketching and prototyping	Wheelchair-accessible interactive play system; novel peripersonal circle interaction articulated and tested
		Casual observations of physical therapy sessions	
	Evaluation of *iGYM*	Pilot studies; observations, surveys, interviews	
		User studies; performance logging, observations, surveys, interviews	
Phase 4 Research into Art and Design	Summative reflection of the research trajectory (Phase 1-3) through the lens of *Ludic Engineering* (Ch. 6)	Autoethnographically informed case study research; triangulation of first-person account and subjective interpretation with external evaluation milestones	Structured insights into *Solar Pink Pong* as a *Ludic Engineering* case study. Speculative *Ludic Innovation Framework*

Table 1: Summary of the research process leading towards (i.e., phase 1+2) and throughout this dissertation (i.e., phase 3+4). The four phases can be loosely associated with Wallas' four stages of creativity (i.e., preparation, incubation, illumination, verification).

development of new ideas and not the description of a multiyear long research process. I use this model only as a loose analogy and adapt its four-fold distinction, because it emphasizes the often-neglected tacit dimension of the early idea development phases that are key for doing both "good research" (Polanyi, 1966/2009) and practice. According to Polanyi, this tacit dimension is essential as the success of any investigation always relies on the quality or originality of a problem that started the investigation (p. 21). Hence the orientation of Wallas' model aligns well with the dissertation's worldview and practice-based research format that focuses on innovation. Wallas based his process distinctions on earlier ideas of Helmholtz and Poincare (Wallas, 1926/1931, p. 80). My adaptation of his distinctions deviates particularly in phase 3, where *illumination* becomes *research through making*, and phase 4, where *verification* becomes a *summative reflection* on the research and development process.

To understand the research and development procedure, it is important to make the following chronological clarifications: first, the formal start of the dissertation, my decision to reframe *Solar Pink Pong* as a *Ludic Engineering* case study occurred in 2017 – ten years after the first sunlight inspiration that gave rise to the project. The dissertation's start coincided with, and was informed by, the re-evaluation of *Solar Pink Pong* for inclusive play in the middle of phase 3. Further, this starting point was also the turning point from arts-based research to HCI-based research that is described in the more detailed chronological overview of *Solar Pink Pong*'s research trajectory in chapter 5. In other words, phase 1 and 2 pre-date the formal start of the dissertation. They are included in the process summary table and briefly described in the following (and in more detail in chapter 4 and 5), because they are critical for understanding the genesis of this practice-based investigation and the related process of enquiry and invention (Rust, 2004).

Taken as a whole, phases 1 to 4 describe the entire arc of the dissertation's idea, research, and development process. The related evolution of research methodologies and methods across these phases from arts-based research to HCI-based research can be summarized as follows:

Phase 1 is where the dissertation's intellectual foundation (i.e., its underlying knowledgebase and values) was built. This phase built primarily on different critique methods which are common in everyday art and design practices. A critique in this context is not a standardized process, but it typically implies that one or several critics (e.g., art professors, curators, etc.) provide criticism that deconstructs and evaluates creative artifacts or processes in order to point out deficiencies that can be improved (Buster & Crawford, 2010). In the case of my earlier work with the artist collective *Assocreation* that informed the dissertation, critiques occurred in many different forms including: classrooms settings, studio visits, exhibitions, jury statements, press reviews, and perhaps most importantly direct feedback from the public in museums and on the street. Since this phase preceded the formal start of the dissertation, describing these critique methods in detail would exceed the scope of the dissertation. That being said, to provide enough context for this phase, I reassessed the outcomes of earlier, related work with *Assocreation* in the light of the PhD's focus on *Ludic Engineering* for the lived body in chapter 4.

Phase 2 is where the dissertation's core idea, *Solar Pink Pong*, was inspired and incubated. This phase is described in detail at the beginning of the *Solar Pink Pong* case study in chapter 5. This phase built primarily on: first, reflecting, consciously and subconsciously, on epiphanic moments caused by lived-experiences (i.e., sunlight reflections, motion tracking systems) over many years; and second, the consequent playful exploration of related materials and idea combinations over several months until the idea for *Solar Pink Pong* emerged. The exploratory methods used in this phase evade mostly rational process descriptions, but they have strong conceptual underpinnings related to "combinatory play" (Einstein, 1954/1995, pp. 25-26) and "bisociation" (Koestler, 1969, p. 35). It is important to note that I wasn't aware of these theoretical underpinnings and related terminologies when I first used these exploratory methods. Making these particular references to better frame the methods used in this phase was one of the results of the dissertation's summative reflection in phase 4 which is described in chapter 6.

Phase 3 is where the dissertation's main body took shape. It is where *Solar Pink Pong* was created and explored by following a research though art and design process that resulted in the project's re-evaluation for inclusive play and the creation of another artifact, *iGYM*, a wheelchair-accessible interactive play system. This phase built primarily on prototyping as a method of testing novel interaction modalities. It included materials research (i.e., hands-on explorations, expert consultations, literature reviews, etc.), development work (i.e., building and customizing motion tracking and projection systems, etc.), and elements of action research (i.e., casual observations and interviews, video documentations, etc.) that culminated in controlled user studies towards the end when the research project entered the field of HCI (i.e., playtests building on performance logging, observations, surveys, interviews, etc.). This phase intertwined making and research activities in a similar fashion as Christopher Frayling (1993) outlined it in his early definition of research through art and design. The activities and outcomes of this phase are described more in detail in chapter 5 and 6. Further methodological distinctions and practice-based research models related to art, design, and HCI that were relevant for this phase are discussed in the following section 3.3.

Phase 4, which overlapped with Phase 3, is where the summative reflection on *Solar Pink Pong*'s research trajectory started. In other words, it was the start of the research into the art and design process of the project itself. It is here where I reframed *Solar Pink Pong* through the lens of *Ludic Engineering* using it as an example to trace the convergence of Art and HCI. This phase built primarily on autoethnographically informed case study research that triangulates my first-person account and subjective interpretation with external evaluation milestones (i.e., exhibitions, awards, patents, reviews, etc.) and the literature review related to *Ludic Engineering* (Chapter 2). The summative reflection on the research and development trajectory was guided by the three scaffolded research questions mentioned in the introduction: **(RQ1)** *How can art (in a broader sense including architecture and design) and human-computer interaction work together under one roof?* **(RQ2)** *How can* Ludic Engineering *be further articulated as an emerging line of research between interactive art and HCI?* **(RQ3)** *What "serious" roles can* Ludic Engineering *play in the innovation process of technologies for the lived body?* The resulting insights of this summative reflection as well as a speculative framework for Ludic Innovation are described in chapter 6. Further, details of the autoethnographically informed case study research approach that dominated this phase are described in section 3.4.

To sum up, phase 1–4 describe methods of creative practice and research related to the entire epistemological spectrum of this practice-based dissertation ranging from tacit knowledge (i.e., implicit in the creative research process and artifacts) to propositional knowledge (i.e., explicit in writing). In other words, they address the knowledgebase and creative process that led to *Solar Pink Pong* as an interactive artwork (phase 1+2), the knowledge that resides in the artwork and that is generated through it (phase 3), and the summative reflection on the creative process underlying it (phase 4). The next two sections address the latter two phases (3+4) that dominated the dissertation's overall research approach more in detail.

3.3 Research through Art and Design

Research through art and design serves as an umbrella term in this dissertation to address different approaches of research through making (Candy, 2019) or practitioner action (Archer, 1995) related to phase 3, where *Solar Pink Pong* and *iGYM* were created and explored. The term was first coined by Christopher Frayling (1993), who derived it from Herbert Read's *Education Through Art* (1943/1974) and proposed it to emphasize a type of research that can be achieved and communicated through art activities including craft or design. Frayling did not distinguish between art and design when he first outlined this model. However, he distinguished *research through art and design* from *Research for art and design* where the primary outcome is an artifact instead of communicable knowledge, and *research into art and design* where the art and design practice itself or related topics are the research interest. I also use the latter distinction to refer to the dissertation's final, reflective phase 4 as *research into art and design* in the next section.

Within this umbrella term, there are at least two different orientations of practice-based research approaches related to the project's research trajectory from *Solar Pink Pong* (i.e., interactive art) to *iGYM* (i.e., interaction design and HCI). First, artistic forms of research, which are often referred to as arts-based research (ABR); second, designerly forms of research, which are often referred to as research through design (RtD) — an adaptation of Frayling's model for HCI that omits art (Bardzell et al., 2015; Stappers & Giaccardi, n.d.). Both of these research orientations exist in many variations. For example, the Handbook of Arts-Based Research lists 29 different jargon terms within the ARB orientation (Leavy, 2017) and the Encyclopedia of Human-Computer Interaction lists 11 different terms under the RtD orientation (Stappers & Giaccardi, n.d.). To further clarify the project's *research through art and design* approach without getting tied up in unpacking this terminological pluralism, I focused on: (1) outlining the shared motivation and philosophical underpinnings of artistic knowing (McNiff, 2008) and designerly knowing (Cross, 2006) vis-à-vis more established forms of knowledge; (2) emphasizing prototyping as the project's primary research and development method in this context; and, (3) describing two established methodological positions that shaped the project most as it transitioned from arts-based research to HCI-based research.

3.3.1 Artistic and Designerly Knowing

Common to both artistic knowing and designerly knowing is the motivation to overcome the dualism of thought and action, theory and practice in the process of inquiry. This motivation can be traced back to John Dewey's *theory of inquiry* (Dewey, 1938), which was further developed by Donald Schön as an epistemology of practice that recognized practitioners as reflective inquirers or *practitioner researchers* (Schön, 1983). Schön describes the key components of his epistemology of practice as *knowing in action* (i.e., tacit knowledge), *reflecting in action* (e.g., improvisation), and *reflective conversation with the situation* – the latter refers also to a mode of designing with the materials of a situation (Schön, 1992).

Similar to Schön's epistemology of practice is also Bruce Archer's third approach to knowledge that emphasizes the term *design awareness* as the ability to deal with ideas that are expressed though the medium of doing and making (Archer, 1979). Archer's third approach to knowledge is a part of a methodological framework in which he makes an epistemological distinction that helps to frame the tacit knowledge contributions in this research project (i.e., the knowledge that resides in *Solar Pink Pong* as an artwork). He proposes *modelling* as the essential language of design (in which he includes all forms of fine arts and useful arts) that is distinct from the languages of science (i.e., mathematical notation) and humanities (i.e., natural language). Archer referred to modelling as dealing with forms of representations (e.g., drawings, diagrams, physical representations, gestures, algorithms, etc.) that capture, analyze, explore, and transmit ideas of artists and designers (Archer, 1979). This kind of modelling, though in a less representational sense, also relates to Rudolf Arnheim's visual thinking (Arnheim, 1969/2004a) and Max Wertheimer's productive thinking (Wertheimer, 1959), which are both non-textual forms of reasoning. Both build on Gestalt psychology and Gestalt principles that shape the way ideas are expressed through art and design activities in a similar fashion as the rules of syntax in language.

Finally, modelling and the emphasis on the form of language itself also relates to Wittgenstein's picture theory of language, which was in fact inspired by a physical model in the first place (i.e., a courtroom model depicting the scene of a car accident) (Monk, 2005, p. 42). This reference to Wittgenstein serves mainly to illustrate that in Archer's framework the recognition, particularly of tacit knowledge claims (i.e., the knowledge embedded in *Solar Pink Pong*), rely both on the limits of each language (i.e., what can be said) and the familiarity with it (i.e., its use) – two considerations that Wittgenstein famously explored at the beginning and end of his career (Wittgenstein, 1921/1998; 1953/2009); as such, the picture theory of language serves as an analogy to illustrate the knowledge communication barriers that this project's *research through art and design* approach faces vis-à-vis other, more established research approaches.

3.3.2 Prototyping

Prototyping was the primary *research through art and design* method for the creation and exploration of *Solar Pink Pong* and *iGYM*. It was used in the above described spirit of modeling and designing with the materials of a situation. Prototyping is a related term that can have different meanings in art and design. The meaning in this project has at least three dimensions related to the (i) making, (ii) testing, and (iii) envisioning of ideas. First, making refers to form-finding or sense-making with the materials of a situation (e.g., physical models or mock-ups). Some form of making or doing is the prerequisite of all practice-based research. Second, testing refers to analyzing or validating ideas through making. It is the key characteristic that makes any type of prototyping activity – ranging from low-fidelity mockups to high-fidelity prototypes or interventions – so effective compared to other methods particularly for practitioners (see e.g., Alexander et al., 1977). Finally, envisioning refers to the potential of prototypes to make sense of future possibilities or future design spaces (Sanders, 2013). Envisioning in that sense is what separates artistic and designerly forms of research from most other research forms (McNiff, 2017). In this sense, prototyping also resonates with the idea of world making or future forming (Gergen, 2015).

In this project, I used all three above described prototyping dimensions to explore ideas in different ways at different stages and in different situations: starting with a sunlight reflection that turned into an interactive shadow play, *Solar Pink Pong*, which then inspired the inclusive game environment *iGYM* (see Chapter 5). This prototyping process was highly iterative. It followed a pattern that is often depicted among designers as a double diamond shaped diagram (see e.g., British Design Council, 2005) representing converging and diverging *design thinking* stages through which ideas are explored (i.e., discovered, defined, developed, and delivered). In this sense of repeated acting and reflecting, the overall process was also similar to the cyclical nature of action research, which many scholars see in the same category as *research through art and design* (McNiff, 2017; Archer, 1995). However, unlike in most action research or design thinking procedures, the success of this prototyping method relied primarily on the skills and artistry of my reflective practice leveraged by the collaboration with engineers and researchers. Further, the decision making that guided this method and determined what form of prototyping is most useful in a given situation was largely subjective, particularly at the beginning of *Solar Pink Pong*'s research trajectory. It relied much on embodied thinking, felt-knowledge, and the imagination that grew out of my personal bodily experiences (Henriksen, 2018). In other words, it was subject to what Wallas would call "the promptings" of my personality or "that imperfectly co-coordinated whole," which are critical for the stage of Illumination in a creative process in general (Wallas, 1926/1931, p. 107) and the creative application of this prototyping method in particular.

3.3.3 Prototype Evaluation

> *There is no test of statistical significance, no measure of construct validity in artistically rendered research. What one seeks is illumination and penetration. The proof of the pudding is the way in which it shaped our conception of the world or some aspect of it. (Eisner, 2003, p. 6)*

Two established methodological positions or *habits of thought* (Ascott, 2011), however, clearly shaped the prototyping and project evaluation particularly at the beginning and ending of the project as it transitioned from arts-based research to HCI-based research: first, the position of the art educator Eliot Eisner; and second, the position of the design researcher Bruce Archer. Both fit within the larger *research through art and design* umbrella, but differ in their emphasis on, and interpretation of, research methodology versus research outcome. Most practice-based research models at the intersection of art and HCI can be negotiated within these two positions. Eisner emphasizes the role of the researcher's body as an instrument and the evocative qualities of the research outcome. For Eisner a work of art has to be successful for the research to be useful. Central to this view is "the power of form to inform" (Eisner, 2003). To evaluate this research approach, Eisner proposes, in reference to Dewey (1934), the use of criteria rather than universal standards similar to how an art critic makes judgments. Archer, on the other side, favors the acquired knowledge though practitioner action over the usefulness of its outcomes

(Archer, 1995). For Archer, the record of the practitioner action and the replicability of the research procedure is key. Central to this view is the power of the research documentation to inform. To evaluate this research approach, Archer suggests that most concerns lies in the soundness (i.e., reliability) of the research methodology.

	Begin: Arts-based research (*Solar Pink Pong*)	**End: HCI-based research (*iGYM*)**
The artifact had primarily a…	value as an artwork (meaning expressed*)	value as a research artifact (meaning stated*)
The researcher was primarily…	bodily interacting with the situation	observing and recording the situation
The situation was largely…	directed, but open-ended (situation talks)	controlled (documentation talks)
The evaluation was primarily…	based on art criteria (artistic habits of thought)	based on methodology standards ("academic" habits of thought)

Table 2: Key methodological differences in this project between arts-based research and HCI-based research that marked the very beginning and end of the research through art and design project phase 3. *adopted from Dewey's (1934) distinction between art and science.

Taken as a whole, both positions provide the rationale for a different emphasis on the role and importance of (1) the artifact, (2) the researcher, (3) the situation, and (4) the evaluation in this project. This was particularly evident at the very beginning and ending of its research trajectory (see Table 2). For example, the first evaluation of *Solar Pink Pong* was marked by an informal play test with my two-year-old daughter in a parking lot, where I mimicked an interactive sunlight projection system with a handheld mirror. In this playtest, my own body became part of the prototyping system. The success of this method relied primarily on my motor and imagination skills in response to the situation (i.e., my daughter trying to kick the sunlight reflection on the asphalt). This method was both effective and sufficiently reliable (i.e., appropriate) to assess the feasibility and validate the experience of a new interaction idea for an interactive art installation. In contrast, the last evaluation of *iGYM* was marked by a controlled user study with 12 recruited participants that engaged with an automated, room-sized augmented reality system. In this study, a research team was observing and recording the situation and interviewing the participants. The success of this method relied primarily on controlling the situation by having both participants and researchers follow the protocol of a study procedure regulating how data was collected and analyzed each step of the way. This method was effective and reliable to verify educated guesses (i.e., hypotheses) regarding the accessibility of the system based on exploratory playtests (i.e., pilot studies). These two examples illustrate key methodological differences that marked the beginning and ending of the project's entire research trajectory, which is described more in chapter 5.

To further reflect on the nature of this *research through art and design* process and contextualize it through the lens of *Ludic Engineering*, I used an autoethnographically informed case study research approach, which I describe in the next section.

3.4 Research into Art and Design

Research into art and design represents the final phase of the project (phase 4), in which I reflected on the entire creative research process in the context of my art and design practice through the lens of *Ludic Engineering*. The main goal of this summative reflection was to further articulate the concept of *Ludic Engineering* for my own practice and for creative practitioners and scholars working at a similar intersection of art and HCI. To achieve this goal, I used an autoethnographically informed case study research approach to reflect on *Solar Pink Pong*'s research trajectory ranging from its epistemologically and value-based foundation (i.e., selected prior work with my artist collective *Assocreation*), its inspiration (i.e., evocative sunlight reflections on the street), its development and implementation as an interactive artwork, to its re-evaluation for inclusive play and presentation as HCI research (i.e., *iGYM*) (see Chapters 4 and 5).

Autoethnography and case study research can both be considered artful modes of first-person inquiry (Stake, 1995; Bartleet, 2013; Marshall, 2016). They are part of alternative approaches of doing research and interpreting lived experiences that were initially created in response to the crisis of representation in social sciences in the 1980s that recognized the limitations of describing and explaining the social world with general theoretical models (Schwandt, 2007; Ellis et al., 2011). In this spirit, both modes of inquiry are often used by artists, designers, and also HCI researchers involved in interaction design (Lucero et al., 2019) to get and share insights from their own research process particularly in the case of speculative and ludic design projects (Gaver, 2006). Within the world view of the dissertation, they can also be interpreted as a step from pragmatism to post-pragmatism (Frisk & Östersjö, 2013), making visible the larger context of the project and the political and cultural implications of its contribution (i.e., the fact that the project was conceived and discussed primarily through a western-industrialized world perspective shaped by my cultural background and views on technology and change).

In the final project phase, I combined autoethnography (Ellis, 2011) and case study research (Stake, 1995) as a method to describe and analyze (graphy) my personal experience (auto) to better understand the wider cultural significance (ethos) of the nature of *Solar Pink Pong*'s research trajectory (case) at the intersection of art and HCI. I applied this method following three basic steps. First, I compiled a chronological timeline listing *Solar Pink Pong*'s main research and development milestones and activities in chronological order including location information based on my research documentation (i.e., notes, files, folders, email correspondences, etc.). I chose only elements that seemed substantive (i.e., well documented) enough to serve as reference points for the later discussion of *Ludic Engineering* as a form of research and practice. Second, I organized these milestones and activities thematically and described them from a first-person account providing both emic interpretations and etic reference points and illustrations (i.e., images, texts, and documents related to exhibitions, awards, patents, reviews, teaching, etc.). Further, I revisited prior art work that informed *Solar Pink Pong* to provide the reader sufficient context for my practice and habits of thought. Third, based on the contextual literature review related to *Ludic Engineering* and guided by my initial research questions **(RQ1-3)**, I reflected on the nature of *Solar Pink Pong*'s research process and its main outcomes. In conclusion, I created a speculative *Ludic Innovation Framework* that illustrates the process of innovating technologies for the lived body with the lived body in form of a modified flow diagram.

To sum up, following this method, I provided a multilayered first-person account and triangulated my subjective interpretations with external evaluation milestones. I emphasized time, place, and person as well as evocative moments to stimulate naturalistic generalizations (Stake, 1995, p. 85) that make the subjectivity of my account visible (Frisk & Östersjö, 2013). In other words, the key goal of this method was to maximize the reader's opportunity to learn (Stake, 1995) about the concept and potential of *Ludic Engineering* as exercised in this case study situated at the intersection of art and HCI.

4 Foundation Work

To describe the practice-based foundation of the Solar Pink Pong *case study, I briefly revisit and reassess some of my earlier work with the artist collective Assocreation in the light of the dissertation's focus on* Ludic Engineering *for the lived body. I contextualize* Solar Pink Pong *as part of a larger oeuvre in the spirit of an illustrated monograph or annotated portfolio focusing on four selected works: Windows, Bump, Common Ground (i.e., my master thesis), and Rolling Shadows. The first three works set the intellectual foundation for most of my interactive installations that inspire ludic behavior in the public. The forth work involves sunlight and shadow play, which become key elements in* Solar Pink Pong. *Taken as a whole, these works embody core values and ideas that shaped my research through art and design process leading to* Solar Pink Pong *and beyond.*

4.1 Windows

Figure 2: *Windows 97*. Installation, 1997. Hundreds of windows connected by wire. Schottentor, Vienna, Austria.

Windows 97 was a temporary public art installation comprising hundreds of windows connected and held in place by wire at a major public transportation hub in Vienna, Austria in 1997 (see Figure 2). It was the first project with *Assocreation*, an artist collective that I co-cofounded as a student with Michael Bieglmayer and Christian Smretschnig and which was later joined by Werner Schmid (until 2002). *Windows* provided the intellectual foundation for much of *Assocreation's* consequent interactive art installations including my work on *Solar Pink Pong* and research interest in *Ludic Engineering* for the lived body.

The idea for the *Windows* installation was inspired by two coinciding events: first, Bill Gates launching the operating system Windows 95; second, many building owners in Vienna replacing their old windows. As a result, there was suddenly an abundance of windows appearing – both virtual windows on computer screens and real windows in dumpsters on the street. In an attempt to make sense of these coinciding events, we started to collect all the windows that we could get our hands on and developed a site-specific installation for one of Vienna's most heavily trafficked public transportation hubs: the Schottentor. It took more than two years of strategic planning and lobbying (i.e., explaining the project to various stakeholders ranging from Vienna's public transit company, a dozen different municipal departments and city officials, to a security and facility management firm) until we finally got the permission to install several hundred windows on this restricted green space in Vienna's city center in 1997.

Windows was an early critique of the disembodied nature and the supposedly transparent and democratic character of the emerging Internet in the mid 90's. For us as young artists and students, working on this large installation in 1995, which was later also bookmarked as "The Year the Future Began" (Campbell, 2015), was a way to visualize and comment on the nature of the emerging Internet in the 90's. At the time, we were very excited about this new medium, but also very conflicted, because all these windows, connected and held in place with wires, were only framing partial views, and the images that we hoped to see were often lost in endless reflections. Back then, we felt reminded of what Baudrillard said about the difficulty to distinguish reality from a simulation of reality (Baudrillard, 1994) or Nietzsche, who made the case that "'appearance' itself belongs to reality" (Nietzsche, 1910, p. 71). However, the most striking question for us about the emerging internet in 1997 was: if, in a world of windows, there was no material or immaterial world, there was "just the world as it appears to us," like Nietzsche says, then – what happens to our bodies (see Figure 3)?

Figure 3: *Windows 97*. Computer graphic and Poster, 1997.

Working with windows on and off screens so closely for more than two years, we got irritated by one big design flaw that we perceived in this system; there was not a single door or opening that would allow us to step or reach through. So how can we truly connect in such a system? Is hiding behind or touching screens really the most we can do with this network? Simple questions like these and a childlike curiosity for hands-on experimentation prompted us to shift our consequent focus as an artist collective from critique to action and start building our own alternative digital interfaces. Most importantly, these questions and shift started a more than 20 yearlong learning and interface development process in my creative practice dedicated at reframing the body and interactivity in the build environment.

4.2 Bump

Figure 4: *Bump* – Asia / Europe. Telematic installation, 2010."Istanbul 2010 – European Capital of Culture." Eminönü, Istanbul, Turkey.

In response to our reflections on the *Windows* installation and our critique on the disembodied nature of the emerging internet, we developed *Bump*, a tactile and telematic installation (see Figure 4). Bump comprises two interactive sidewalks (each 50ft long) that tangibly connect two distant public places in real time. With every step on the planks, an impulse is triggered and digitally transferred to the other city via internet. The respective boards in that city then rises a few centimeters and vice versa.

Bump premiered at the Ars Electronica Festival in 1999 as a tactile communication bridge between Linz and Budapest, 10 years after the fall of the "iron curtain" that divided Eastern and Western Europe for decades (see Figure 5). Since then, *Bump* has been shown across Europe various times including at venues such as the CeBIT in Hannover (one of the largest international computer expos), and most recently in Istanbul, where the installation bridged the Bosporus between Asia and Europe as part of "Istanbul 2010 – European Capital of Culture."

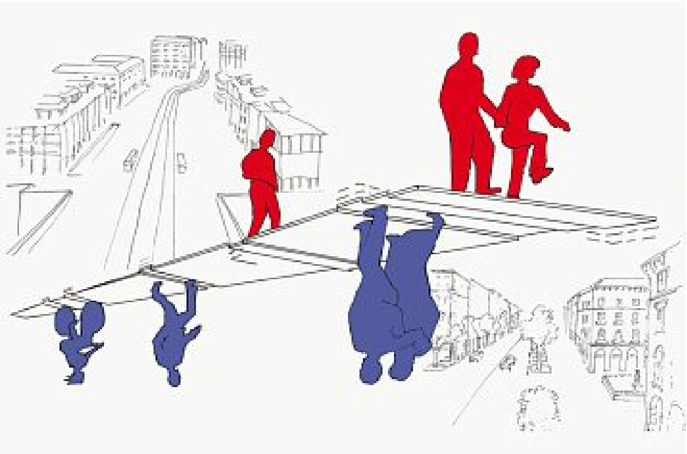

Figure 5: *Bump* – Linz / Budapest. Concept drawing, 1998

The idea for the *Bump* interface was, like *Solar Pink Pong*, inspired by a very distinct and memorable experience. In this case, the inspirational experience occurred during the ideation phase for *Bump* in 1998 as I was walking down a busy shopping street in Vienna with my *Assocreation* collaborators. As we came across wooden trench covers at a construction site waiting for a traffic light to turn green, we suddenly felt a strong knocking underneath the boards. It felt as if somebody underneath was hammering a nail in those boards. I remember the vibration was so strong that we thought the nail would penetrate one of our shoe-soles. People nearby showed a similar visceral reaction and jumped off the boards screaming. The whole pedestrian traffic stopped for a few seconds. Then people seemingly amused about the impact of this unexpected sensation triggered by an invisible human being (probably a construction worker underneath the boards) laughed at each other and carried on. This disruptive but very social experience made us realize the significance of the ground as the only surface that we are always connected to and that we immediately pay attention to – even on a busy shopping street. Looking for alternative and non-screen-based interface ideas to tangibly connect people, we took this experience almost literally as an inspiration; we built a telematic installation using pneumatically operated pistons hidden underneath wooden boards that simulate an unexpected physical encounter connecting two distant public places in real time. And, we called this installation *Bump*, for "bump into each other."

Bump has been connecting people at various locations and venues from museum and gallery spaces, computer expos, to shopping malls and streets. The most interesting venue for us, however, turned out to be the most recent one in Istanbul in 2010, where *Bump* bridged two locations at the shores of the Bosporus strait between Asia and Europe only a few miles apart from each other. At this geographic location more than 300,000 people crossed the Bosporus every day with ferry boats. This meant that in Istanbul, *Bump*, as a telematic installation, was bridging two locations that actually needed a bridge. Further, many daily commuters, who crossed the installation on one side of the Bosporus strait, could also experience it on the other side. This realization was not without irony, because *Bump* was initially conceived with the expectation in mind that connecting people at geographically very distant places would be most interesting. At the end, we realized that bridging political, cultural, and social borders in close proximity was perhaps even more interesting to facilitate with the *Bump* installation.

This realization and interest to connect people in close proximity also aligned with observations we made during the first installation. When *Bump* premiered at the Ars Electronica Festival in Linz and Budapest, we noticed already that it had at least as much potential to inspire local interactions between passers-by than telematic interactions across distances. Further, we noticed that the installation stimulated a playful and social atmosphere particularly in the presence of children, who were often the first to explore it. *Bump* often provoked ludic behavior and made people smile or laugh in public.

As an artist collective, these ludic effects or aspects of our work were initially not desired or fully embraced. In fact, they seemed to undermine the seriousness of our critique that we wanted to deliver as part of our work, for example, regarding the effects of screen-based technology on social interactions. It was not until much later when we were invited to show *Bump* in the group exhibition "playware" (an exhibition focusing on play as the core component of video games and interactive art) in LABoral Centre for Art and Creative Industries in Gijón, Spain, that we started to acknowledge the ludic dimension as a distinct quality of our work — a dimension that successfully engages the public and helps to inspire new (social) interaction behaviors as well as our learning from it.

4.3 Common Ground

Figure 6: *Common Ground* – Department of Dance. Interactive installation, 2003.Group exhibition "The Ideal City," 2nd Valencia Biennial. Convento del Carmen, Valencia, Spain.

Common Ground resulted directly from our reflections on the *Bump* installation and it was part of my collaborative diploma thesis (i.e., master thesis) in architecture with Michael Bieglmayer in 2002. *Common Ground* was an analog yet highly interactive installation made of granite tiled pavement mounted on compression springs. Its objective was to provide a tangible telematic experience for pedestrians in close proximity. Every step on its surface caused waves of movement along the surface, spreading to take hold of other passers-by (see Figure 6).

Commissioned by Will Alsop (our thesis supervisor) and Bruce McLean, curators of the 2nd Valencia Biennial "The Ideal City," *Common Ground* was first realized (after building and testing many different models and versions of it) as a large temporary installation in Valencia, Spain in 2003. At the Valencia Biennial, it became part of "The Department Store of Proper Behavior" that transformed an 800-year-old monastery into an eclectic space full of unexpected installations or "shops of experience." In addition to contributing to the curators' playful interpretation of the exhibition theme, *Common Ground* was meant to serve as a proof of concept for a potential permanent public art installation in the future.

The main idea of *Common Ground* was to take what we learned from *Bump* and create an interface that heightens our awareness of each other in close proximity. We were interested to develop an ultra-short-range telepresence interface that seamlessly integrates in the urban environment and makes pedestrians aware of the ground as a shared surface that they are all connected to. For this interface, the traditional sender-receiver communication model that we used for *Bump* and that basically mirrored the functioning of old radio and telephone technologies was not an appropriate framework anymore. Our new *Common Ground* interface, whose inner workings we also referred to as "analogue computing," was not about sending and receiving information. It was about providing a common ground – a platform that is both firm and flexible enough to connect everyone simultaneously. In other words, our main idea focused on establishing the same ground as an interaction platform accessible to all.

In retrospect, this early concern regarding the inclusiveness of public interaction and communication platforms (regardless if digital or analog) expressed as an artist collective are similar to the accessibility concerns that later inspired the re-evaluation of *Solar Pink Pong* for inclusive play. In the *Common Ground* installation, we tried to address this concern by providing a shared paved surface that – despite being made of heavy granite stones – behaved like water and could be triggered by anybody stepping or walking on it. In the augmented reality system described in chapter 5, we addressed this accessibility concern more explicitly by providing a shared playing field through a peripersonal circle interaction feature that enabled people with different abilities to play together.

Another concern of *Common Ground*, one that relates to the practice-based focus of this dissertation, was academic and epistemological in nature. It was about the appropriate form of a diploma thesis in architecture that captured the installation and our research interest in developing experiential interfaces from the ground up. For our diploma thesis, it turned out to be particularly hard to capture the experiential nature of *Common Ground* on photo or video. Further, we found it difficult to characterize or contextualize the experience walking and interacting on its surface beyond referring to simple water analogies (Most people thought there was water underneath the granite surface. In fact, getting back on firm ground after staying on its moving surface for longer periods of time could result in feelings similar to returning from a long boat trip).

In response to this documentation challenge and our inability as visual artists to address it by conventional academic standards, we decided to abstain from using words and submitted a diploma book with fluorescent pink shoe sole prints instead (see Figure 7). These pink prints were collected during a public happening in front of the Vienna Künstlerhaus, where an early model of *Common Ground* was on display at that time. The prints were meant to highlight the soles' fleeting contact with the ground, which we saw as key "material" of the ground and street-level interactions in our work. Once submitted, our diploma thesis with pink prints and without any text was rejected. Later, after some explanation and negotiation with the dean's office (and in consultation with university lawyers), which resulted in the inclusion of a CD as supplementary material (containing an abstract, video, and photo files), our thesis was successfully defended and accepted. Finally, and to our surprise, it was selected for the diploma exhibition showcasing selected thesis works and it received a special award by the Kunsthalle Wien.

Figure 7: *COMMON GROUND bodenlos*. Pink Prints – shoe diploma and object series, 2002. Austrian National Library, Vienna, Austria.

The academic and epistemological concern illustrated by this thesis anecdote is of course inherent in any practice-based research that struggles with finding the right forms or formats of knowledge representations particularly for a doctoral dissertation. I mention this anecdote mostly for two reasons: first, to fully disclose an early academic reference point from which my still ongoing learning process about writing and scholarly forms of knowledge contributions leading to this dissertation started; second, to explain part of the motivation for *Solar Pink Pong*'s name and color choice. After the diploma thesis, fluorescent pink became *Assocreation*'s primary color of choice (see also the *Pink Prints Streetwear* series), since it provided the most vivid contrast to the mostly light or dark grey street surfaces that we usually worked with. The same turned out to be true later when experimenting with different colored sunlight reflections on the street for *Solar Pink Pong*.

4.4 Rolling Shadows

Figure 8: *Rolling Shadows* – A Car Show for Pedestrians. Interactive installation, 2012. Sigmund-Freud-Park, Vienna, Austria.

Rolling Shadows is a much later work that directly preceded *Solar Pink Pong* and fully embraced the ludic dimension both in its creation and execution process. It is an interactive sidewalk spectacle, in which hundreds of miniature solar toy cars are placed side by side in the shadows of pedestrians. As the pedestrians walk away, the sun hits the solar toy cars and causes them to drive in all directions dissolving the carefully arranged pixelated shadow image (see Figure 8).

Rolling Shadows was first exhibited as a side attraction during a car cruise event in Detroit, Michigan, USA, in 2012. Since then, it has been shown in numerous places both as a happening on the street and interactive mixed media assemblage in galleries (see Figure 9). In the gallery, the solar toy cars were mounted on an insulation board forming a pixelated human shadow image. Mounted on the wall, the toy cars' polished solar panels reflected the image of the visitors. Further, when the afternoon sun shined through the gallery windows, it activated the toy car engines, whose wheels started to spin mimicking the rush hour on the street.

The idea to use solar toy cars for an art installation evolved after my relocation to Ann Arbor, Michigan, USA, when cars became an increasingly important part of my daily life. Like *Solar Pink Pong*, it was motivated by a perceived lack of sunlight and disconnect to the outdoor environment particularly in my new work environments, which often had no windows. Further, it was inspired by two events: first, one of my students playing with solar toy cars in her studio; and second, running into an organizer of a car cruise event, who was open to the idea to experiment with (Chinese) solar toy cars at his event in Detroit, the historic birthplace of the automobile industry.

The resulting work was meant to shrink the fetish "automobile" down to the scale of a sidewalk spectacle, which *Assocreation* is most familiar with. In the context of our work, we also described *Rolling Shadows* as an "electronic flea circus" of sorts that uses tiny solar toy cars to play with our shadows and reflect on the image of our inventions.

Rolling Shadows is the most recent and direct practice-based foundation for *Solar Pink Pong*'s shadow play and the thesis's focus on *Ludic Engineering* for the lived body. The toys cars used for this work are a literal reference to play and playful manipulation of the public ground as an interface for the human body.

Figure 9: *Rolling Shadows* – Energy Plan of the Western Wo/man. Interactive mixed media assemblage (96/48/2 in), 2012. Group exhibition "Quantified Self," The Gallery Project, Ann Arbor, MI, USA (right); *Rolling Shadows* – A Car Show for Pedestrians. Interactive installation, 2013. Group exhibition "INTERCIDADES," Schwanke Contemporary Art Museum, Joinville, Brazil. Photo: Carlos Felipe Urquizar (left).

5 Solar Pink Pong: A Ludic Engineering Case Study

The Solar Pink Pong *case study is the core element of the dissertation. It is an account of its practice-based, research through art and design process. It covers a time frame of nine years from the project's first documented inspiration (i.e., golden sunlight reflection on the street in 2010), its implementation and first major public recognition as an art installation (i.e., Award at the Japan Media Art Festival in 2016), to its re-evaluation for inclusive play and HCI research (i.e.,* iGYM *system and inclusive play study published in CHI and CHI Play in 2019). The purpose of this account is to illuminate the tacit dimension of* Solar Pink Pong*'s project development (i.e., the knowledge that resides in, and was generated through, the artwork as a research artifact) and provide reference points for the discussion and further conceptualization of* Ludic Engineering *in chapter 6.*

5.1 Chronological Overview

The chronological overview in Table 3 shows the case study's main research and development milestones and activities in chronological order. It highlights two important turning points in its practice-based research process: First, the point where the process transitioned from inspiration and incubation to ideation; and second, the point where the underlying research framework moved from arts-based research closer to HCI-based research. These two turning points also mark the main research trajectory from "Pink" (i.e., generating a pink sunlight reflection) to "Pong" (i.e., creating a street video game and inclusive play system) and its implications that will be discussed in this dissertation.

For the compilation of this overview, I chose only milestones and activities that seemed substantive and discrete enough to serve as reference points for the discussion of *Ludic Engineering* as a line of research. The roles of the milestones and activities and their results is discussed in more detail in the following thematically organized sections.

2007	Summer	First conscious recollection of experiencing a bright blue sunlight reflection on the street
2010	Aug	First documented experience of a golden sunlight reflection on the street
2012	Apr	First experience of a Kinect full body motion tracking system
	May – Jun	Playful explorations of dichroic color filters and mirrors (i.e., red, green, blue, gold/yellow) for art installations manipulating sunlight
		Playful explorations of skeleton and membrane figure mockups for interactive installations using Kinect full body motion tracking capabilities
	Turning point 1: from inspiration and incubation to ideation and implementation	
	Aug	First concept idea drawings of *Solar Pink Pong (SPP)*

	Sept	Concept exploration playtests and creation of demo video with hand-held mirror mock-up of *SPP*
	Nov	Gallery exhibition of *SPP's* concept idea with a floor projection of the demo video and display of the artist statement (Faculty exhibition "First Encounter")
2013	Feb	Seed grant project proposal for *SPP* (Faculty Development Grant, Office of the Vice President for Research, University of Michigan – awarded in April: $11,250)
	May – Sep	Prototype development of *SPP1.0* (i.e., first working prototype with target speed of 1.3m/sec)
	Oct	Prototype playtests and outdoor implementation in studio parking lot and first video documentation
2014	Jan	Gallery exhibition of *SPP's* prototype and video documentation (Faculty exhibition "Constellations")
		Invention Report 1: "Sun-Powered Street Video Game Console"
		Invention Report 2: "Laser-Like Projector"
		Invention Report 3: "Sun-Powered Gobo/Film/Video Projection System or Media Façade"
		Early Commercial Assessment of the invention reports (Office of Technology Transfer, University of Michigan)
	Feb	U.S. Provisional Patent Applications for Invention Reports 1-3
	Mar	*Daylight Media Lab*: proposal for Art & Tech research initiative dedicated to developing experiential artworks that blur the boundaries between sky and screen, natural and artificial light (Faculty Research Seed Grant, Stamps School of Art & Design, University of Michigan – awarded in May: $25,600)
	Mar – Oct	Prototype development of *SPP1.1* (i.e., off-the-grid prototype with a target speed of 2.5m/sec)
	May – onwards	*Daylight Media Lab*: Start of domain specific research collaborations, literature review, expert consultations, speculative design and material explorations
	Sep – Dec	Undergraduate Engineering Course: Solar Graffiti (Harvey Mudd College)
	Nov	First exhibition of *SPP* as an interactive installation at "ISEA2014, the 20th International Symposium on Electronic Art," Dubai, UAE
2015	Jan	Exhibition and interactive installation of *SPP* at "Arts Track at TEI 2015, the 9th International Conference on Tangible, Embedded and Embodied Interaction," Stanford University, Stanford, CA, USA. First HCI-related publication of SPP as an extended abstract (2pgs)
	Feb	U.S. Utility Patent Application, Title: "Interactive Projection System"
	Sep – Oct	Customer Discovery Workshop exploring *SPP's* value proposition and product market fit (Grand Valley State University)
	Sep – Dec	Graduate Engineering Course: Next Generation Interactive Outdoor Games (University of Michigan)
	Jan – May	Concept development of *SPP2.0* (i.e., hybrid laser/sunlight projection system with a smaller form-factor)
	Jun	Exhibition and interactive installation of SPP at "FILE 2015 - Festival Internacional de Linguagem Eletrônica," São Paulo, Brazil
		Submission of *SPP* as Work-In-Progress (5pgs) to CHI PLAY, the international and interdisciplinary conference for researchers and

		professionals across all areas of play, games and human-computer interaction (HCI), London, England, 2015 (Rejected in July)
	Aug	Correspondence with National Science Foundation grant officers
2016	Jan	Proof of concept of a stereoscopic tent camera obscura system to enable an immersive analog 3D viewing experience (i.e., the most tangible *Daylight Media Lab* project outcome besides *SPP*)
	Feb	Excellence Award for *SPP* (3 out of 700 entries) and interactive installation at "19th Japan Media Arts Festival – Exhibition of Award-Winning Works," The National Art Center, Tokyo, Japan
Turning point 2: from arts-based research to HCI-based research		
	Sep – Dec	Re-evaluation of *SPP* for the design space of inclusive play and exercise; start of new research collaboration with faculty in HCI and computer engineering
	Oct	Nomination of *SPP* (20 out of 478 entries) for "New Technological Art Award 2016" and interactive installation at "update_6 / NTAA 2016," Zebrastraat Ghent and the Centre for Fine Arts Brussels, Belgium
2017	Jan	Issuance of U.S. Utility Patent, Title: "Interactive Projection System"
	Jan – Apr	*iGYM* concept development and first floor projection prototype with a single projector
	May – Dec	Expanded floor projection system with two projectors and air-soccer game development
2018	Jan	Playtests of expanded floor projection system and game with 4 to 12-year-old children
	Feb	*iGYM* Grant Proposal (University of Michigan Exercise & Sport Science Initiative – awarded in April: $150,000)
		Presentation of an early version of the *Ludic Innovation Framework* at CAA's 106th Annual Conference, Los Angeles, "Speculative Play" Session
	Apr	Institutional review board approval (IRB) and first playtests and pilot study with players with different abilities
	Sep	Submission of *iGYM* pilot study as a long paper (10pgs) to Conference on Human Factors in Computing Systems (CHI) in Glasgow, UK, 2019 (Rejected in December)
	Dec	Invention Report: Projection-based augmented reality system for inclusive recreational sports
2019	Jan	Submission of revised *iGYM* pilot study manuscript as Late-Breaking work (6pgs) to Conference on Human Factors in Computing Systems (CHI) in Glasgow, UK, 2019 (Accepted and presented in May)
	Mar - Apr	U.S. Utility Patent Application, Title: "Peripersonal Boundary-Based Augmented Reality Game Environment"
		iGYM inclusive play study with 12 participants
		Submission of *iGYM* study as a long paper (10pgs) to CHI PLAY, the international and interdisciplinary conference for researchers and professionals across all areas of play, games and human-computer interaction (HCI), Barcelona, Spain, 2019.
	Apr	*iGYM* Play Day event
	Oct	CHI PLAY 2019 Best Paper Award for "*iGYM*: An Interactive Projection System for Inclusive Exergame Environments" (top 1% of submissions)

Table 3: Chronological overview of the *Solar Pink Pong* case study and its main research and development milestones and activities.

5.2 Phenomenological Inspiration

Figure 10: Two views of the first documented sunlight reflection. Vienna, Austria, 2010.

Solar Pink Pong's initial inspiration were two encounters of very distinct and memorable experiences of unusually bright and colorful sunlight reflections on the street in Vienna, Austria.

The first encounter happened sometime in the summer of 2007 when I was walking down the street to my tax advisor's office in Vienna's 5th district during a lunch break. This encounter was not documented on photo, but is still vividly present in my mind's eye: The sun was burning down on the street. The surfaces of the sidewalk and adjacent building façades were bouncing off the heat and bright light of the sun. I was looking down, squinting my eyes, as I noticed two bright blue and sharp-edged rectangular color fields on the sidewalk's light grey asphalt surface. I stopped to look more closely. It took me a few seconds to realize that the source of this stunning visual effect was not part of an extravagant sidewalk design, but an accidental reflection of a tinted shopping window close by. I was completely mesmerized by this strong visual effect in bright daylight, which I had never experienced in this form and intensity before. I even remember fantasizing that this effect might be of good use for an art project in some form. However, I stopped thinking about this effect any further when I arrived at my tax advisor's office.

The second encounter happened three years later on August 13, 2010 when I was walking home from a visit and tour of the Wittgenstein House in Vienna's 3rd district. This time I had a camera with me as I experienced several amorphic and highly luminescent golden sunlight reflections on a paved walkway (see Figure 10). The visual effect of this encounter was dramatically amplified since some parts of the sunlight reflection fell on an area of the walkway that was shaded by a tree. The resulting spots on the ground were immersed in such an intense golden color that I instinctively kneeled down with some disbelief to touch the cobblestones and make sure that I was not mistaking this color effect for a cleverly spray-painted graffiti. I then must have spent a good 15 minutes with my digital camera tying to properly document this effect and its source, the sun's mirror image high up in the tinted glass façade of a nearby office building. I remember, I was somewhat frustrated that despite all my efforts and camera equipment, I didn't come anywhere close to capture the quality of the highly luminescent golden color and the resulting experience as it presented itself in that moment. The frustration grew even stronger as I later at night reviewed the camera images on a computer screen and realized how unspectacular my photos portrayed the scene. Nevertheless, the lived experience of this second encounter was so convincing that I told myself to explore it further as a material for an art installation at some point in the future.

To sum up, the significance of these two encounters was that they demonstrated the basic potential of artificially modified sunlight as a "material" for an aesthetic experience in an art installation. However, these encounters alone didn't offer any hints as of how to develop them further for an art installation or interactive system. The start of the conceptual development inspired by this experience was motivated by different coinciding factors that happened after my relocation to the USA years later.

5.3 Personal Motivation

My personal motivation to start *Solar Pink Pong*'s conceptual development was linked to my relocation to Michigan, USA in 2011, where sunlight, or the absence of natural light in office spaces, was increasingly becoming a concern for me. I have never experienced so many windowless studio and office spaces before. Unlike in Austria, where I grew up and lived before, there are no regulations regarding the size or even the requirement of windows for office workers in Michigan. As a result, there is often no way to look outside or synchronize one's internal clock with the light and dark patterns of the outdoor environment. This perceived lack of sunlight and disconnect from outdoor environments brought back the memory of the two above described encounters of colorful sunlight reflections in Vienna. It was the main motivation to deliberately recall the distinct encounters of the two sunlight reflections experienced years ago and start actively exploring their potential as a material for an art installation in the Summer of 2012.

5.4 Concept Development

My initial objective was to learn to re-create colorful sunlight reflections similar to those I had experienced in Austria many years ago. At this initial stage, the concept idea was simply to generate large static color fields on the street in bright daylight.

To achieve such effects, I first researched and learned about different mirror and color filter options. I consulted technicians of optical coating and components manufacturers and light designers in person and on the phone. Eventually, I ordered a range of dichroic color filter samples and first surface mirrors to start exploring visual effects. Most samples I received were very small (a few centimeters in square or diameter) and the material was very expensive. Although some of the visual effects that I could achieve with the samples in direct sunlight seemed very impressive (i.e., most notably using concentrated sunlight and filters to create highly luminescent color effects), I was unsure if the high material

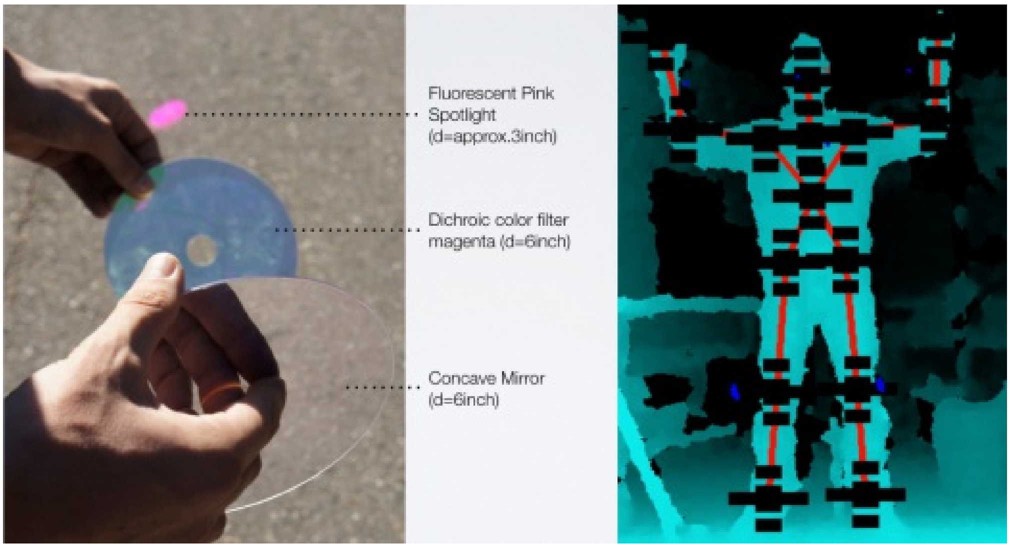

Figure 11: Color mirror explorations (left) and motion tracking explorations (right), 2012.

costs would make it feasible to further explore the concept idea of large color fields in bright daylight (Fig. 11, left). In fact, I was considering stopping this line of exploration.

Around the same time, and unrelated to this exploration, I made my first direct experience of a Kinect sensor in a performing arts technology student exhibition. This sensor technology was cutting edge back then. It had the capability of tracking bodily movements without the need of special markers attached to the body. Seeing my own bone structure traced on a computer screen in real time was a distinct experience of similar magnitude as the colorful sunlight reflection on the street (Fig. 11, right). It was the first time that I, figuratively speaking, could feel the eyes of a computer on my skin.

Inspired by this experience, I started a series of (in retrospect) relatively fruitless attempts to translate the Kinect sensor capabilities into the physical realm: first, by building mock-ups of a stick figure that would mimic the movement of a person in front of it like a mirror (Fig. 12, left); second by using a stretchable membrane that would function as a skin and mimic bodily movement more abstractly as a geometric shape (Fig. 12, right).

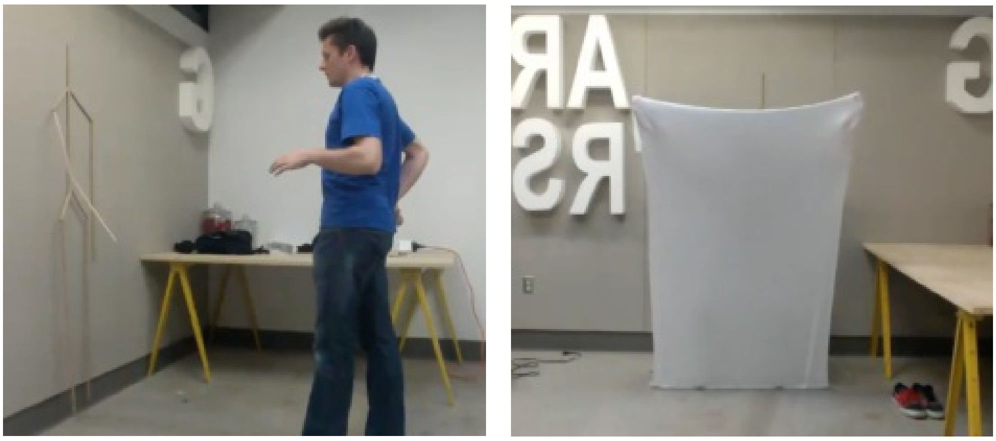

Figure 12: Skeleton figure explorations (left) and membrane figure exploarations (right), 2012

However, my concern with these whole-body sensor concept explorations was that they were too literal translations of the initial screen experience; they didn't seem to be unorthodox or poetic enough to justify the effort of pursuing them further, particularly given the technical difficulty of prototyping them mechanically. In fact, I was considering stopping this line of exploration, too.

Solar Pink Pong's conceptual breakthrough was a classic eureka moment (reflecting on both fruitless explorations while taking a bath), in which I suddenly realized that I could combine both separate lines of exploration – the manipulation of direct sunlight and the application of whole-body sensor technology – to create something new. The new concept that emerged as a result was the use of an animated sunlight reflection as a target of an interactive "Pong-inspired" whole-body game on the street (see Figure 13). There is no detailed recollection of the rational for this match-making process other then suddenly starting to see a connection between both explorations and then holding on to this connection and trying to rationalize it to make it clearer and the emerging concept stronger. The conceptual clarification process started first in my mind's eye and then crystalized as a concept sketch and three words on paper. For example, the color "Pink" was a visual reference to my previous work with the artist collective *Assocreation*, in which fluorescent pink color highlights the soles' fleeting contact with the ground (see e.g., the *Pink Prints* – shoe diploma described in chapter 4). Further, "Pong" was a historic refence to one of the first video games and early screen-based interactive play behaviors. Together, "Pink" and "Pong" are reminiscent of the physical and social interaction of a ping-pong game. Finally, "Solar" was a reference to both the sun as the light and power source of an interactive media experience. "Solar" was later added as it became clear that the device, to be conceptually most thought provoking, should operate completely off-the grid. This is in a nutshell how *Solar Pink Pong*, as a concept, was initially formed.

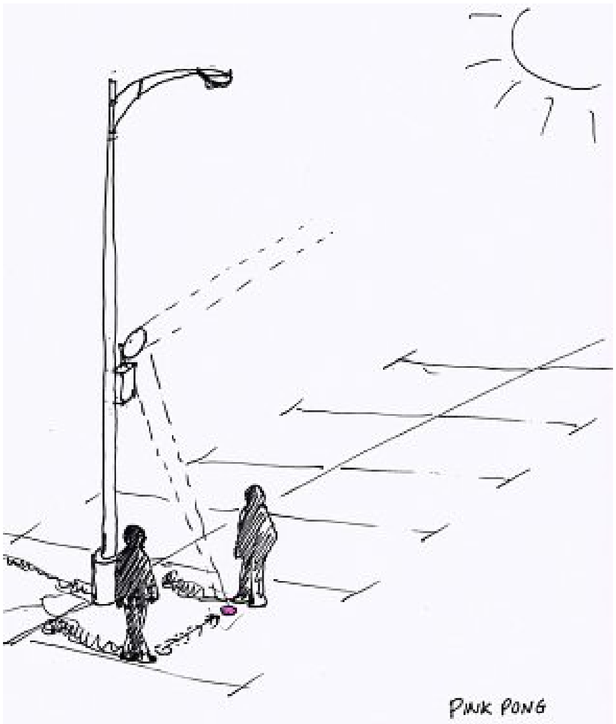

Figure 13: *(Solar) Pink Pong*. First concept sketch, 2012.

In order to promote *Solar Pink Pong*'s early concept idea for an internal university research seed grant application, I asked Eric S. Rabkin, a distinguished colleague and writer in the English Language and Literature department for a very brief quote. Eric S. Rabkin was also affiliated with my Art & Design School and highly appreciated for his ability to comment on art projects in studio critique sessions. He paraphrased and contextualized *Solar Pink Pong*'s early concept idea as follows:

> *Solar Pink Pong is Kick-the-Can for our age, and for all ages. Like children delighting in the noisy clatter of a found plaything, children and adults delight in the visual responsiveness of a spotlight they discover that they can enliven as their kicks propel it until it slows to a halt on the sidewalk or bounces back from a wall or a partner. Solar Pink Pong passes the ancient torch of joyful physical exploration by inviting us to pass the light, making basic delight visible in our built world.*
>
> Eric S. Rabkin

To sum up, key for *Solar Pink Pong's* concept development was the creative hunch to piece together two disparate and simultaneously occurring lines of exploration related to sunlight and interactive media. Taken alone, each exploration posed challenges that seemed hard to overcome. Combined they offered new perspectives and possibilities. The origin of the creative hunch to combine both lines of explorations is the least documented part in this case study. However, following this hunch was the key element that enabled a successful idea development from two rather vague inspirations (i.e., experience of sunlight reflection and Kinect sensor) to a formalized concept that fits into the context of my prior body of work with the artist collective *Assocreation* (see Chapter 4). Further, this hunch led to a successful seed grant proposal for the design and prototype development of *Solar Pink Pong* as a sun-powered street video game described in the next section.

5.5 Prototype Development

Solar Pink Pong's technical development process from low to high-fidelity prototypes had two main concerns: first, the quality of the visual effect (i.e., the sunlight reflection) and second, the quality of the interaction with it (i.e., the motion tracking). For the development of the first, I worked with a dichroic filter manufacturer to custom-design the desired pink color mirror and resulting visual effect. For the development of the latter, I consulted engineering colleges at the University of Michigan and hired Surat Kwanmuang, a PhD student with computer vision software and hardware prototyping experience to collaborate on this project. Further important development objectives for *Solar Pink Pong* were to create a system that worked completely off-the-grid (i.e., sun-powered) and that met maximum size and weight regulations for international air travel for the ease of transportation and display as an interactive art installation.

The first *Solar Pink Pong* mock-up, however, was nothing more than a simple hand-held dichroic color mirror. To test the potential of an animated sunlight reflection as a target of an interactive game, I generated and manually controlled a sunlight reflection on the asphalt with a hand-held mirror. My main objective was to better understand how it feels to "kick" a sunlight reflection with my shoes. To achieve this, I positioned myself in front of a wall in my parking lot. I kicked the reflection with my shoes while tilting the mirror so the corresponding reflection moved towards the wall and bounced back from it as if it was a ball that I was playing with. I practiced my hand and feet coordination and then demonstrated this simulated game to my two-year-old daughter, who immediately started to chase the reflection trying to kick it – which provided an early proof of concept (see Figure 14) and gave confidence to move forward with this idea and build a first functional prototype.

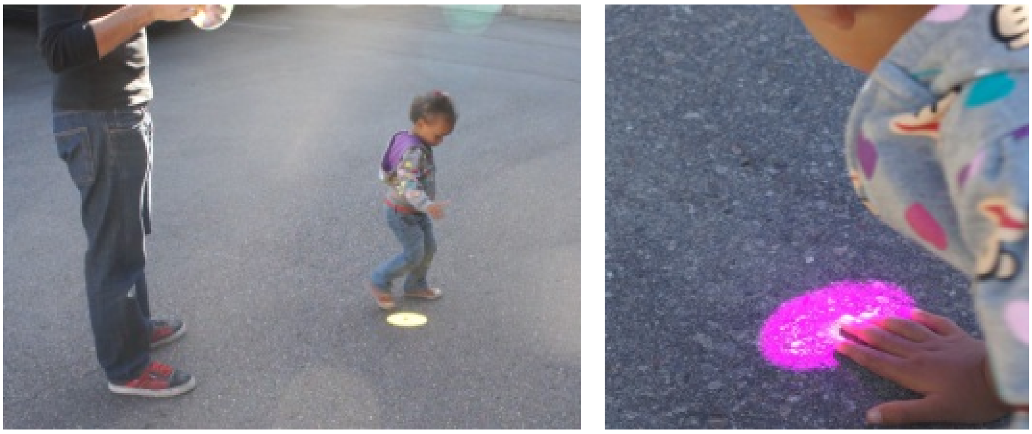

Figure 14: Two views of first, hand-operated, *Solar Pink Pong* mock-up and playtests, 2012.

The first functional prototype used a two-axis motion-controlled laser pointer and a webcam for motion capture. This prototype was set up indoors on a small camera tripod for convenience and development purposes (see figure 14). It enabled interaction with slow moving laser pointer on the floor and helped to develop and test different computer vision and actuator components of the system. In this development phase, different motion capture technologies, optical systems, and form factors of the device were explored, too. Some of the key findings was the difficulty to collimate sunlight (i.e. create focused and sharp-edged sunlight spots) and the impracticality of many off the shelf sensor technologies (including Kinect) due to the high IR components of sunlight and reflections from ground surfaces that can blind the camera.

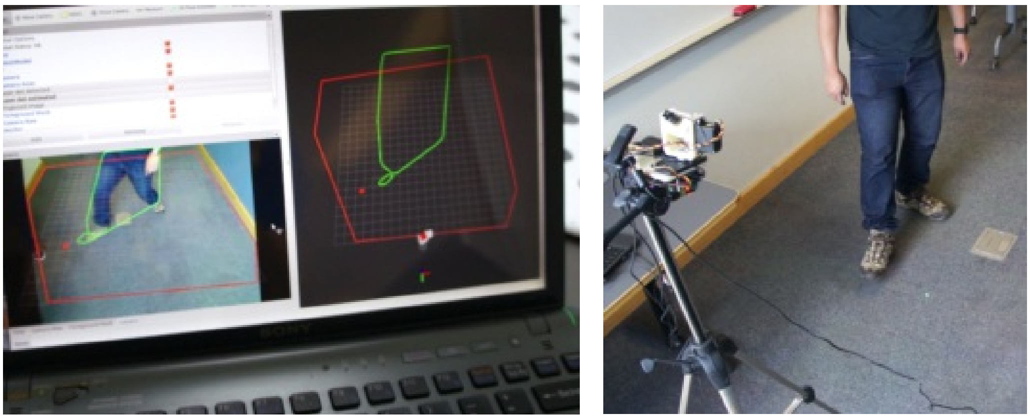

Figure 15: Two views of first functional indoor prototype with a motion-controlled laser pointer projecting a moving target (i.e., green laser point) on the floor, 2012

The first outdoor prototype was developed and tested several months later in the studio parking lot on a light pole. This prototype had already the final form factor that resembled a satellite (see Figure 16). This particular look was both a consequence of optimizing the system and a deliberate design choice seeking to emphasis its off-the-grid character by reinforcing the satellite image. This outdoor prototype allowed already testing whole-body interactions with an animated sunlight reflection. Interestingly, the players' shadows, which we initially wanted to exclude from the interaction in our system design, turned out to be a particularly enjoyable element to play with. This finding or happy accident actually helped to make the development easier from the motion tracking perspective, since it only required a single camera and not a stereo vision system. However, the target speed of the pink sunlight reflection felt too slow (1.3m/sec), the mirror-head was not projecting the pink target smoothly enough, and the detection had an input lag that disrupted the natural interaction feeling.

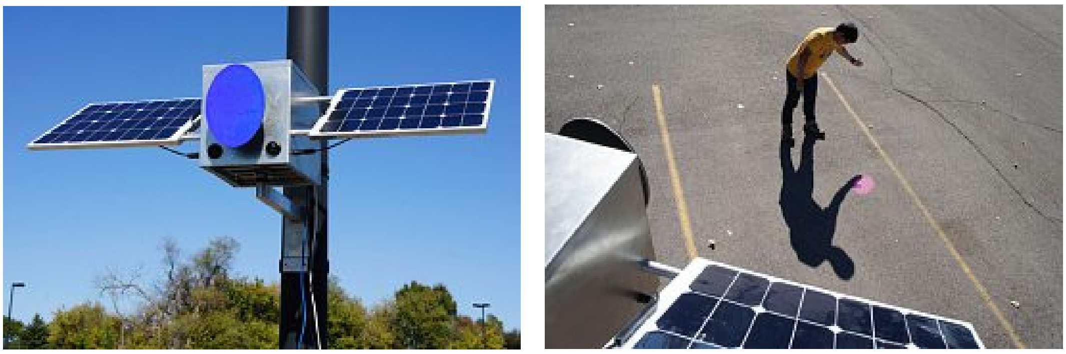

Figure 16: Two views of the first functional *Solar Pink Pong* outdoor prototype with a motion-controlled dichroic-color mirror generating an interactive sunlight reflection on the asphalt, 2013.

A final and improved prototype was tested after additional software and hardware development which took almost another year. The final prototype was set up and tested in the studio parking lot over the course of several weeks. This prototype was already fully operational as an off the grid device and could be remotely accessed through a web interface (see Figure 16). Most importantly, the target speed (2.5m/sec) and tracking

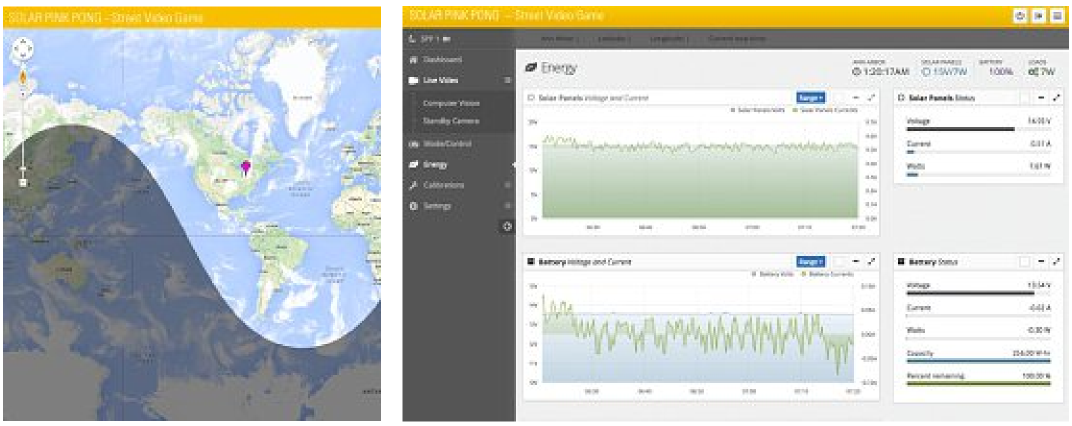

Figure 17: Two screen captures showing *Solar Pink Pong*'s web/operator interface, 2013.

speed was significantly improved. As a result, the system provided a more engaging and natural interaction feeling than before. Further playtests with adults and children (i.e., including my daughter, who has first interacted with the hand-held mirror prototype) indicated the system was ready to be deployed as an interactive art installation to the public.

5.6 Invention Reports and Patent Applications

Developing *Solar Pink Pong* for almost two years generated insights and further ideas related to interactive sunlight media systems, which led to three invention reports (see Appendix A) that were later transferred into provisional patent applications, one of which was further pursued and issued in 2016 (see Appendix B). This patent application process was initiated when I reached out to the Technology Transfer department at the University of Michigan for support to find potential industry partners and funding in this field.

The first invention report titled "Sun-Powered Street Video Game Console" is directly related to *Solar Pink Pong*. It describes technology related to the application of a street video game, in which a moving sunlight reflection becomes the target and the street's surface the screen. It highlights the advantage of re-inventing the street as a public interface for playful interaction as opposed to conventional video game technology that is limited to computer screens and dimmed indoor light conditions.

The second invention report titled "Sun-powered 'laser' projector (Cyber Sunlight)," describes technology related to the application a sun-powered "laser" projector for interactive outdoor displays and sunlight "laser" shows. It highlights the advantage of creating new sun-powered laser-like visual effects in bright daylight that can be operated fully off the grid.

The third intervention report titled "Sun-powered gobo/film/video projection system (Solar Cinema)" describes technology related to the application of a Sun-powered gobo/film/video projection system for outdoor displays, billboards or movie systems. It highlights the advantage of creating new artistic and commercial daylight projection systems that can also be operated fully off the grid.

Based on these invention reports, the Technology Transfer department conducted an early commercial assessment that included: (1) technology details, (2) potential applications, (3) market overview, (4) products, companies, and competition, (5) commercialization challenges, and (6) relevant patent and publication search results. The assessment's marketing summary described the potential value of the proposed technologies as follows (see Appendix C):

> *The sun's rays reach the Earth's atmosphere at an intensity of over 1,000 W/m^2. Conventional system powers range from 0.75 watts for personal laser pointers to ~10's of watts for laser light show systems to 100's of watts for projectors. Harnessing the sun's power could create a next-generation outdoor projection system capable of displaying advertising, information, aesthetic accents, or even video games with sufficient intensity to been easily seen even on bright days at*

practically zero power cost. Such a system would be, self-sufficient, off-grid, and customizable for a variety of uses.

This early assessment was the basis for the Technology Transfer department to hire a Patent Lawyer and file three provisional utility patent applications for each of the invention reports described above (see Appendix A). After a year of further exploration and deliberation with the Technology Transfer department, only the most concrete provisional utility patent application related to *Solar Pink Pong* was further pursued. The final utility patent that was eventually filled and later issued (with all claims) described its technology more broadly as an interactive projection system enabling body and shadow interactions regardless of the use of artificial or natural light sources (see Appendix B).

Going through this technology transfer review and patent process was initially not planned or desired, but it provided unexpected benefits for the further research trajectory. For example, working with the patent lawyer on the background and description of the utility patent helped to better define both the novelty and the boundaries of design space related to *Solar Pink Pong*. Further, it helped to better articulate two important needs for future technology development in this area: first, the need to provide an interactive media experience that is not limited to indoor applications and that is capable of employing natural sunlight as the operable light source for the media experience; and second, the need to provide an interactive media experience that can naturally co-exist and augment the physical environment in which it is used to create an immersive interactive experience that is encumbered by any wearable technology. These two needs were also foundation of the much broader *Daylight Media Lab* initiative that is described in the next section.

5.7 Daylight Media Lab

5.7.1 Research

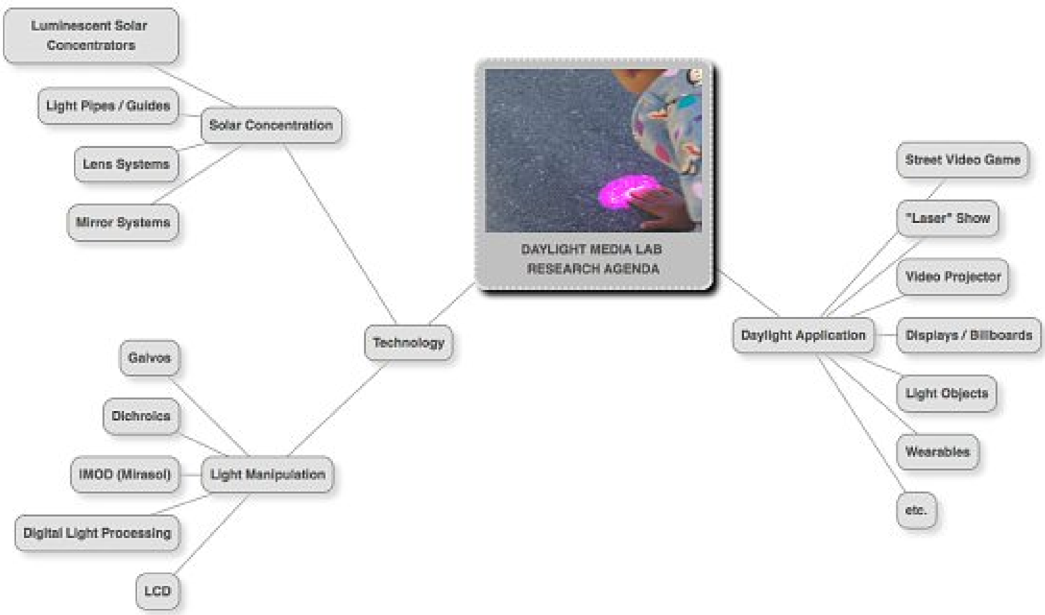

Figure 18: Diagram showing the *Daylight Media Lab* research agenda (i.e., daylight applications of optical components and entertainment electronics).

The *Daylight Media Lab* was an Art & Technology research initiative that I founded to formalize and better explore the larger research agenda and broader needs that were revealed through developing *Solar Pink Pong* and its related patent applications (see Figure 18). Supported by a University of Michigan seed grant, this initiative was a vehicle to better connect and collaborate with researchers in other fields under the umbrella of "Daylight Media" – a term that aimed to combine two typically disparate lines of research related to the use of (1) sunlight and (2) artificial light in interactive media systems. The strategic plan behind the *Daylight Media Lab* was to develop the ground work for a larger Art & Technology research proposal, for example, for the National Science Foundation (NSF). This plan, however, took a slightly different turn as I explain in the following.

The *Daylight Media Lab's* broader vision was to overcome the binary opposition of artificial light and sunlight that has impacted technology development and shaped our lives since the invention of Edison's light bulb (see Figure 19). As an Art & Technology lab, it was meant to build on the powerful connection of light in our lives and address some of the side effects of related technological progress, for example, on alienating people from exploring outdoor environments. However, it also acknowledged that the evolution of artificial light – from fire, candles to gas and electric light – has introduced new ways to look at the world, most recently, in the form of augmented reality systems.

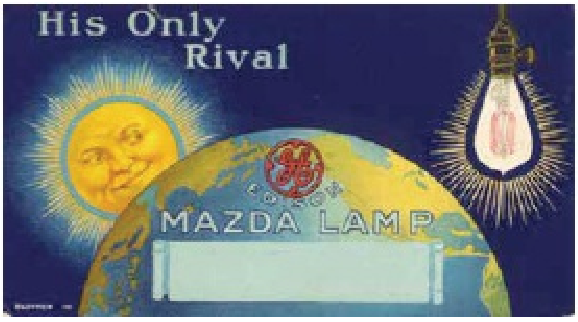

Figure 19: Edison's MAZDA lamp illustrated by Maxfield Parrish in 1917 showing the historic divide between artificial and natural light.

The artistic and technical objective of this initiative was to manipulate daylight and develop experiential artworks and devices that allow people to enter a world, in which the boundaries between sky and screen, natural and artificial light, real and virtual, dissolve. The goal was to use technology to heighten our perception of daylight as a medium through which we can interact with the world. In other words, the goal was to blur the boundaries of our analog and digitally conditioned perception systems to re-experience or re-imagine daylight as a medium in the 21st century. An early precursor related to this goal is the Light and Space movement in Southern California, particularly the works of James Turrell and Robert Irwin, which I discussed in more detail in chapter 2.

As part of the *Daylight Media Lab* initiative, I explored a wide range of daylight applications of optical components and entertainment electronics. I conducted literature reviews, phone and in-person meetings with researchers and inventors in industry and academia ranging from optics and material science to computer engineering. I visited labs on campus and conducted exploratory hands-on material investigations inside and outside my studio. Particularly the latter, visiting researcher in their lab or have them visit and review my material explorations, helped to widen my knowledgebase most effectively. It revealed, for example, next generation technologies that I didn't know existed such as interferometric modulator displays (IMOD) that operate with ambient light or transparent solar panels that look like window panes. Further, it allowed me to play with materials I would otherwise not have access to such as a carbon nanotube coated material sample that absorbs more than 99.9% of all visible light and qualifies as the "perfect black" material. In addition, the exchange with optics and material science experts also made me alert of many limitations and technical challenges early in the exploration process.

Figure 20: Two views showing sunlight projection tests, 2014.

For example, a challenge that I didn't anticipate involved using direct sunlight as a light source for a projection system, which was key to my initial aspiration. Creating focused and sharped edged sunlight reflections or even parallel light beams (i.e., collimated light) seemed to be a relatively trivial task based on casual explorations with parabolic reflectors and lens systems (see Figure 20). However, replicating these effects particularly over a longer distance showed there is a limit to how well sunlight can be focused (see Figure 21). It required consulting two laser scientists and a meeting with a telescope manufacturer to fully work through these challenges theoretically and clarify some of the production costs to focus sunlight over a larger projection distance. I learned the sun is simply too big to be equated as a point source in an optical system. As a result, direct sunlight is impractical to use in any optical systems that seeks to achieve light effects similar to a stage light or a video projector. This fact is relatively easy to understand and it can also be observed (e.g., by watching how a sunlight shadow becomes less sharp the further away an object is from the projection surface). However, it was less trivial to explore mathematically in an optical system even for laser scientists; and it was even harder to predict the desired visual effects. Further, chromatic aberrations, the fact that different wavelengths of sunlight bend differently (which results in rainbow effects), created another challenge and layer of complexity. Conducting hands-on explorations in person with a laser scientist was key for eventually making the decision to not push this idea further. Using sunlight in a conventional projection system seemed to have too many limitations. Most importantly, it was too expensive to custom design precision optical systems with a small seed grant to prototype visual effects at a scale of a few centimeters which may at the end not have enough visual and evocative quality.

Figure 21: Sunlight projection tests with two double-sided convex lens system and a dichroic color filter (left, middle) and visibility and contour sharpness tests (right), 2014.

In response to these sunlight concentrating challenges, I also reviewed light collectors (e.g., parabolic mirrors or lens arrays) that are used for daylighting systems to deliver daylight to windowless spaces via light guides (e.g., fiber optics or light pipes). However, off-the-shelf light collectors tend to be bulky and expensive devices and have to track the sun, which made them less versatile for many alternative application ideas.

A material scientist who visited my studio and saw the limitations that I encountered recommended exploring luminescent solar concentrator (LSC) as an alternative sunlight concentration method. LCS's are devices that often come in the form of thin flat luminescent sheet materials that absorb solar radiation and convert it by luminescence

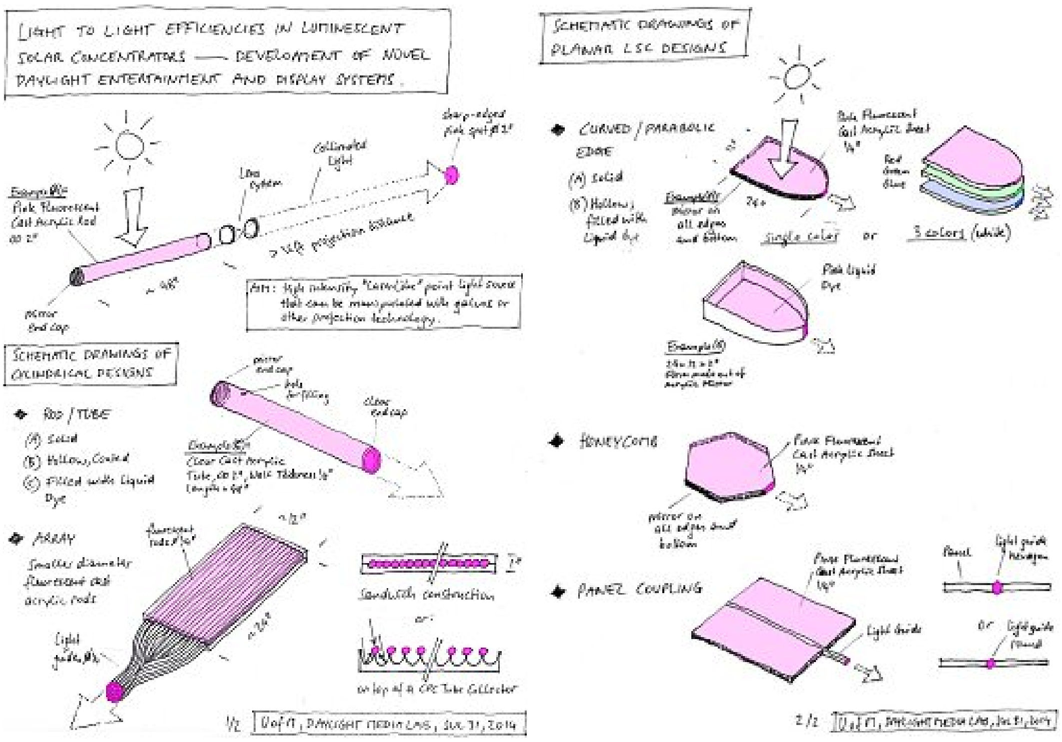

Figure 22: Concept drawings of luminescent solar concentrators for LSC projection systems based on literature review and conversation with material scientists, 2014.

into light with a narrower frequency range (e.g. from the whole visible light spectrum to only a single color). This light can then be directed through internal reflection to the edges of the sheet material, where it illuminates the edges. Such an edge-lit effect can, for example, be seen when looking at the edges of fluorescent color cast acrylic sheets that glow as if they were actively illuminated from within even in dimmed light conditions.

The most studied application of this technology is, however, to convert the collected light at the edges into electricity by photovoltaic cells attached only to the edges instead the entire surface like in the case of conventional solar panels. There is only a small group of researchers worldwide that explores the light-to-light efficiency of LSC for collecting sunlight for daylighting applications, which I saw as more interesting for the research agenda of the *Daylight Media Lab*. I made several concept drawings (fig. 21) and consulted a few researchers in this domain and talked to technicians of dyes and luminescent material manufactures to get a range of samples for hands-on explorations. I spent several months exploring the potential of this technology to be scaled up for creating sunlight projection systems or new forms of art installations or daylight sculptures. The clear advantage of LSC technology is that it doesn't rely on direct sunlight and also works well on cloudy days unlike most daylighting systems I explored earlier. Further there is a certain magic of the luminescent effects that can be generated, at least at a small scale. The disadvantage, however, is that many of the most promising luminescent materials or dyes turned out to be highly toxic chemicals that could not be safely explored outside specially equipped labs, which made a playful exploration of this technology very difficult and expensive. Further, operating with toxic chemicals seemed

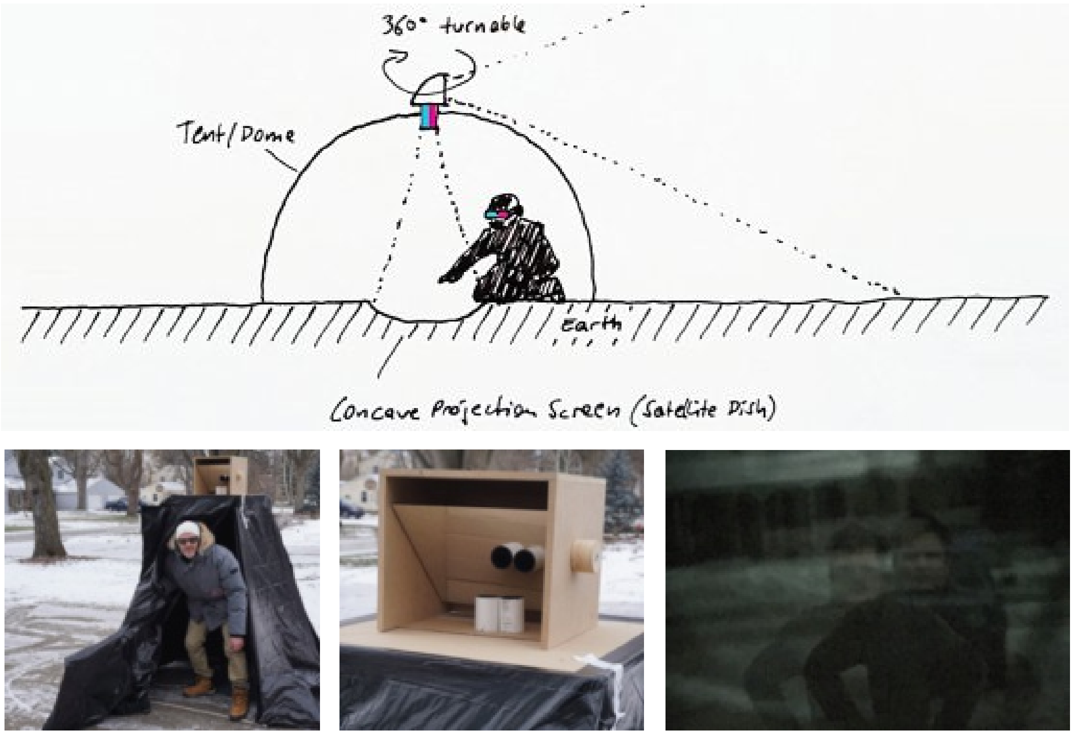

Figure 23: Concept drawing of 3D camera obscura system (top) and proof of concept showing viewer with polarized 3D eyewear (left), stereoscopic projection system (middle), and stereoscopic projection/image on a passive 3D silver screen (right), 2016.

to undermine the values and vision of the *Daylight Media Lab* as an environmentally aware art & technology research initiative.

As a result of all these technical challenges and safety and environmental concerns, the overall prototyping process of the *Daylight Media Lab* initiative didn't move much beyond casual explorations. The most concrete outcome, in addition to *Solar Pink Pong*, was a proof of concept for a stereoscopic camera obscura lens system that functioned like a view finder projecting the exterior of the environment into the interior of a life size dome in full 3D (see Figure 23). This idea was inspired by visiting a re-construction of a historic tent camera obscura that Robert Platt, a painter and artist colleague, uses for his work. In consultation with an optic expert and lens manufacturer, we then modified this historic optical device into a polarized 3D projection system that generated an immersive, analog 3D experience for viewers who entered the dome with polarized 3D glasses – the same eyewear used for 3D cinema experiences. Our goal with this project was to merge both current and historic visual technologies as a way to explore and comment on the past/present continuum of our collective fascination with novel visualities.

To sum up, overall the large scope and interdisciplinary nature of the *Daylight Media Lab* research agenda would have been stimulating and insightful enough for me as an artist and designer to continue. However, it didn't result in an adequate research proposal idea for the National Science Foundation (NSF), which was one of the initial objectives that I outlined in the research seed grant. In conversations with different NSF grant officers, I quickly learned that both my experience-oriented *Daylight Media* research agenda as well as *Solar Pink Pong* as an artifact and outdoor game, were far away from fitting into any available NSF grant program. Without any particular topical concern or framework, for example, related to education, health, or sustainability, it seemed unproductive to make further funding inquiries. Despite this obvious funding and framework challenge, a few *Daylight Media Lab* collaborators were interested to further explore "Daylight Media" as a subject in engineering courses as described in the next section.

5.7.2 Teaching

The *Daylight Media Lab* initiative also resulted in teaching collaborations and student projects. They were particularly inspired by its focus on using and manipulating sunlight and developing interactive media systems that re-connect youth (e.g., young video game players) to outdoor environments. For example, in one instance, the *Daylight Media Lab* acted as a client for engineering students in an introduction to engineering design and manufacturing course at Harvey Mudd College, in Claremont, California. This course was led by Gordon Krauss, an early *Daylight Media Lab* collaborator and engineering professor, who I started to work with at the University of Michigan before he moved to California. In this course, three student teams worked on "Solar Graffiti," one of the *Daylight Media Lab* concepts for interactive outdoor displays. For the purpose of this engineering course, the following problem statement was formulated by Gordon Krauss:

> *Create a device for which the input is user information and sunlight and the output is an artistic display. The display should be highly visible and rapidly changing. It should encourage interaction from many users by being intuitive and easy to use.*

The result of this course, which also gave the students tight budget restrictions, were three group projects and lo-fidelity prototypes (see Figure 24): The first group used *Kinect* to detect the user's gesture and a modified LCD screen and an overhead projector to project an image on a screen or wall. The second group used a series of optical devices to reflect sunlight and collimate it on a reflective canvas. The canvas could be a modified etch-a-sketch with reflective dots or an aluminum plate covered with dark ink that could be rubbed out using fingers. The third group used a hexagonal plate that could spin around its center. A set of triangle mirrors with various colors could be placed on the plate to form different light patterns.

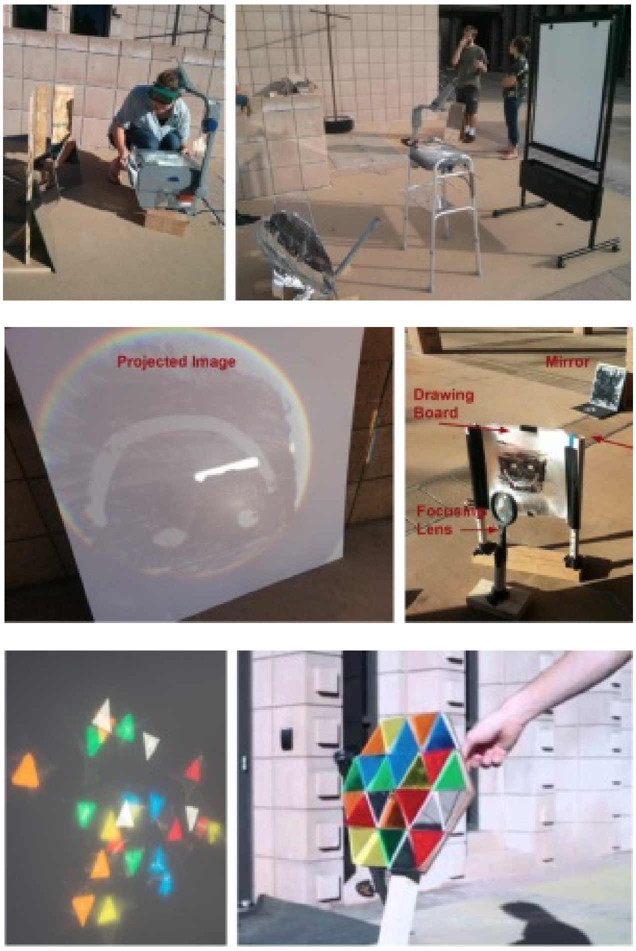

Figure 24: Two views showing student projects: the Kinect and modified LCD screen projector prototype of student group 1 (top), the etch-a-sketch prototype of student group 2 (middle), and the color triangle reflector prototype of student group 3 (bottom), 2014

Another teaching collaboration focused on exploring motion-tracking and mirror-head designs for interactive outdoor media systems in a special topics graduate engineering course at the University of Michigan. This course was offered by my *Daylight Media Lab* collaborators Jason Corso and Edwin Olson, who were also involved in the *Solar Pink Pong* project. This special topic course was hosted in a robotics lab and provided hands-on experience in hardware, software and mechanical systems related to the previously developed *Solar Pink Pong* technology. In this course, a team of five graduate

Figure 25: Two views showing the computer vision and interactive laser display game system developed in a special topics graduate engineering course, 2015.

engineering students developed an interactive laser display to test and develop different computer vision and control systems for similar interactive game systems (see Figure 25).

Finally, *Solar Pink Pong (SPP)* itself became the topic of an independent research project by Deepak Sharma, a graduate engineering student. The initial objective was to better understand the technical limitations of the existing artwork and research prototype *(SPP1)* from an engineering perspective. The goal was to propose design changes that lead to a new device *(SPP2)* that would be easier to install and could potentially be commercialized as an outdoor game console in the near future. The project went through many design iterations from concept sketches, full scale cardboard models, final 3D CAD model, to prototyping key components such as the mirror-head, mounting arm, and gearbox of the device (see Figure 26). The proposed design changes resulted in a significantly reduced form factor, improved mirror head design with less backlash, and a

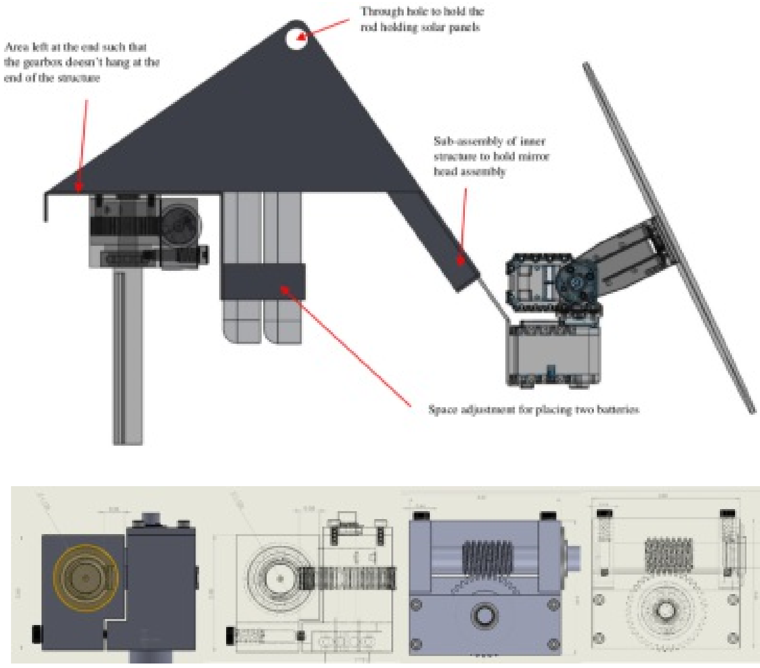

Figure 26: Sideview of *SPP2*'s proposed re-design of structure and mirror head (top) and gearbox (bottom) reducing overall form factor and enabling easier set-up and operation, 2015

mechanical system, the integration of an optional laser projector was explored, for example, for applications on cloudy days or at night. However, it was beyond the scope of the independent research project to build and test *SPP2* as a prototype.

To sum up, "Daylight Media" did show some promise as a subject to engage students particularly in California. However, in Michigan the relative low temperatures and restricted availability of sunlight during most of the academic year made outdoor tests and demonstrations impractical. As a result, most ideas were explored as engineering drawings, simulations, or in the form of indoor mock-ups (see e.g., Figure 25) in windowless lab spaces – which seemed to undermine the *Daylight Media Lab* mission.

5.8 Exhibitions

This section summarizes all public exhibitions of *Solar Pink Pong* from its first concept presentation in a local gallery in Ann Arbor, MI, USA in 2012 to its latest exhibition as an art work nominated for the "New Technological Art Award," in Ghent, Belgium in 2016. It describes key reflections, observations, challenges, and audience reactions that emerged by engaging both the public and experts in different domains (i.e., artists, game designers, curators, HCI scholars, etc.) with the display of *Solar Pink Pong*.

5.8.1 First Encounter (Ann Arbor, MI, USA)

Figure 27: Exhibition view showing first *Solar Pink Pong* presentation in the group exhibition "First Encounter," Work Gallery, Ann Arbor, MI, USA, 2012.

In November 2012, *Solar Pink Pong* was first presented to the public as a concept at the faculty show "First Encounter" at a local gallery in downtown Ann Arbor. Unlike most shows, First Encounter, curated by Gunalan Nadarajan, was an explicit invitation to introduce the public to the creative process instead of finished work. First Encounter, in this sense, was meant to refer to a curator's first impression and insights into creative processes of an artist as a result of a studio visit.

As an artist and designer, who often works on the street, I decided to project a video on the gallery floor (see Figure 27) showing *Solar Pink Pong*'s first hand-held mirror prototype (i.e., the manually operated sunlight reflection game) that I had play-tested with my two-year-old daughter in a parking lot a few weeks ago. In addition, I included the following artist statement on the wall to describe my creative process:

> *When I explore our built world I often feel like a child trying to find basic delight. A wobbly pavement stone or a colorful sunlight reflection on the street can disrupt my everyday life and make me pause or start to play. Such unexpected sensations can be strong and stay, sometimes for years, until they slowly work their way up from the feet to the head – it becomes a process that turns sensations into thoughts unfolding a meaning, which comes to life in a piece of art that reacts to the world that I encounter.*

Prompted by this exhibition, this statement was the first time I publicly reflected on (or admitted) the role of playful exploration in my work and the fact that many of my ideas for interactive artworks can be traced back to distinct lived experiences and bodily sensations. Further, the statement captured a significant moment in *Solar Pink Pong*'s development process as it tried to rationalize its incubation phase, in which ideas are emerging, but are not yet fully formed or understood.

5.8.2 Constellations (Ann Arbor, MI, USA)

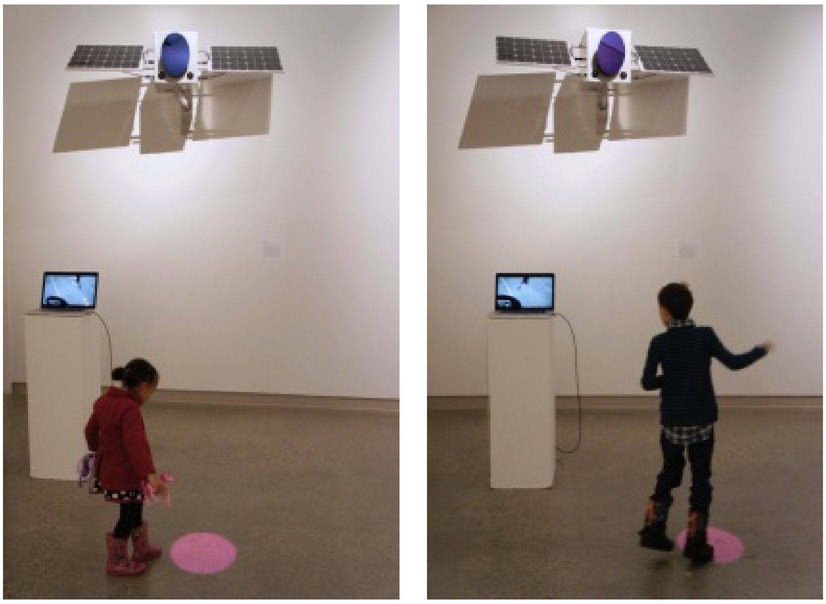

Figure 28: Two views of *Solar Pink Pong*'s exhibition as a static prototype and video documentation in the group exhibition "Constellations", Ann Arbor, MI, USA, 2014.

In January 2014, *Solar Pink Pong*'s functional prototype was first presented as a static object in the group show, Constellations, in another university gallery on campus (see Figure 28). For this show, *Solar Pink Pong* was mounted on the wall. A spotlight on the ceiling was used to mimic the sun and create a static pink spot on the exhibition floor. In addition, a laptop, placed on a pedestal, showed a video of people interacting outdoors with *Solar Pink Pong* installed on a light pole in a parking lot. In the exhibition catalog, the curator Peter Dykhuis, referred to *Solar Pink Pong* as "Machinis Socialus" saying:

> *While many people engaged in technologically driven industries are earnest about the world of functional machines that they create, artists often treat machines as creative playthings and gleefully repurpose cutting edge technologies to "do stuff" that they were never intended for.*
>
> *Peter Dykhuis*

In this exhibition, mostly visited by students, *Solar Pink Pong* worked even as a relatively small object in a large exhibition space. However, during the whole exhibition, I felt conflicted about agreeing to show an interactive installation as a static object. A video documentation showing the project in action on a screen next to the prototype didn't feel appropriate as a substitute for the direct interaction with the installation itself. That being said, one interesting observation was that particularly some of the younger, school-aged, visitors, who watched the video, returned to the pink spot on the exhibition floor and tried to kick it. The installation set up was obviously misleading and misinterpreted as functional by some of the younger visitors with an obvious stronger urge to play.

5.8.3 ISEA2014 (Dubai, UAE)

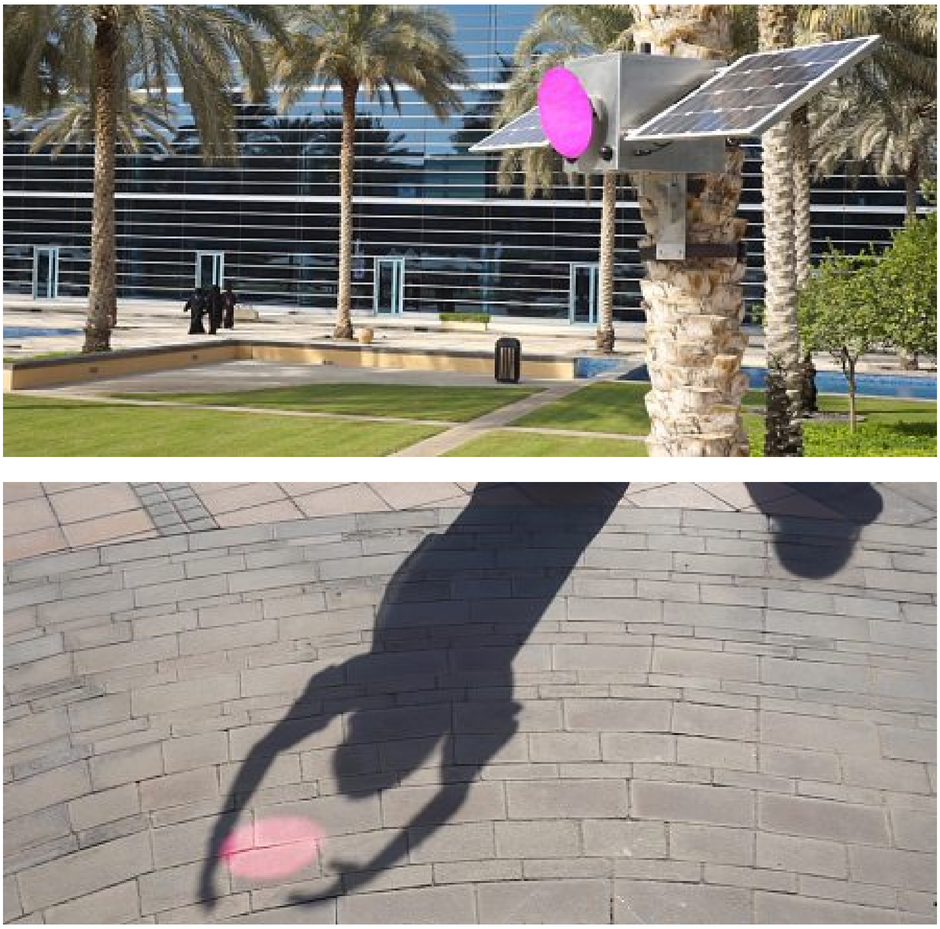

Figure 29: Two views showing first exhibition of *Solar Pink Pong* as an interactive installation at "ISEA2014, the 20th International Symposium on Electronic Art," Dubai, UAE, 2014.

In November 2014, *Solar Pink Pong* was first presented as a functional prototype at "ISEA2014, the 20th International Symposium on Electronic Art," Dubai, UAE (see Figure 29). This venue in the Arabian Desert seemed to be ideal for the premiere of a sun-powered media art installation. The device was designed to operate off the grid anywhere in the city powered by solar panels and connected to the internet via 3G wireless network. However, it became much harder than anticipated to find the right location for it. Preceding the exhibiting was a several months long location scouting with the help of local curators, google street view, and a sun position calculator. More than 15 locations with sidewalk and utility pole or south facing building façades onto which *Solar Pink Pong* could be mounted were reviewed in detail. Hardly any of them provided either the right playfield area, position, or an un-obstructed view to the sun throughout the day – at least not in areas with pedestrian traffic.

To better communicate *Solar Pink Pong*'s technical requirements that were often misunderstood, I created a drawing that illustrated the parameters that, unlike in the case of other interactive projection technologies, constantly change throughout the day (see Figure 30). Despite the development effort to make the set up simple, the ephemeral nature of daylight and the course of the sun, seemed to further complicate the challenges that come with any site-specific set up of interactive art installations in public spaces.

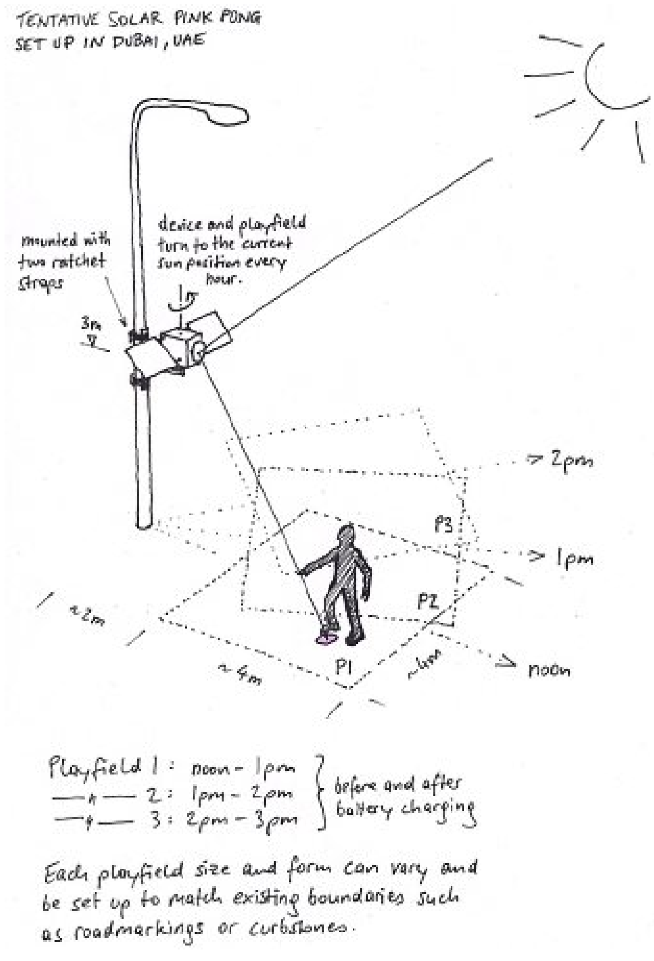

Figure 30: Drawing illustrating *Solar Pink Pong*'s installation requirements for curators and exhibition organizers, 2014.

A week prior to the exhibition, the location was still not clear and it was too late to seek permission for a handful of sites that I identified upon my arrival during further extensive location scouting. At this point, the facility management of Zayed University, where the main symposium took place, suggested to installing *Solar Pink Pong* on one of the palm trees in the main court yard of the university campus. Using a palm tree as a utility pole for this first *Solar Pink Pong* installation, changed the backdrop and reinforced the image of using this installation to connect people to the sun and the outdoor environment. *Solar Pink Pong* was installed further away from public city life than planned, but still accessible to conference goers, university staff and female students (male students, following gender-segregated campus policies, typically arrived later in the evening when the system was already in sleeping mode).

Over the course of several days, I observed dozens of students, staff, other symposium participants interact with the work. I listened to their comments among each other and sometimes engaged in direct conversations. Comments that stood out in Dubai were, for example, "It's like playing with a real ball" (i.e. comments referring to the realism of the interaction) or "This is fun!" or "This is cool!" (i.e. comments expressing basic enjoyment or excitement). One interesting observation was that shadow interactions seemed to be particularly frequent when the sun was lower and the shadow image more dominant. Overall, I didn't observe a clear preference for either shadow or body interactions. I did however, see at later installations accessible to younger kids their preferences or instinct to use their feet to interact with the sunlight reflection on the floor. In addition to direct observations, I video-recorded people's interactions with a smaller, less intrusive DSLM camera. When filming campus students, whose faces could not be video-taped, I recorded mostly shadow interactions on the ground.

At the end of each day, right after sunset when *Solar Pink Pong* set itself in sleeping mode, I reviewed the entire video footage in the university cafeteria nearby. As long as my memories were still fresh, I highlighted video clips and scenes in which I heard comments

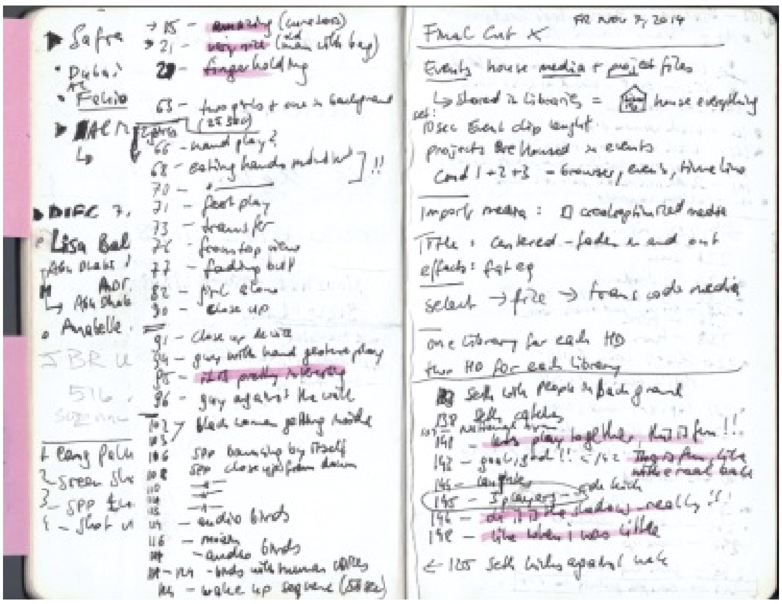

Figure 31: Scan of notebook pages showing examples of highlighted scenes in the video documentation, 2014

or observed interaction behavior that stood out (see Figure 31). My goal was not to analyze data objectively, but simply to identify evocative moments and scenes that struck me because of their composition and narration quality or other potential qualities for a video documentation and presentation of the project. In other words, I used a montage technique, in which the story (i.e., the way *Solar Pink Pong* is presented) emerges mostly based on a subjective interpretation of the material and the selection of what constitutes strong evocative moments or images. This is a technique that I have used and practiced repeatedly for previous art work documentations. It is not much unlike the creative process inherent in developing an artwork such as *Solar Pink Pong* itself that was inspired by evocative moments (i.e., experience of a sunlight reflection) not knowing what it will lead to (i.e., a sun powered street video game). The rationale for the storyline in this process was developing as more strong scenes were tested next to each other in the video editing timeline. The only rule or restriction that I typically follow is to use only original audio and comments from the scene similar to Lars van Trier's Dogme 95 approach.

5.8.4 TEI 2015 (Stanford, CA, USA)

Figure 32: Installation view of *Solar Pink Pong* during "Arts Track at TEI 2015, the 9th International Conference on Tangible, Embedded and Embodied Interaction," Stanford University, Stanford, CA, USA, 2015.

In January 2015, *Solar Pink Pong* was exhibited again as a functional prototype, this time, at the "Arts Track at TEI 2015, the 9th International Conference on Tangible, Embedded and Embodied Interaction," Stanford University, Stanford, CA, USA (see Figure 32). As part of this exhibition, I also submitted a short description of *Solar Pink Pong* which was reviewed by the HCI community and published as an extended abstract in the ACM library.

In Stanford, finding a utility pole for the installation of *Solar Pink Pong* turned out to be a challenging task once again. Several locations were explored together with the exhibition organizers. The final approved location was unexpectedly denied by the facility management a day before the conference opening. As a result, we decided to install *Solar Pink Pong* on the other end of the campus, this time without asking for permission in good faith that it would not be taken down or stolen over the course of a few days or nights.

The site we chose based on observations of sunlight, shadow, pavement, and pedestrian traffic turned out to be one of the most frequented places on campus, the Lane History Corner. This location was a good test ground for *Solar Pink Pong* in an urban environment for which it was initially developed and in which passers-by unfamiliar with the installation could engage with it. The only reference to the exhibition was a small object text on the utility pole that only few passers-by took notice of. As in most art installations that I am working on, passers-by have no means to identify me as *the* artist, which allows me to became a participant observer. I observed hundreds of passers-by, who often spoke aloud about their experience while interacting with *Solar Pink Pong* or who commented on the system's potential as a gaming platform. Two particular interesting (i.e. unexpected) comments can be subsumed as follows: "How do you win?" (i.e. comments expressing a desire to play a competitive game with clear goals); "When will this be on the market?" (i.e. comments addressing expectations of a future commercial deployment). These comments and related technology development expectations also motivated the participation at a customer discovery workshop, which I describe later in the case study.

The most significant feedback I received related to similarities and differences of media art and HCI occurred at the TEI conference itself: An established HCI scholar, who was interested in *Solar Pink Pong*, was questioning the importance of sunlight for the installation. He questioned what difference it would make if people interacted with a motion-controlled artificial spotlight on the floor instead of a sunlight reflection. For me as a media artist and designer, this question first sounded like a provocation. In response, I talked about my intent as an artist and the need for sunlight to be the light source of an interactive media experience and my related motivation to blur the boundaries between daylight as a medium and interactive media. My motivation or intent, however, did not seem to impress or interest the HCI scholar very much, who seemed to genially doubt the importance of sunlight for *Solar Pink Pong*'s gameplay. Nevertheless, the same scholar invited me to submit *Solar Pink Pong* as a work-in progress paper to the next CHI Play conference in London, England.

Encouraged by this invitation from a distinguished HCI scholar, I submitted a short work-in progress paper based on *Solar Pink Pong* to the CHI Play conference only a few months later in June 2016. The reviewer's ratings (1.0 and 1.5), however, were extremely low and the submitted paper was rejected right away. The reviewers basically indicated that while *Solar Pink Pong* is an original idea and art installation, the submitted paper was not a significant enough contribution to the CHI Play community since there was not enough related literature review and no study or evaluation, for example, of the interaction methods involved. In retrospect, I can see that reviewers were basically reiterating the feedback I received from the HCI scholar earlier at TEI. They were not interested in the inherent statement or critique that I made as an artist by developing an unorthodox artifact that aimed to inspire people think about new ways of interaction with each other and the environment. They were mostly interested in a study evaluating concrete interaction behaviors enabled by the proposed system. At the time, however, the different emphasis between inspiring new perspectives (e.g., through an artifact's evocative power) and validating a new interaction method was not obvious to me in this context. In fact, I didn't fully understand why an original artifact and interaction idea doesn't also count as an academic contribution in the field of HCI, at least to an extent that warrants a publication. As a result, I felt *Solar Pink Pong* was rejected without fully understanding why. It was not until years later when I got more familiar with the field of HCI and successfully submitted my first CHI and CHI play paper as a lead author (described at the end of this case study) that I better understood that the evocative quality of an artifact as such plays a relatively minor role for most HCI scholars compared to, for example, a concrete interaction modality that can be enabled by it and evaluated in a user study.

5.8.5 FILE (São Paulo, Brazil)

Figure 33: Installation view of *Solar Pink Pong*'s interactive installation at "FILE 2015 – Festival Internacional de Linguagem Eletrônica," Avenida Paulista, São Paulo, Brazil, 2015

In June 2015, *Solar Pink Pong* was exhibited at the "FILE 2015 – Electronic Language International Festival" in Sao Paulo, Brazil. At the curator's request, *Solar Pink Pong* was mounted on the façade at the entrance of the Centro Cultrual Fiesp building in which the exhibition took place facing the exit of a subway station on Paulista Avenue (see Figure 33). Due to the many skyscrapers at this location, direct sunlight was only available at particular times during the day – not enough to fully recharge the batteries during the day and keep the device in standby mode overnight. As a result, *Solar Pink Pong* had to be connected to the power grid and the playtime was reduced to only a few hours during the day. A full day of sunlight and street observations were necessary to determine possible playfield positions during the day according to sunlight direction, pavement textures, pedestrian flows, and the position of street vendors and street artists. Despite all efforts to set the installation up within these constraints, the high pedestrian traffic at this location made the pink sunlight reflection on the pavement hardly noticeable for most passers-by, with the exception of mostly young kids, who in general tend to be more aware to changes at the ground level. Compared to previous exhibitions, there were only few moments were the pedestrian traffic cleared up enough for people, mostly exhibition visitors, to consciously interact with the installation. For most of the time, the pink spot moved seemingly randomly back and forth between passers-by. However, it was very interesting to look at this movement pattern from the computer vision perspective above. From this perspective, it looked like the device was scanning the scene and either playing with the negative spaces between passers-by or their shadows (see Figure 34).

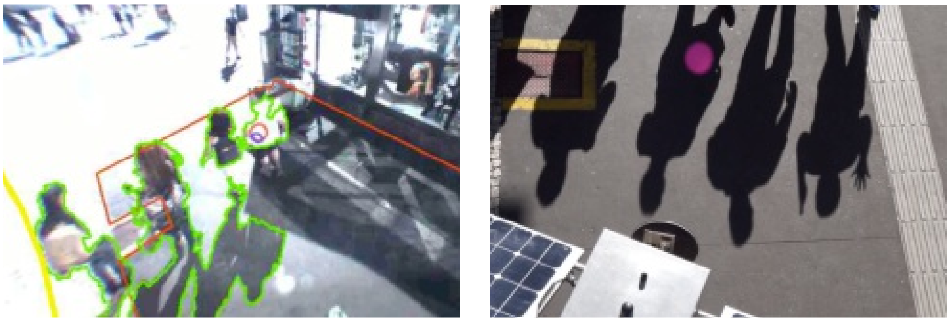

Figure 34: Computer vision camera perspective (left) and view from above (right) showing *Solar Pink Pong* interacting with passers-by without them taking notice, 2015

This occurrence was conceptually interesting, because it gave the impression that the algorithm which was designed to facilitate human gameplay took over and started to autonomously play with passers-by without them taking notice. The seemingly subversion of *Solar Pink Pong*'s algorithm taking control of participants has no direct significance for the consequent research trajectory described in this thesis. However, it is a good example of the type of personal observations or "aha" experiences that register and might later become inspiration for other media art projects.

5.8.6 Japan Media Arts Festival (Tokyo, Japan)

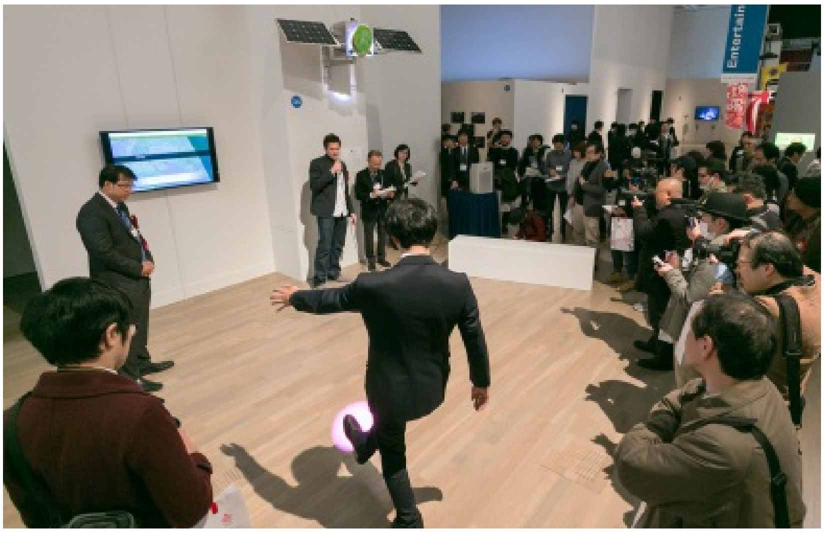

Figure 35: Installation view of *Solar Pink Pong* at "19th Japan Media Arts Festival – Exhibition of Award-Winning Works," The National Art Center, Tokyo, Japan, 2016

In February 2016, *Solar Pink Pong* received a major international award (Excellence Award in the Entertainment Division) and was exhibited at the 19th Japan Media Arts Festival at The National Art Center, Tokyo (see Figure 35).

An outdoor exhibition would not have been very feasible in Tokyo due to limited sunlight hours around this time of the year, therefore, I agreed to the curators request to show *Solar Pink Pong* indoors next to the other award-winning works. To allow visitors to experience *Solar Pink Pong* as an interactive installation, two powerful stage lights were mounted on the ceiling to simulate the sunlight required to operate the installation. One stage light had an extremely narrow beam angle and focused directly on the computer-controlled mirror to create a pink reflection on the exhibition floor for visitors to interact with. The other stage light had a wider beam angle and was casting peoples' shadows on the floor so they could also use their shadows to interact with the pink spotlight. To see how the installation operated off the grid in outdoor environments, a documentation video of *Solar Pink Pong* was shown on a TV-screen on the wall next to the installation.

This exhibition and award marked, for several reasons, a significant milestone at the end of *Solar Pink Pong*'s arts-based research trajectory: first, the award was an international acknowledgement of *Solar Pink Pong*'s significance for the media art community. It was an external evaluation of the originality of the artistic concept (only 3 out of 700 entries were selected in this award division) and the ludic experience provided by the installation. The jury statement described it as follows:

> *Many of us have childhood memories of reflecting sunlight with a handheld mirror, sometimes shining the cheeks of the other with light. This work is the technological offspring of these memories. There are three types of interaction: Human to mechanism, human to nature, and human to human. The project also provokes unexpected interactions between pedestrians in various settings. It is a physical device, independent of video projection, that is versatile in design, and that can be carried and mounted anywhere. An autonomous system that requires only sunlight. The instructionfree friendliness allows the light to approach the player. These qualities are combined into a gaming device that is simple yet eye-opening. Physical and real-life characteristics like the sunlight and shadow, human gestures, variable settings, and others, separate this project from a game contained inside computer graphics. No two settings are ever the same, making the game even more enjoyable.*
>
> *Ichiro Higashiizumi*

Second, the curators placed *Solar Pink Pong* facing a showcase of historic Nintendo game consoles ranging from 1977-91 (e.g., The Color TV-Game 6, Famicom, and Nintendo Entertainment System) developed by Masayuki Uemura, Nintendo's lead designer and hardware developer during that time (Uemura received a lifetime achievement award at the festival). *Solar Pink Pong*'s placement vis-à-vis Nintendo game consoles seemed to leverage my initial intent as an artist to comment on mainstream video game and entertainment cultures and plant alternative interface ideas for future generations (see Figure 36). Further, the placement probably also influenced the perception of game designers, who were asking, more so than during previous exhibitions, about commercialization plans for this interface idea. In addition, *Solar Pink Pong* was featured

Figure 36: View showing the display of historic Nintendo game consoles, e.g. The Color TV-Game 6 (1977), Famicom (1983), Nintendo Entertainment System (1985/91), in the same exhibition section as *Solar Pink Pong* at The National Art Center, Tokyo, 2016.

on national Japanese television (see Figure 37) and I received first inquiries for permanent installations of the project. All these factors indicate that the project was perceived as emerging technology as much as speculative design. This perception of *Solar Pink Pong* as emerging technology was probably also influenced by cultural factors in Japan that is known for early adoption of technology. It encouraged to think about a further development of *Solar Pink Pong* beyond an interactive art installation.

Figure 37: Screen capture showing *Solar Pink Pong* featured in a two-minute segment on NTV (Nippon Television Network), NEWS ZERO CULTURE, 2016.

Third, as a consequence of *Solar Pink Pong*'s indoor set up, I could for the first time evaluate the quality of the body and shadow interactions largely in isolation from its original artistic concept and the surprise factor of a pink projection in bright daylight. I was surprised to see that visitors, especially young children, enjoyed interacting with the installation not much less than in previous outdoor installations. This indicated that *Solar Pink Pong*'s minimalistic interaction modality has a quality that can, at least partly, transcend to an indoor setup even if it is staged with artificial spotlights simulating the sun. That being said, to make the indoor installation more engaging, we decided to augment the gameplay with acoustic feedback (i.e., a "pong" sound) every time visitors hit the pink spot on the floor with their shadows or feet, which we hadn't done in previous installations. However, the relative success of this indoor installation, inspired thinking about developing similar minimalistic augmented reality games systems for indoor spaces using conventional projection technology such as video beamers.

5.8.7 update_6 / NTAA 2016 (Ghent, Brussels, Belgium)

Figure 38: Two installation views showing *Solar Pink Pong* at the opening event for the "New Technological Art Award 2016" and "update_6 / NTAA 2016" exhibition, Zebrastraat Ghent, Brussels, Belgium, 2016.

In October 2016, *Solar Pink Pong* was nominated for the "New Technological Art Award 2016" and exhibited together with other nominated art works (20 out of 478 entries) at "update_6 / NTAA 2016" at the Zebrastraat in Ghent, Belgium (see Figure 38). As in Tokyo, the sun conditions in Ghent were not in favor of an outdoor installation at the time of the exhibition. After reviewing several indoor locations suggested by the exhibition organizers ranging from an underground parking garage to the interior of a historic building, we decided to install *Solar Pink Pong* in a large, semi-permanent tent structure covering the main courtyard of the Zebrastraat building complex. The tent was tall enough to enable a similar set up like in the National Art Center in Tokyo; two stage lights were mounted high above the ground simulating sunlight for the human shadow play and operation of the system.

This was the last in a series of art exhibitions of *Solar Pink Pong* – at least for the time being. It occurred after the turning point from arts-based research to HCI-based research described in the next two sections below. The main driver for participating at yet another indoor exhibition was to further promote *Solar Pink Pong* in the media art & technology community. At this stage, no groundbreaking new insights were expected from the exhibition in Ghent. That being said, the exhibition demonstrated once more the feasibility of an indoor installation of *Solar Pink Pong* from a technical and interaction perspective. Conceptually, however, the installation in a circus-like tent was a far stretch from its original concept. At one point, the installation was even operating at night during an opening event with live music and hundreds of visitors gathering inside the tent. At this point, next to other stage lights installed for the show, *Solar Pink Pong* resembled more a robotic stage light than an interactive art work. Its motion tracking algorithm, overwhelmed by the close gathering of people, responded only occasionally mostly to children, who noticed and chased the pink spotlight on the ground.

5.9 Customer Discovery Workshop

The participation at a customer discovery workshop was initially not a planned or anticipated part of *Solar Pink Pong*'s *research through art and design* process. In the above described exhibitions, *Solar Pink Pong* was presented as an art installation and not a product development. As with most of my previous interactive installations, my main objective was to learn from it by observing the public interact with the work, listen to their conversations, and to contribute to the wider art & technology discourse through international exhibitions and related publications. However, *Solar Pink Pong's* repeated perception as a product idea that could be commercialized, particularly in Stanford and Tokyo, prompted me to take *Solar Pink Pong's* research and development process in a new direction.

To explore *Solar Pink Pong*'s commercial value proposition, I applied for a six-week long customer discovery program that one of my *Daylight Media Lab* contacts and colleagues in material science suggested. This program was a local version of the national I-Corps program that was co-developed by Steve Blank, an entrepreneur and Stanford University professor, for the National Science Foundation (NSF). The program was based on the business model canvas and the Lean LaunchPad method (Blank, 2011). Its goal was to teach scientists lean startup methods to help turn their discoveries into profitable, job-producing businesses. In other words, one of the original motivations behind this program was to increase the return on investment for federal research funding. The program was typically reserved for scientists, who had already received an NSF grant. In my case, the University of Michigan Center for Entrepreneurship reviewed *Solar Pink Pong* and agreed to make an exception and sponsor the participation at this program with an interactive installation that was mostly exhibited in an art context before. At the core of this customer discovery program were two elements: first, in-person interviews with different stakeholders in a customer segment related to the business or product idea. The goal of the interviews was to get early and candid feedback on its perceived value proposition and "product-market fit" and to better understand the ecosystem around it (see Figure 39); second, weekly presentations of the related interview findings and insights in-front of a group of entrepreneurs and business coaches, who gave direct and relentless feedback in a similar fashion as in the entrepreneurial-themed reality show Shark Tank.

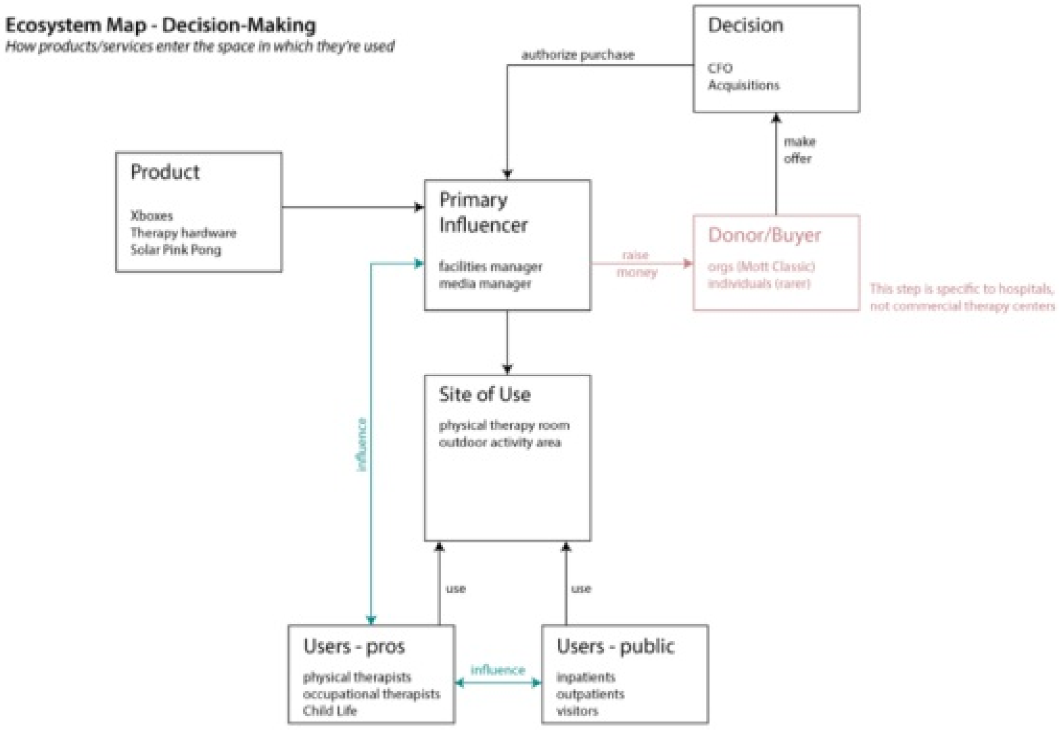

Figure 39: Diagram showing a tentative ecosystem & decision-making map related to *Solar Pink Pong*'s potential value proposition for physical or occupational therapy environments, 2015.

Unlike in academic research, there were no strict protocols to follow for the interviews. The main rule was the interviews had to be in-person. Phone interviews or even interviews using video calls didn't fully qualify as an interview in this context. Special emphasis was put on observing the body language of the interviewees as a means to better interpret their level of excitement, for example, by watching pupils dilate in response to a presented value proposition. To conduct as many in-person interviews as possible, which was one of the key indicators for success in this program, we were encouraged to approach interviewees out of the blue if necessary (e.g., by walking into a building without an appointment). Risk taking and improvisation to get to the right place and people quickly was seen as important part of an entrepreneurial toolkit. That being said, it also felt like a stress test for researchers to see if they are genuinely interested in entrepreneurial activities and etiquettes that define startup cultures outside academia.

To participate in this intensive, six-week long program, I teamed up with Seth Ellis, an artist and designer colleague, who agreed to play the role of the Entrepreneurial Lead (EL). The EL was responsible for reporting to the business coaches and supporting my role as the Principal Investigator (PI) in conducting interviews and exploring value propositions most objectively and detached from my potential pre-conceptions as the inventor. Both of us had never participated in such a program. Further, we were the only artists and designers participating in this program.

We began the program by investigating a number of potential customer segments based my recollection of common threads in the feedback and observed reactions from hundreds of people interacting with *Solar Pink Pong* at many different locations. Discussing my takeaway from this feedback with the Entrepreneurial Lead pointed the way towards values in entertainment and marketing, health care and well-being, as well as education. Following this direction, some of the related initial key insights from first interviews with marketing, retail, hospital, and museum professionals were:

- We overestimated the amount of money facilities such as hospitals, shopping malls, or museums spend themselves on play or entertainment infrastructure. Most of those offerings are financed by outside entities such as advertisers, cooperate sponsors, or donors.
- This might affect the scalability of *Solar Pink Pong* as a product. Many entities that are interested or have the place to install such a system won't automatically expect to have to pay for it.
- Demos, user testing, and physical evidence of the systems effectiveness are important to convince stakeholders.

After this initial investigation, we were quickly advised to pick a single segment to focus on, in order to get the most out of the program. As a result, we made the deliberate decision to focus on health care, in particular physical and occupational therapy. We didn't expect this segment to be more lucrative than others (e.g., interactive toy for cats, which would have been my best bet in terms of a profitable business idea), but we found the potential value proposition in this area most interesting and related to our core values as socially engaged artists and designers.

For the rest of the program, we focused on interviewing different stakeholders throughout the segment of health care, including patients, therapists, facility managers, researchers, and administrators. We conducted a total of 21 casual interviews. Related key insights in this health care segment were:

- Therapists, patients, and researchers all stressed the importance of mental stimulation both during and outside of therapy. Patients often get bored and depressed, which makes them less active and decreases the effectiveness of physical therapy.
- There are already some interactive game and therapy systems, mostly screen-based platforms such as Kinect or Nintendo Wii. However, they are often unused, because not all therapists are tech-savvy enough to set them up. Further, in recreational contexts, they are often perceived as not socially engaging activities.
- Most tech-based and recreational therapy isn't billable; some therapists would like it, but the insurance provider would currently not pay for it particularly if it was part of a social group activity. Tying it to individual improvement metrics, would make justifying them easier.

Based on these 21 interviews, we concluded the program by tentatively identifying a general need for non-directed physical movement, social engagement, and mental stimulation in physical and occupational therapy. In response to our final presentation, one of our business coaches framed our key value proposition as "making therapy more fun." Further, we could clearly see enthusiasm in mid and high-level decision-makers as we had received multiple offers for *Solar Pink Pong* pilot installations in the course of our interviews. However, we could not find enough evidence for a lucrative market or identify a strategy that would solve the scalability or billability for such a system, at least not in the current insurance and market situation. Our business coaches referred to this situation also as the "iPhone before the internet" stage.

The main customer discovery takeaway, however, was not directly part of this preliminary conclusion. It happened when a physical therapist that we contacted during the interview process invited us to observe a therapy session with one of her patients, who was interested to learn about the *Solar Pink Pong* project. When I arrived, I met an eleven-year-old boy, who participated in a therapy session using a power wheelchair that enabled him to move with great speed and precision despite being diagnosed with Cerebral palsy which affected his motor skills. In the consequent exchange with him and his mother, I learned that he is a great sport enthusiast and would be very interested to play an interactive game like *Solar Pink Pong*. In fact, the therapist suggested to install *Solar Pink Pong* in front of the pediatric rehabilitation facility. This feedback was both exciting and inconvenient at the same time, because I doubted that *Solar Pink Pong* in its current form, relying largely on human shadow play, would be very fun or accessible for players using power wheelchairs. This realization turned out to be the single most important takeaway of the customer discovery program. It was not on my radar when I started the program, but inspired the re-evaluation and shift of *Solar Pink Pong*'s research trajectory towards the design space of inclusive play and exercise.

5.10 Re-evaluation of Solar Pink Pong for Inclusive Play (iGYM)

Figure 40: View showing *iGYM*, an augmented reality system that was the outcome of *Solar Pink Pong*'s re-evaluation of for inclusive play; two children competing on *iGYM*'s interactive floor.

Motivated by the takeaway from the customer discovery workshop, I decided to shift *Solar Pink Pong's* research and development trajectory from focusing on "daylight media" towards inclusive play and exercise. This shift from prototyping future outdoor media experiences to enabling new play and exercise opportunities also marked the begin of my HCI-based research and learning process. As a media artist and designer, it helped me better understand the intersection of interactive art and interaction design from the other side – the perspective of an HCI researcher. As a result of this shift, *Solar Pink Pong*'s research trajectory culminated in the development of *iGYM*, an inclusive play and exercise system (see Figure 40) as well as related studies that are described more in detail in Appendix E.

To re-evaluate *Solar Pink Pong* for inclusive play and exercise, I started a new research collaboration with two faculty colleagues and one graduate student, who were interested to work on this project idea: Sun Young Park, a design researcher with a background in HCI and health informatics; Hun Seok Kim, an electrical engineer and expert in computer vision and machine learning; and Priyanka Raju, a master of design student in integrated design, who was supporting this project collaboration as a research assistant when it started.

Key for *Solar Pink Pong*'s re-evaluation and the consequent design of an inclusive play system were three design considerations that were informed by lessons learned from my previous development efforts and interviews in the customer discovery program:

First, to build an inclusive play system, we decided to use a conventional ceiling mounted indoor video projection system. The main objectives behind this consideration were practical concerns such as being unrestricted to sunlight or weather conditions and to focus on the system's: (1) affordability and robustness, (2) ease of implementation and potential for scalability, (3) versatility and flexibility of computer software-based system implementation, (4) high display speed and accuracy, and (5) good visibility in the typical light levels of exercise environments.

Second, to adapt *Solar Pink Pong*'s whole-body and shadow silhouette interaction for an indoor space using a conventional video projection technology, we developed a new interaction concept that we initially referred to as "virtual shadow" – a circle projected around each player's body that enters the playing field. This circle was inspired by *Solar Pink Pong*'s shadow interactions and a related laser circle interaction concept for play with a robotic disc that I had developed earlier. This circle dynamically adapted to the player's body movement and could be used to manipulate a simulated target on the floor in a similar intuitive fashion as players engaging with *Solar Pink Pong* using their bodies or shadows.

Third, to keep players engaged over longer periods of time for increased physical activity, we turned *Solar Pink Pong*'s potential for ludic engagement into a competitive game with clear goals (building on feedback of people, who interacted with *Solar Pink Pong* and expressed an interest to compete). We designed a hybrid of a soccer and air hockey game (i.e., air-soccer) by merging the game mechanics of air hockey with soccer. The resulting game play seemed particularly promising, because our "virtual shadow" circle feature shared some similarities with the input modalities of the pushers used in air hockey. Hence, due to this input similarity we could use the same game mechanic with little adaptations. Further, soccer characterized best the ambition to increase the scale and social play setting for the game environment.

Based on these three design considerations, we started to develop a new interactive floor projection system that we titled *iGYM* – "i" for inclusive play and exercise. The system was designed to enable people with mobility disabilities to compete on par with, and in the same physical environment as, their peers without disabilities. The system's design and development process from low-fidelity (i.e., single projector, improvised playfield with butcher paper) to high fidelity (i.e., two high lumen projectors, large playfield with non-slip vinyl flooring) prototypes (see Figure 41) was highly iterative similar to *Solar Pink Pong's* development. It was informed by constant usability and play testing, first by our research team members, and then by children ranging from 4-12 years old including my own children. In this case, however, the development was particularly focused on interaction modalities and accessibility concerns. The development process built on further observations and conversations with an occupational therapist who specialized in technology-based rehabilitation and introduced us to different configurations and input modalities (i.e., switches) commonly used in this context.

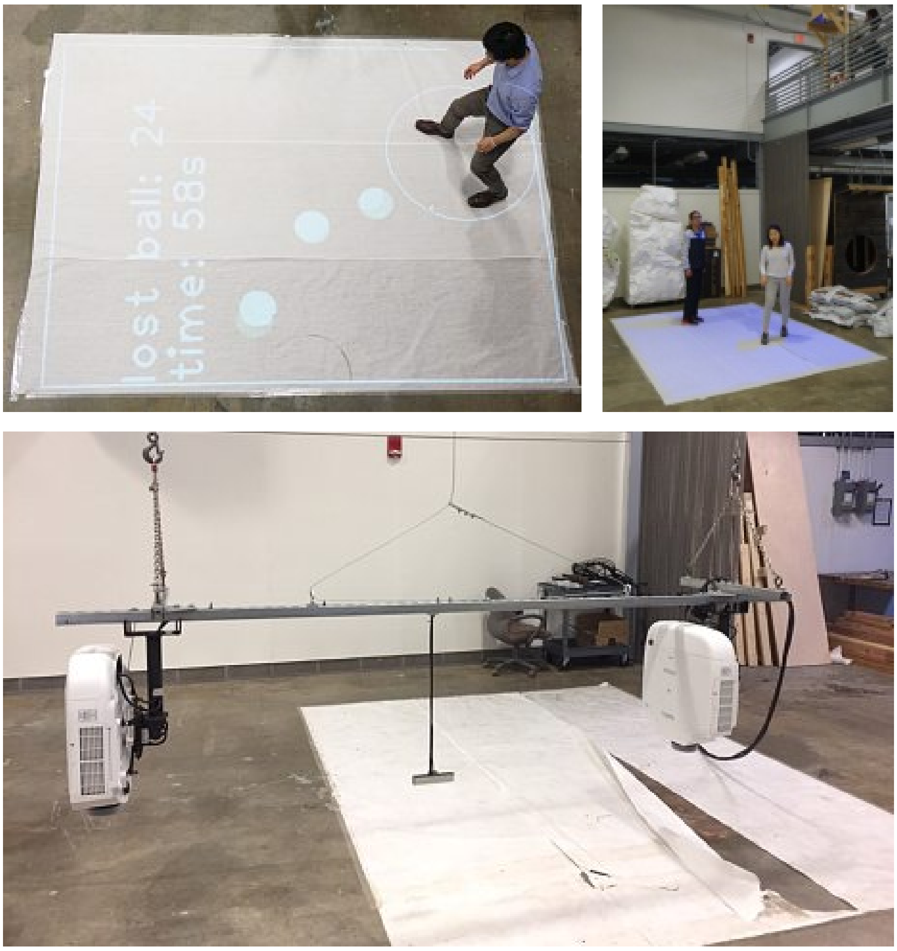

Figure 41: Views showing first single projector test field (top) and adjustable rig for expanded playfield with two high lumen projectors and computer vision camera (bottom), 2017.

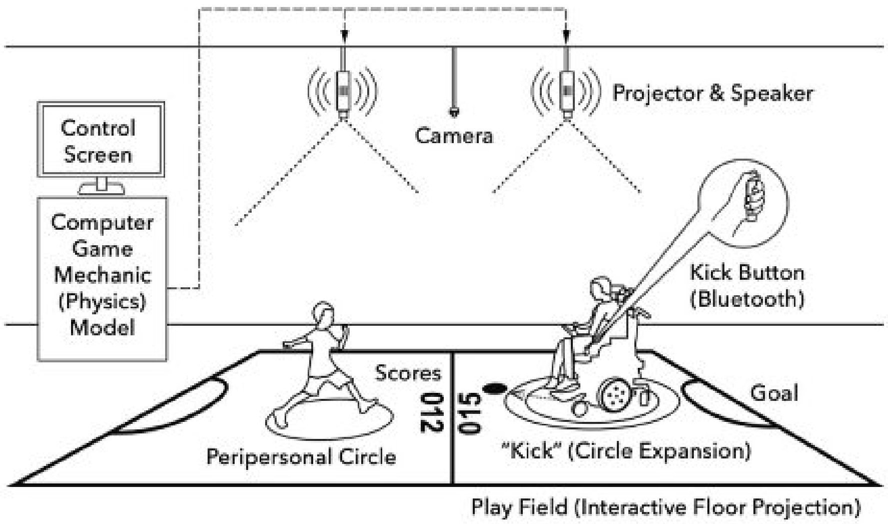

Figure 42: Illustration showing *iGYM*'s concept and spatial configuration. Players' peripersonal circles can be expanded to "kick" a target on the interactive floor via limb movement or kick button activation.

The resulting *iGYM* system included two design features: (1) the above described "virtual shadow" circle projected on the floor with which players could manipulate a virtual target on the floor by body movement, limb extension or pressing a kick button to simulate limb extension; (2) adaptable game mechanics using physics simulation to create a realistic ball game environment, which allows balancing players' individual differences in response time or mobility by controlling game mechanics such as the circle size and puck speed and customizing them for each player (see Figure 42).

Our initial play test sessions among our research team members and some of our children clearly indicated that the *iGYM* system was engaging and fun. In other words, we felt we were onto something interesting. However, we initially had difficulties articulating "what" our actual contribution was from a system design perspective. Further, we had difficulties moving forward with our research and outlining an appropriate study design for players with different abilities for the institutional review board (which had to approve our study plans), since our research team lacked domain expertise in accessible game technologies.

As a result, I took a stab at an extensive literature review. This review included, among others, the domains of adaptive sports, exergames or active video games, interactive floors, and game accessibility. Regarding our study design, I could relatively quickly identify a need related to non-screen based, recreational exergames that enable particularly young people with different mobility abilities to play and exercise with each other; there was clearly a research gap in the related literature and a need for further studies. Regarding our system design contribution, it took much longer and required persistent questions of our research assistant asking for clarification, until we could fully identify and conceptualize our key contribution. In an effort to articulate what the "virtual shadow" is and why it was working so intuitively and similar to *Solar Pink Pong*'s shadow play, I came across studies related to the concept of body schema and peripersonal space. This was another "aha" moment, in which I realized that our circle interaction feature did not just mimic a virtual shadow object, it did in fact visualize the players' peripersonal space boundaries (i.e., the space immediately surrounding the body) on the floor. Further, and key for the better understanding of the two input modalities of our circle interaction feature (i.e. extending limbs and pressing a push button) were studies describing how these peripersonal space boundaries can be modulated both by extending limbs or using tools such as a cane or tennis racket (Biggio et al., 2017). From this point on, we referred to the circle feature as "peripersonal circle." We were finally able to articulate and better explain the key element in our system design. In retrospect, it seems counterintuitive that the *Solar Pink Pong* inspired circle interaction feature that we developed relatively quickly was not fully recognized as a key system design contribution earlier. In fact, I initially found this feature to be very trivial, which may explain why it was initially overlooked as worthy of a contribution.

This seemingly simple articulation of the research gap and our system design contribution was a major breakthrough in the HCI-based research process. It laid the foundation for: (1) a successful application for a major pilot grant from the U-M Exercise & Sport Science Initiative (ESSI); (2) another patent application, this time, related to peripersonal boundary based augmented reality game environments (see Appendix E); and (3) studies and publications first at CHI 2019 as work-in progress paper and then at CHI Play 2019 as a full paper (see Appendix D) – both are highly respected HCI conferences. In addition, and most relevant for my goal to further articulate *Ludic Engineering* as a practice at the intersection of interactive art and interaction design, I was not studying the fringes of HCI from the outside anymore (i.e., from the perspective of interactive art). Instead, I was suddenly involved in HCI research myself.

These three outcomes mark the end of the *Solar Pink Pong* case study. As our research team grew further, I switched my role from the principal investigator and lead system designer to the role of the "study designer" and lead author of the two papers mentioned above – a role that was beyond the scope of my dissertation when I initially outlined it. As a result, I gained a much better understanding of research methods used for the successful articulation of a knowledge contribution in the field of HCI. For example, as my effort to articulate the peripersonal circle interaction shows, I gained a better understanding of bridging, epistemologically, differences between the tacit knowledge contribution of a practitioner (e.g., the ability to design novel interfaces) and the propositional knowledge contribution of a scholar (e.g., the ability to validate new knowledge generated through it). Further, by designing and conducting several studies with a large interdisciplinary research team, I learned through experience and peer review feedback (e.g., rejection of two paper submissions) the relevance of clear study procedures and methods related to data collection and analysis. I also became aware of the time and effort needed for planning and preparing a study and related publication, which is not much unlike the effort needed to get work ready for an exhibition. Finally, having gone through this study and publication process, I learned that in the context of HCI research evaluating *interaction* or *interactivity* plays a similar role as in media art providing *evocative* or *provocative* experiences in the same form. I finally better understood why simply commenting on future design spaces with *Solar Pink Pong* as an artifact – as novel and evocative as it may be for an art audience for example – was of lesser interest for the HCI researchers, who I discussed *Solar Pink Pong* with earlier. Further reflections on this interactive art and HCI intersection and the main outcomes of *Solar Pink Pong*'s research trajectory are discussed through the lens of *Ludic Engineering* in chapter 6.

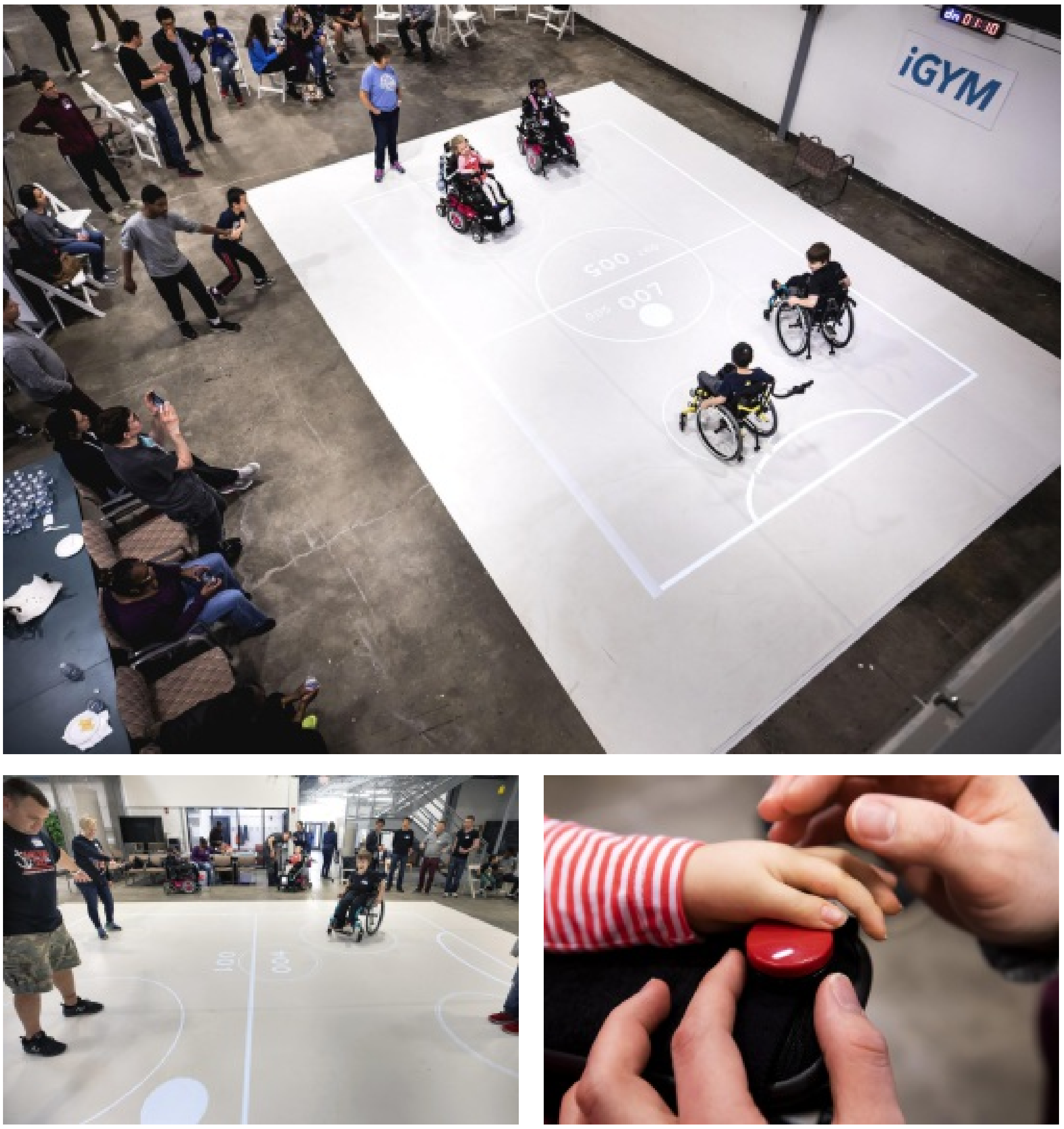

Figure 43: Three views showing the *iGYM* Play Day event, which was organized for families and children after the formal studies were completed: interactive court with four children competing against each other (top), parents playing with children (left), and close-up of the kick-button for players using wheelchairs (right), 2019. Photo: Joseph Xu/Michigan Engineering.

6 Results and Summative Reflections

This chapter presents the summative reflection and key insights into the Solar Pink Pong *case study through the lens of the literature reviewed for* Ludic Engineering *in chapter 2. The reflection is organized in three sections based on the most tangible results and best documented contributions of the research though art and design process (i.e., interactive exhibitions, utility patents, inclusive play studies). It is a response to the research question (RQ3) that aimed to explore the "serious" roles that* Ludic Engineering *can play in the innovation process of technologies for the lived body. In conclusion, this chapter also presents a speculative* Ludic Innovation Framework *based on a reflection on the case study's underlying creative process. This framework draws an analogy between playfulness concerns in childhood and technology development in response to the research question (RQ2) that aimed to further conceptualize* Ludic Engineering.

6.1 Interactive Exhibitions: Experience Contribution

Provoking novel interactive experiences and making them accessible to the public and experts in different domains in form of exhibitions or demonstrations was the primary outcome of the *Solar Pink Pong* case study. As such, I articulate this outcome as an *"experience contribution"* through the lens of the reviewed literature for *Ludic Engineering* that brings together Dewey's (1934/2005) *Art as Experience* and McCarthy and Wright's (2004) *Technology as Experience* (see Section 2.2). *Experience contribution* in this dissertation refers specifically to the exhibitions of *Solar Pink Pong* as an art installation at seven different venues ranging from art gallery and museum spaces to academic conferences and public spaces in the USA, UAE, Brazil, Japan, and Belgium. In five of those venues, *Solar Pink Pong* was exhibited as an interactive system including three times outdoors operating in sunlight. These exhibitions then inspired the development of *iGYM,* a game environment, which was also made accessible (outside of user studies) though to a much smaller local audience during several ad-hoc play sessions and one public play day event. Providing interactive experiences in this form clearly marked the beginning and end of this case study and is overall the most substantial and best documented contribution of the dissertation. Although the experiences provoked by the "expressiveness" (Dewey, 1934/2005, p. 90) of *Solar Pink Pong* and *iGYM* cannot be duplicated with words, they have been described and documented in various forms including, among others, exhibition catalogues, academic papers, websites, local and national news media, and video documentations (see e.g., www.solarpinkpong.com; www.igym.solutions).

This *experience contribution*, as the *Solar Pink Pong* case study shows in summative reflection, built first of all on my prior experience as an artist and designer, particularly the body of work and value-based foundation of my artist collective *Assocreation*. "Prior experience" has to be emphasized, because it seems unlikely that a creative process inspired by a sunlight reflection would otherwise have led to all three of those: (1) a fluorescent pink color reflection without *Assocreation's Pink Prints* series particularly the *Shoe Diploma,* my collaborative master's thesis; (2) an art installation that uses the street as a surface of playful interaction; and eventually (3) an inclusive game environment without prior accessibility concerns explored as part of *Assocreation's* ludic communication platforms *Bump* and *Common Ground* that also reframed the body and interactivity in the built environment. These are just three examples, but they illustrate well Dewey's (1934/2005) concept of "creative production" as the "remaking" of past experiences in the process of expressing new ideas – or enabling new experiences in this case. Second, the case study shows the extent with which designing novel interactive experiences for the lived body built on "thinking through the body" (Shusterman, 2012). This aspect was particularly evident by *Solar Pink Pong*'s first and most critical "proof of concept" in which my body became part of the prototype system by mimicking a computer-controlled mirror with my hand; prototyping the experience of an animated sunlight reflection in this form can literally, as well as in the context of studies on playfulness and creativity (see e.g., Russ & Doernberg, 2019), be characterized as a "pretend-play" or "make-belief play" – only in this case it happened between both an adult and child playing together (see Section 5.5). This example illustrates the potential of playfulness that can be activated by directly engaging the imagination of a two-year-old child (i.e., my daughter) while simultaneously manipulating and interacting with the resulting half real, half imagined situation. In many similar parts of the development process throughout the case study, creativity was often a form of "situated creativity" (McCarthy & Wright, 2004) or "kinesthetic creativity" (Svanæs, 2013). Overall, the lived body clearly was both means and end for this *experience contribution* in the case study.

The modes of evaluating *Solar Pink Pong*'s *experience contribution*, however, have differed drastically throughout the case study depending on whether the experiences were considered for an art exhibition, utility patent, or user study. Among those three, the format of an art exhibition had clear advantages for evaluating the fuller scope and multifaceted nature of this contribution. In fact, in this context evaluation was mostly criticism and sometimes specifically "interaction criticism" (Bardzell, 2009) both from – in a Deweyan sense – a producer (i.e., curator, jury member, artist, etc.) and consumer (i.e., visitor, passerby, etc.) perspective or a combination of both (e.g., if a jury member engaged with *Solar Pink Pong* in person as opposed to only watching a video documentation of it). This criticism can be illustrated, for example, by short comments made by passers-by that ranged from "it's like playing with a real ball" or "my cat would like this" to more detailed jury statements that referred to *Solar Pink Pong* as "a technological offspring of childhood memories" (i.e., referring to reflecting sunlight by playing with a handheld mirror) that provokes a three-fold interaction (i.e., human to machine, human to nature, human to human). As such, the provided criticism was, at least in its rudimentary form, always a judgement in a Deweyan sense. For Dewey (1934/2005) such judgement grows out of the object "as it enters the experience of the critic by interacting with his own sensitivity and his knowledge and funded store from past experiences" (p. 322). The advantage of this form of criticism was that it allowed both expert and passerby to judge "the pattern and structure" (p. 45) of the provoked experience according to their own criteria, which emerged ad-hoc or were somewhat defined (e.g., among jury members). Hence this format didn't build on a standardized process. However, it provided a rich account of different perspectives that expanded and complemented my own inner experience as well as my direct observations without probing participants with explicit questions.

The relative trivial, but often overlooked insight in this respect is that from a producer (i.e., artist, practitioner) perspective such criticism of an art installation is almost never random. Instead, it is a response to the "expressiveness" (p. 90) of the installation, which was deliberately designed and set up in a site-specific manner to engage the consumer (i.e., visitor, passer-by) in a "conversation" with a specific situation. In the case of *Solar Pink Pong*, I often spent like many artists more time preparing or analyzing the situation itself (i.e., location scouting, sunlight and pedestrian traffic observations, etc.), which includes both the social and spatial context, than the actual exhibition lasted. In other words, every comment or observed reaction during the exhibition was a response to "questions" implied by the structure of the situation; as such every exhibition was a critical learning opportunity for the construction of future situations. A similar sensibility and care for the situation as the background needed for the pattern and structure of a specific experience to unfold went later also in the development of *iGYM*. In this case, little adjustments (i.e., signage, timer, playfield orientation, etc.) set the stage (i.e., shaped the social and spatial ambience) for the experience and interaction modalities that were then studied.

This care for the whole situation is not unrelated to the sensibility to study an artifact in relation to its ground that the McLuhan's (1988, p. 9) referred to in their framework when they highlighted the respective training and awareness of artists; this awareness is also springboard for common phenomenological differences between, for example, an interactive installation at an art exhibition and an interactive demonstration at an HCI conference: the first typically focuses on provoking an experience in a particular context providing and preparing space for individual contemplation; the second focuses on demonstrating an experience or interaction modality often in isolated form similar to a funfair with less room for individual reflection. These phenomenological differences are certainly not always as clear as described (i.e., interactive demos can also be set up in similar fashion as art installations and vice versa). However, they are almost always driven by different motivations following Dewey's epistemological observation that "[s]cience states meanings; art expresses them" (p. 87), which applies particularity to the intersection of interactive art and interaction design that I discussed.

To conclude, as an artist and designer I was best equipped to operate in the dimension of the experience. It was in an art practice context where I found the most suitable evaluation tools (e.g., critiques) and publication formats (e.g., exhibitions) to provoke new experiences and learn from them most directly. The "serious" role that *Ludic Engineering* can play in this context – by more fully integrating tested art practices particularly in early technology development stages – is to better illuminate the multifaceted nature of *an experience contribution*.

6.2 Utility Patents: Technology Contribution

"[B]ringing new technology into being" (Schön, 1967, p. 1) was the secondary outcome of the *Solar Pink Pong* case study. I articulate this outcome as a *"technology contribution"* in reference to Schön's (1967) view in *Technology and Change* and Shteyn and Shtein's (2013) scalable system approach to innovation that I reviewed for *Ludic Engineering* (see Section 2.2.4). It is important to clarify, however, that neither *Solar Pink Pong* nor *iGYM's* underlying technology has yet been brought *into use* (Schön, 1967) or *scaled up* (Shteyn and Shtein, 2013) in a way that would qualify as an innovation according to these views. *Technology contribution* in the context of the dissertation refers primarily to a series of inventions in form of invention reports and utility patent applications that describe their novelty, utility, and non-obviousness as interactive systems. In the case of *Solar Pink Pong*, I filed three invention reports that led to one early commercial assessment and one utility patent application; this patent was granted with all 14 claims related to an "INTERACTIVE PROJECTION SYSTEM" (see Appendix B) in 2016. In the case of *iGYM*, I filed one invention report on behalf of our research team, which also led to one utility patent application in 2019; the latter is still pending and includes 20 claims related to a "PERIPERSONAL BOUNDARY-BASED AUGMENTED REALITY GAME ENVIRONMENT" (see Appendix E).

Utility patents are certainly less associated with the domain of art than engineering, where they fit in more naturally as the scalable system approach to innovation that I reviewed earlier showed (Shteyn & Shtein, 2013). Using utility patents to examine the technology of an interactive art installation had little in common with the non-standardized critique formats with which *Solar Pink Pong*'s *experience contribution* was mostly evaluated (i.e., judged); it was a highly regulated and lengthy process. This process built on the US patent system with its classification system that includes over 250,000 classification entries in its current form (*CPC Scheme - Sections*, n.d.); it was characterized by conventions that regulated every element in the application ranging from the arrows in drawings to the form and punctuation of claims that give patents both their distinct technical jargon and style as well as their descriptive precision. As such, this process was very different compared to the submission of *Solar Pink Pong* for a juried exhibition or an award, for example. However, what both completely different examination formats – the art critique and the utility patent – had in common was that they were both concerned with the novelty of an interactive artifact or system as such. For example, it would have been unlikely that *Solar Pink Pong* was selected for an international award if the same or a very similar work had already been developed and exhibited by somebody else before; the same conditions naturally applied for the utility patent application only that in this case the examination of novelty was approached from a much narrower angle that focused primarily on the operational value (i.e., the utility) of an interactive system.

The ability to examine the novelty of an interactive system has also been argued to be key for HCI and interaction design research as it raises the critical question for any prototype-driven researcher "when is a new design a knowledge contribution?" (Wiberg & Stolterman, 2014). Although novelty in this HCI case was discussed related to design patents and not utility patents, the critical question of when a new design qualifies as new knowledge was also a key concern in the *Solar Pink Pong* case study. In fact, this question was at the center of my initial confusion and first unsuccessful attempt to submit a short work-in progress paper related to *Solar Pink Pong* to an HCI conference; at that time, I was still largely operating under the assumption that a novel design that is patentable must somewhat automatically present a knowledge contribution that warrants a publication in the eyes of a reviewer. This assumption was particularly mis-guided by my training and habit as an artist and designer to *see* and *judge* the "expressiveness" (Dewey, 1934/2005, p. 90) of objects as such as opposed to *conceptualizing* it within theoretical frameworks or *evaluating* it with studies. The latter was the *knowledge contribution* approach eventually followed successfully with *iGYM* at the end of the case study. In retrospect, I see how this specific example and my initial confusion simply illustrates the larger context of the theory-practice divide (Sanders, 2017) or research-practice barrier (Zimmerman et al., 2007). The question of when a new design qualifies as new knowledge, however, continues to be difficult to address not only in this dissertation; since there are no established frameworks yet that would provide a simple answer to this question, I refer to novelty aspects related to *Solar Pink Pong*'s design as something else, that is, *technology contribution*. Regarding this *technology contribution* and the relevance of utility patents in this context, I have made particularly, the following three observations in the case study:

First, the utility patent format appeared to be overall more compatible with *Solar Pink Pong* as an interactive installation than, for example, design patents that I have also filled in the past (i.e., outside this case study); the latter focus primarily on the ornamental characteristics of a design (for which patent drawings are central) as opposed to its utility (for which patent claims are central). This might seem counterintuitive as claims related to utility are typically considered as less relevant for the domain of art than drawings and their ornamental characteristics. However, in light of the reviewed literature and my experience with both patent processes, it is less the notion of *utility* and more the notion of *interactivity* that makes particularly utility patents relevant for interactive art and interaction design; in other words, interactivity implies some sort of functionality that, even if unorthodox, may in fact be of use, or future use, in an emerging field of application. Myron Krueger's *Video Place* (1974) is a prominent example of a form of interactivity, whose functionality preceded an established field of application (i.e., augmented reality). Likewise, *Solar Pink Pong* may or may not fit in a field of application in the future that has not been established yet (e.g., daylight media).

Second, utility patents were particularly insightful in this case study, because they provided an established system and procedure that prompted to articulate what *Solar Pink Pong* as an interactive artifact or system enables that prior art does not; in other words, in this examination of *Solar Pink Pong*, a narrow focus on the novelty of its structural functionality (patent) replaced a wider focus on the novelty of its expressiveness (art). Following this narrow focus and discussing with the patent lawyer what *Solar Pink Pong* as an interactive system enables helped, in turn, define some of the boundaries of the larger design space and related human needs (e.g., the need for interactive daylight media systems that can naturally co-exist and augment the physical environment); metaphorically speaking, it helped to identify some of the functional "bone structure" underlying the criticism that motivated this project and the expressiveness of the artifact. As such, it helped to conceptualize *Solar Pink Pong*'s role as dialectical counterpart to mainstream technology and the *Daylight Media Lab* as an alternative research program that promotes a counter culture in a McLuhanian (1988) sense. A key difference of this criticism was that it was implied in engineering terms as opposed to the prose of a typical art work description.

Third, the nature of both *Solar Pink Pong* and *iGYM*'s patent application process was as much "unruly" and imaginative as it was rulebound and analytical. Particularly the initial conversations with patent lawyers, in which the background and scope of the invention were discussed relied heavily on open ended thought processes such as brainstorming that shape creative work in general. The main difference, however, was that they were supported by experts, who are trained to structure and classify ideas to make them comparable (i.e., searchable) within an elaborate classification system; brainstorming joined by such experts was effective insofar as it allowed to freely speculate about different embodiments of an invention or components of it without having to worry about how to structure and classify them in this system. This combination of convergent and divergent thinking styles and expertise simultaneously present in one process amplified the ability to imagine a larger potential design space around the invention that can be negotiated within an elaborate patent system. As a result, what made the invention eventually patentable (i.e., new, useful, non-obvious) relied equally on the experience and skills with which the patent lawyer structured the claims of the invention and its scope within the patent classification system. Therefore, the novelty of the *technology contribution* in this case (i.e., as examined by a utility patents) was as a twofold creative effort that built equally on the skillful classification and generation of ideas. This example illustrates also how "expert creativity" (Helfand et al., 2016) operated based on domain-specific experience and skills. It shows that for an invention to take place "a person who brings novelty into a symbolic domain" (Csikszentmihalyi, 1996, p. 6) – or in this case the patent classification system – relies equally on experts who validate the invention.

To conclude, I certainly don't see utility patents as the best or most appropriate way to "bringing invention into use" (Schön, 1967, p. 1) particularly given other, open source forms of innovation. However, I have learned throughout the case study that exploring the operational value of interactive artifacts and systems through the lens of a utility patent application is surprisingly compatible with creative work in general and its evaluation in particular as Simonton's (2012) three criterion definition of creativity shows (i.e., new, useful, surprising). Further, it can benefit larger research and development efforts beyond simply protecting intellectual property rights. In this case study, it helped to analyze and further conceptualize the design spaces related to *Solar Pink Pong* and *iGYM* as an interactive artwork and system. In addition, it was a way to articulate the novelty of their design as a *technology contribution* within the established patent classification system. Finally, in the context of the reviewed literature for *Ludic Engineering*, utility patents can be seen as a step towards a *knowledge contribution* in a Deweyan sense of stating new meanings (e.g., new applications of technical components) versus expressing them.

6.3 Inclusive Play Studies: Explicit Knowledge Contribution

Inclusive play studies and publications related to the *iGYM* system were the tertiary outcome; they resulted from the shift from arts-based research to HCI-based research at the end of the *Solar Pink Pong* case study. I refer to this outcome as *"explicit knowledge contribution"* to distinguish it from the implicit or tacit knowledge dimension (Polanyi, 1966/2009) that shaped most of my practice-based research trajectory and ludically-engineered artifacts. As such, *explicit knowledge contribution* was not superior but different from the other two outcomes that I outlined in this chapter as *experience contribution* and *technology contribution*. *Experience contribution* referred, as discussed above, to the "expressiveness" (Dewey, 1934/2005, p. 90) of *Solar Pink Pong*. *Technology contribution* referred to "bringing new technology into being" (Schön, 1967, p. 1) in the form of utility patents related to *Solar Pink Pong* and *iGYM*. The latter can also be interpreted as step towards a *knowledge contribution* in a Deweyan sense of stating new meanings as opposed to expressing them; in fact, *iGYM's* background description in the utility patent built on similar text fragments as the first academic publication draft.

Explicit knowledge contribution in a Deweyan sense was a concrete step of "stating meaning" in the field of HCI at the end of this case study. It refers to two studies and publications that described and validated some effects and implications of *iGYM* as an augmented reality system for inclusive play and exercise. First, it refers to a pilot study that showed, in a nutshell, that the *iGYM* system was wheelchair accessible and that the peripersonal circle size and kick button had more effect on the playability (i.e., the ability to score and defend goals on the projected playing field; see Section 5.10., Figure 42) than other game parameters such as target speed calibration. This study was published in a short paper in the proceedings of CHI 2019 (i.e., a large conference that covers the entire field of HCI). It was conducted with 9 participants between 7 and 19 years old that included 7 players with mobility disabilities (i.e., 5 using power wheelchairs, 2 using manual wheelchairs) and 2 participants without disabilities. Second, it refers to a subsequent study that explored the effects of this peripersonal circle and kick button in isolation by introducing three adaptation levels with which players competed against each other. These levels made the system (i) more accessible, (ii) more playable, and (iii) more balanced. Key findings indicated that amongst study participants higher adaptation levels were not always preferred and that perceptions of fairness were often formed regardless of whether players used wheelchairs or not. This study was published in a long paper in the proceedings of CHI Play 2019 (i.e., an HCI conference focused on all areas of games and play). It was conducted with 12 participants between 9 and 16 years old including 8 players with mobility disabilities (i.e., 5 using power wheelchairs, 3 using manual wheelchairs) and 4 players without mobility disabilities, who participated without mobility aids. The full extent of this *explicit knowledge contribution* based on both studies with these small groups of selected participants is described in *iGYM: An Interactive Floor Projection System for Inclusive Exergame Environments* (see Appendix D). In this summative reflection, I don't reiterate the findings, but focus on the specific nature of this third contribution compared to the other two contributions in the case study.

From a practice-based perspective, this *explicit knowledge contribution* played overall a relatively minor role for the actual system development of i*GYM*; the system had already been developed through iterative prototyping and casual playtests prior to the inclusive play studies much like *Solar Pink Pong* and my other ludically-engineered artifacts with Assocreation. However, the related learning effects particularly regarding study designs and procedures in HCI played a major role for conceptualizing *Ludic* Engineering and better understanding how it can benefit as a practice from both HCI-based research and arts-based research. As such, it was critical to learn how to correctly describe and validate the effects and implications of *iGYM's* interaction modalities in a way that can be accepted as *a knowledge contribution* to the field of HCI. This most recent and still ongoing learning process has not been without difficulties particularly at the beginning (i.e., illustrated by the first two rejected papers); it has clearly been affected by my habits of thought as a practitioner operating mostly in the tacit knowledge dimension of the field of art and design.

Key to making i*GYM's knowledge contribution* explicit in the field of HCI, from my learning perspective as a practitioner, was to control the situation to isolate effects and better study the interaction modalities that are enabled by the system. With "control," I refer to the procedure and protocol that had to be followed for preparing and conducting the inclusive play studies as outlined in the study design (e.g., the three adaptation levels). For example, preparing the study followed participant selection criteria and recruitment plans both of which had to be approved by an institutional review board before any action could take place. Conducting the study required to following a protocol that defined the roles of research team members, the pairing of players, the stages of data collection and analysis, as well as procedural details such as randomizing the matches to avoid ordering bias. Much of this type of control is a largely standardized prerequisite for system design oriented HCI research; it is needed to make a study documentation or publication "talk" in a transparent (i.e., replicable) way. The reason why I focus on this control element in the summative reflection is that the implications of controlling a situation and the efforts needed to do so effectively were the most overlooked aspects from my practice-based perspective – particularly vis-à-vis the nature of an *explicit knowledge contribution.*

In the case of the i*GYM* study, we had to rehearse and refine the entire study procedure twice (i.e., among our research team; with a small group of test participants) until we were confident that it worked first of all on a basic social and logistical level for all involved parties (i.e., managing the time, effort, and needs of children, parents, and researchers, etc.) and then related to the delivery and settings of all study components (i.e., participant on-boarding, consent, and interview settings; number and delivery of questions; form of questionnaires and support tools such as smiley face Likert scales on movable whiteboards; duration of matches, pre-tests, and breaks; communication protocol among researchers; crowd management, etc.). As such, rehearsing and refining the study procedure felt much like a design or prototyping process. Likewise, working towards controlling the situation felt much like an "invisible" but important effort for the *iGYM* study similar to working out the right site-specific set up of *Solar Pink Pong* for example; the former was critical for the quality of the study documentation; the latter was critical for the quality of the visitor experience; both required a significant preparation effort prior to the actual event (i.e., study and exhibition).

The benefit of having the situation largely controlled in such a way for conducting a study was evident. It helped to evaluate the *iGYM* system in a transparent and replicable way particularly regarding our four main research questions (i.e., How players perceived the nature and benefit of the game? How players felt about the presence or absence of a kick button? What adaptation level players preferred most? How players felt about competing against people with different abilities?). However, it also showed that making the control element transparent to the reviewer of reader in the documentation didn't necessarily make it transparent for the study participant in the situation. While it was clear that the controlled study design helped to isolate effects and address our research questions, it limited the ways players could engage with the system and with each other. For example, after the study session players had extra time to play and often engaged in ad-hoc multiplayer games with parents, siblings, or friends which in return led to a different social setting and sometimes also a different player behavior. In one case, a player who used a manual wheelchair during the study asked if it was ok to continue to play using crutches (which we excluded in our selection criteria) after the study. Similar observations of participants engaging with the system and each other in a variety of unexpected ways were made during a later public play day event. The atmosphere and social setting at this event had more in common with a celebratory exhibition opening than a formal study. In the context of our study design, these observations could only be addressed in the limitations section of our paper. They were clearly outside the scope of the *iGYM* study.

However, such multifaceted observations were at the center of *iGYM*'s potential *experience contribution;* they helped to illuminate its "expressiveness" (Dewey, 1934/2005, p. 90) as a system similar to the range of observations during the public exhibitions of *Solar Pink Pong*. In the context of the reviewed literature for *Ludic Engineering*, these observations revealed the challenge to design and conduct a study that strikes the balance of capturing both the "expressiveness" (p. 90) of an interactive system and its effects "in the wild" (Rogers & Marshall, 2017). The related key insight is that this study design challenge was in fact not much unlike a system design challenge, particularly since the *iGYM* system enabled new interaction modalities for which no pre-existing study procedures could simply be adopted. In other words, the design of a study for a novel system posed similar "wicked problems" (Rittel & Webber, 1973) and required similar "expert creativity" (Helfand et al., 2016) than the design of a novel artifact or interactive system itself. In the case of *iGYM*, the key challenge was to align the study design with the system design in a way that didn't cut short its "expressiveness" as a system too much (e.g., the range of enabled interaction modalities and provoked experiences). To achieve this, existing study designs that we reviewed had to be adapted and combined since most of them focused on screen-based games for players without disabilities. The success of this study design process required a particularly steep learning curve on my end and was supported by the experience and skills of my research collaborators and consultants (i.e., domain experts). Further, the successful execution of the study itself included also many tacit elements that typically don't fit in a method or procedure section of an academic paper; these elements relied largely on the combined experience and skills of our research team members (e.g., interviewing young children, setting up the system and space to engage them, make children and parents feel comfortable, etc.).

To conclude, finding the right approach to effectively "state meaning" that qualifies as *explicit knowledge contribution* while not cutting short *iGYM*'s *experience contribution* felt akin to a design process and creative problem solving. Although we didn't fully manage to strike the balance between both contributions in this case, working towards such a balance seemed like an important effort to help bridge the theory-practice divide (Sanders, 2017); it certainly helped to reduce some of my blind spots as a practitioner, who was operating almost exclusively in the dimension of the experience; it made me aware that a new design or design space doesn't necessarily qualify as *new knowledge* in this research context even if it expresses new meaning or enables new interactions that were clearly recognized as such (i.e., *a contribution)* by jury statements or utility patent applications. The trick, in summative reflection, was to find an effective way to make the study documentation "talk" to a specific research community. In this case, it was the CHI Play community, which is at the interaction design side of the intersection of *Ludic Engineering*. In reference to Dewey's metaphor of a city traveler who follows signs (i.e., science) to arrive at places where experiences may emerge (i.e., art), this *explicit knowledge contribution* can be attributed a "signboard function" (Dewey, 1934/2005, p. 88). In that sense, the newness of *iGYM's* stated interaction modalities relied largely on the "directive efficacy" of the "signboard function" (p. 88) of the *explicit knowledge contribution* within the traffic rules and regulations of a specific research community.

6.4 Ludic Innovation Framework

The *Ludic Innovation Framework* is the result of a summative reflection on the play element in creative work and innovation in light of the *Solar Pink Pong* case study and the situationist drift through the related literature in chapter 2. As such, it doesn't conceptualize *Ludic Engineering* in form of a scholarly argument. Instead, it relies largely on speculative reasoning in form of diagrams and images inspired by my experiences in the customer discovery program and questions that emerged at the end of the literature review for *Ludic Engineering*. In other words, its conceptualization was an act of symbolic thinking that operated mostly in the "neutral zone of creative fantasy" (Jung, 1921/1976, p. 113) with the goal of making new connections and exploring new meanings for future research. This framework brings together playfulness concerns in childhood development and technology development in a similar "non-rational" (i.e., playful) fashion that combined color mirror explorations and motion tracking explorations to create *Solar Pink Pong*. It conceptualizes *Ludic Engineering* as an emerging form of playfulness-oriented research and technology-inspired creative practice that draws from human play experience in the course of action over the lifetime of individuals or groups.

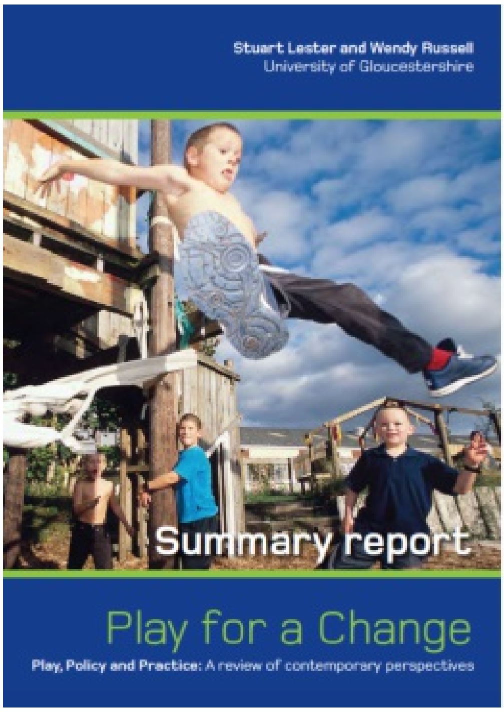

Figure 44: Cover page of play summary report published for Play England by the National Children's Bureau, UK, in 2008 (left); recruitment poster for the National Science Foundation Innovation Corps, USA, based on the original artwork for Uncle Sam's World War I and II recruitment poster as drawn by Montgomery Flagg in 1917 (right).

Key inspiration for the *Ludic Innovation Framework* were two images (see Figure 44) that best illustrate the two distinct project development cultures that shaped *Solar Pink Pong*'s case study: first, the cover page of a summary report for Play England by the National Children's Bureau (Lester & Russell, 2008) showing children at an adventure playground;

second, the recruitment poster used in the customer discovery workshop showing Uncle Sam, a (white) patriotic personification of the US government.

The first playground image symbolizes the "unruly" hands-on play and prototyping culture that defined the creative process throughout most of the case study and that I was most familiar with (i.e., that I grew up with). This image was used for the cover page of a systematic literature review related to the play of children and young people from birth to 18 years in mostly western countries including, among others, Northern Europe, North America, and the UK. In this review, the authors (Lester & Russell, 2008, p. 25) map their findings on a pentagonal spider web representing the five program goals of the *Every Child Matters* initiative in the UK (i.e., "enjoy and achieve"; "make a positive contribution"; "achieve economic well-being"; "be healthy"; "stay safe"). The spider web emphasized the interconnectedness of the design features and benefits of play for children. Play in this context was described as "flexible, unpredictable, imaginative, peer/self-directed, 'as-if' behavior" (p. 25). Play according to this report can enhance brain plasticity and influence adaptive systems; as an enjoyable experience "it promotes positive affect, which in turn encourages further exploration, novelty and creativity" (p. 20); the relationship between play and creativity as such was located in "the flexibility of responses to novel and uncertain situations and the non-serious interpretation of a range of stimuli" (p. 21); play in this context was also described as "training for the unexpected" (Spinka et al. as cited in Lester & Russell, 2008, p. 26). Further, resilience was overall seen as a key benefit of play for children and was placed in the center of the spiderweb. In the context of the *Solar Pink Pong* case study, the *Every Child Matters* program goals and potential play benefits described in the report were well aligned with the goals of developing technologies for the lived body. In fact, the development of *iGYM* at the end of the case study exemplifies some of these goals and potential benefits; as an inclusive play system, *iGYM* responded to equally new and uncertain challenges vis-à-vis both child development and technology development.

The second image with Uncle Sam pointing his index finger at the viewer symbolizes the very direct boot camp culture and rhetoric of the business coaches in the six-week-long customer discovery program in which *Solar Pink Pong* was explored (see Chapter 5). The spirit of this program was not unlike the reality TV show *Shark Tank*; it was supposed to mimic the pressure of, and training for, the Silicon Valley inspired start up and business innovation culture particularly in North America. As such, it was a format meant to quickly assess, in form of mostly ad-hoc in-person interviews, the amount of "pain" of potential customers vis-à-vis a perceived value proposition of a novel technology; "making physical therapy more fun" was an example of such a value proposition explored with *Solar Pink Pong*. Likewise, from a high-level perspective, the program focused also on identifying the potential barriers to innovation in the related business ecosystem vis-à-vis the perceived market opportunities. Taken as a whole, the objectives to identify and discuss customer pain points and innovation barriers in such a condensed format made the development culture of this program an equally insightful and emotionally stressful experience. As such, it provided a different experience than the "adventure playground" culture that I was most familiar with as an artist and designer.

What makes both images inspiring is that next to each other – the innovation corps recruitment poster on the right and the cover page of the play report on the left – they reveal a symbolic tension or conflict: side by side these images can be interpreted as

Uncle Sam personifying a strict teacher or parent reprimanding unruly children at a playground and disrupting their flow experience and natural urge of play. This symbolic conflict and, in the context of the case study, perceived tension between the cultures of play and innovation is what the *Ludic Innovation Framework* builds upon; it can also be illustrated with two diagrams that show the dynamics and inner workings behind these images as I experienced them in the case study (see Figure 45): first, a diagram showing Csikszentmihalyi's (1975/2000; 1990/2008) concept of "flow" that illustrates the optimal (i.e., most enjoyable) experience as it relates to play, creativity, and other activities; second, a diagram showing the concept of "disruptive innovation" as it was popularized by Christensen (2011) and used in the customer discovery program to illustrate the "optimal" (i.e., most profitable) innovation strategy. Although "flow" and "disruption" are not the only characteristics of play and innovation cultures, they are among the most widespread notions associated with it. Both diagrams next to each other show striking parallels in their depiction of an idealized "flow" channel (i.e., the optimal play experience) and "innovation" channel (i.e., the optimal innovation strategy). Contrasting these diagrams reveals the different values and "operating systems" or views underlying the respective development cultures related to play and technological innovation. In that sense, they further illustrate the symbolic conflict that the images above represent.

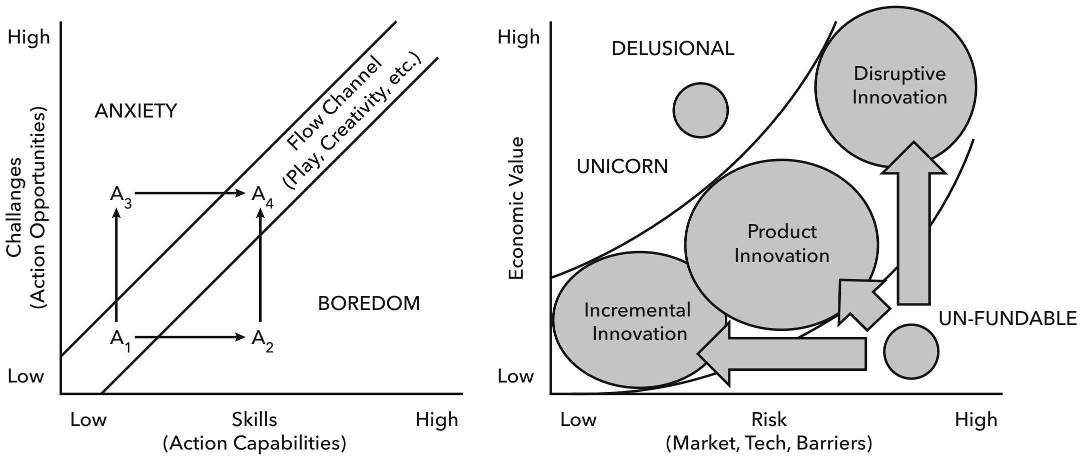

Figure 45: Initial flow diagram (left) illustrating the optimal experience related to play, creativity, etc., overlaid with four experience stages ($A_{1\text{-}4}$) that explain the flow channel in a later diagram (Csikszentmihalyi 1975/2000, p. 49; 1990/2008, p. 74); innovation diagram (right) illustrating disruptive innovation as the "optimal" strategy for startups (*Introduction to Customer Discovery*, University of Michigan, Center for Entrepreneurship, and Grand Valley State University, 2015).

The *Ludic Innovation Framework* combines elements of both views and diagrammatic representations to create a new diagram, whose construction I discuss in the following. The goal of this play-innovation convergence is to visualize the interplay of flow and barriers (or "pains") on the same plane as they were experienced in the case study and fit into the context of the literature reviewed for *Ludic Engineering* in chapter 2. It is important to note that Csikszentmihalyi has already been addressing flow as it relates to barriers in detail from a psychological perspective (see e.g., 1975/2000; 1990/2008; 1996) since he first drew a flow diagram on the blackboard in a seminar that focused on adult play activity (1975/2000, pp. xvi, 49). However, barriers as such, which define the nature of creative work and innovation as much as flow, have not been directly represented (i.e., visually illustrated) in Csikszentmihalyi's flow diagrams. Instead, they have been implied as situations (i.e., depicted as points in the diagram) within the two dimensions of experience that are most important in flow theory: challenges and skills. Figure 45 (left) shows Csikszentmihalyi's initial flow diagram (1975/2000, p. 49) overlaid with an often-cited later diagram (1990/2008, p. 74) in which four such situations are explained with the letter A representing Alex, a boy who learns to play tennis. Alex, in a nutshell, is initially in a flow state as he learns the basics (i.e., hitting the ball over the net) that pose the right challenge for his rudimentary skills (A_1); he gets bored as his skills improve (A_2); he feels some anxiety when he meets a more experienced opponent (A_3); and, he gets back in a flow state when his improved skills are in the right balance with greater challenges (A_4); as such, the diagram illustrates that both A_1 and A_4 represent situations in which Alex is in flow; the important difference, however, is that A_4 represents a more complex experience than A_1 since it involves greater challenges and demands greater skills from the player. Csikszentmihalyi used these four situations as an example to illustrate the dynamic nature of the uprising flow channel and explain why flow activities don't just represent an enjoyable experience, but also lead to growth and discovery. For Csikszentmihalyi (1996), to cultivate the flow experience and enable the process of invention required to learn balancing challenges and skills and overcoming the struggle or "barriers of entropy" to get in the flow state (pp. 116-117). Key, however, for the experience of flow in this view – and for the creative process in this case study – are not only the "real" nature of the challenges that a situation presents, but the perception of those challenges (1990/2008, p. 75).

The *Ludic Innovation Framework* focuses exactly on this subjective perception of challenges or barriers related to the flow channel in the context of creative work. Related to this subjective perception there is a coping mechanism that creative individuals often develop to put problems into a manageable context according to Csikszentmihalyi (1996); he refers to this mechanism as personal approach or "internal model" (p. 118). The *Ludic Innovation* diagram that I construct represents such an "internal model" both in the way I experienced creative challenges in the case study and made sense of them in this summative reflection; its goal is to illustrates the "internal" aspects that can make one individual stay and the other individual drop out of the flow channel in a situation that may look similar to an external observer. To achieve this, I further expand Csikszentmihalyi's flow diagram and view on the human experience with diagrammatic elements that draw from two related and complementary views that I reviewed earlier: Dewey's concept of *an experience* and Jung's type theory. The first focuses on the structure of *an experience* and related view of *creative production,* which I adapt to illustrate the perception of barriers alongside the flow channel. The second focuses on the structure of the consciousness and related view of play as a symbol forming function, which I adapt to illustrate the notion of combinatory and imaginative play that helps to overcome those barriers. Both Jung and Dewey's views offer key elements for the construction of a modified flow diagram that illustrates the process of *Ludic Innovation*.

Dewey's (1934/2005, p. 37) concept of *an experience* and *creative production* that I discussed in chapter 2 aligns well with Csikszentmihalyi's description of the dynamic nature of the flow channel; having *an experience* for Dewey is defined by the seamless way in which every part of the experience flows freely towards fulfillment; flow in *an experience* is "from something to something"; it gives successive parts of it greater definiteness (p. 38). Further, Dewey's view provides a way to conceptualize creativity as action (Glaveanu et al., 2013) in response to challenges as opposed to, for example, a succession of cognitive stages like most classic models of creativity including Wallas' (1926) four-fold distinction (i.e., preparation, incubation, illumination, and verification) that I adapted to clarify the development phases of this dissertation. Figure 46 shows a graphic representation of Dewey's concept of *an experience* which was the basis for such an action framework developed by researchers (Glaveanu et al., 2013), who studied creative activity in different domains including art and science; at the core of this action framework and representation is the "*continuous cycle between doing and undergoing.*"

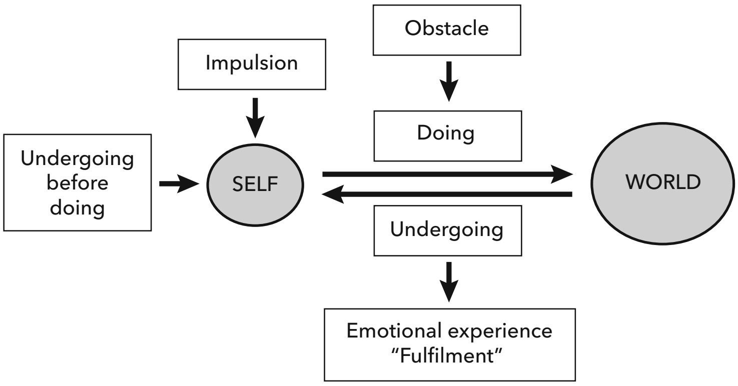

Figure 46: A model of human experience after Dewey (Glaveanu et al., 2013).

For the *Ludic Innovation Framework*, I modify elements of this graphic representation that builds on the logic of a flowchart in a way that emphasizes the continuous cycle between doing and undergoing differently. To better explain the framework and difference, I first unpack the notion of the self, or what Dewey (1934/2005) also referred to as "the whole organism" (p. 60) – which is driven by an impulsion and encounters obstacles that can trigger a process of thoughtful action and result in creative production. To achieve this, I look at Dewey's concept of creative production and the notion of self through the lens of Jung's (1921/1976) type theory as discussed related to the play instinct in chapter 2 and as further illustrated in figure 47 (left).

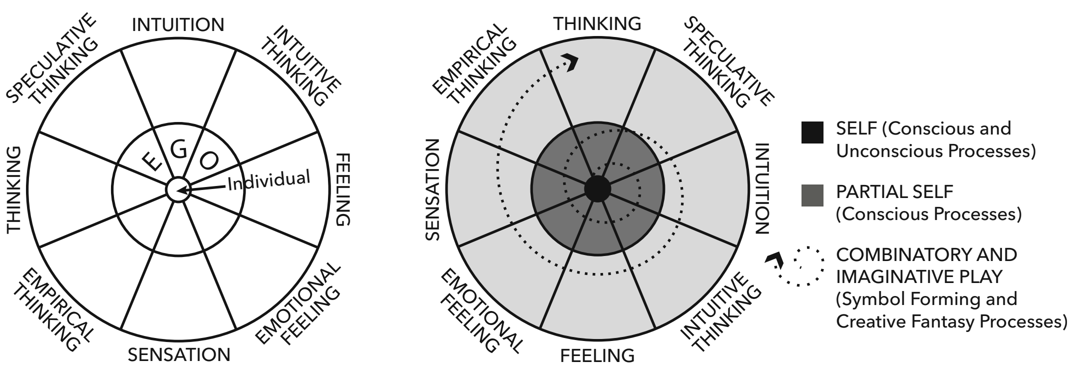

Figure 47: Original type theory diagram (left) showing all of Jung's functions of consciousness idealized as sectors of a circle with the ego (i.e., partial self) and the individual (i.e., self or sum of the conscious and unconscious processes) in the center (Jung, 1925/1989); and, adapted type theory diagram (right) with a spiral representing the notion of *combinatory* and *imaginative play* as a symbol forming function that cycles through all functions of consciousness.

Jung's (1921/1976) type theory proposed different non-rational and rational functions of consciousness that are each modified by two psychological attitudes: introversion and extroversion. In a related seminar lecture, Jung (1925/1989) showed a diagram (Fig. 47, left) depicting an idealized condition with all eight resulting functions of consciousness simultaneously present as sectors of a circle. In the center of the circle is the self (i.e., "individual") that represents the sum of the conscious and unconscious processes as well as the ego or partial self, which for Jung is not in contact with the unconscious processes (p. 120). In this seminar context, he described the functions of consciousness as follows:

> *Let us start with thinking, or pure intellect. This as a rational function is connected with the irrational function intuition by what we call speculative thinking, or intuitive thinking. Then we pass to the polar opposite of thinking, namely feeling, through intuitive feeling, and from there to the polar opposite of intuition, sensation via emotion of feeling. Emotion is that sort of feeling which is a physiological condition, and which is perceived by sensation. From sensation we get back again to thinking through a kind of thinking we call empirical, i.e., thinking to the fact. We have now the conception that thinking passes by easy transition to both intuition or sensation, or vice versa, but that it is furthest removed from feeling. (Jung 1925/1989, p. 121)*

For the *Ludic Innovation Framework*, I adapted Jung's diagram (Fig. 47, right) and turned it 90 degrees clockwise so that *thinking* faces up and *intuition* faces forward (in a left-to-right reading culture). The spiral represents the notion of combinatory and imaginative play as a symbol forming function that operates largely in the zone of creative fantasy (Jung, 1921/1976, p. 113). It cycles from the virtual center of the self (i.e., the unconscious) through different functions of consciousness that each – depending on the individual or situation – may play a part in responding creatively to barriers or obstacles. As such, I integrate the spiral to further expand the notion of the self in a modified diagram of Dewey's concept of *an experience* and *creative production* (Fig. 48). Unlike the flowchart-like graphic representation above, this diagram does not represent the self in a cycle between doing and undergoing next to the world. Instead, it represents the self as an extended body or organism moving through a channel of doing and undergoing that defines the boundaries of the world in which creative work takes place.

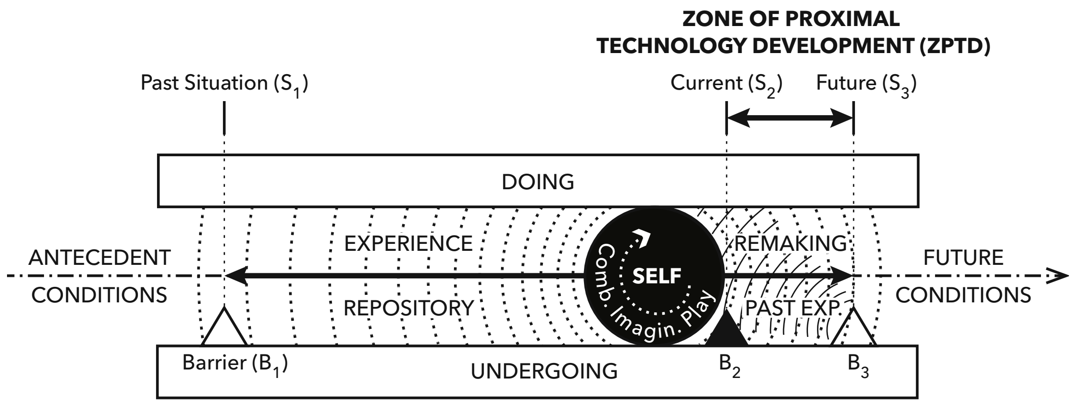

Figure 48: A modified graphic representation of Dewey's concept of *an experience* and *creative production* with the self (i.e., based on Jung's adapted type theory) moving through a doing and undergoing channel; the self expands through *combinatory* and *imaginative play* to remake past experiences and turn barriers (B) in means or media for expression; through play it enlarges the *zone of proximal technology development* to anticipate 'shadows' of future situations (S_3).

This modified graphic representation of Dewey's concept of *an experience* and *creative production* is at the core of the *Ludic Innovation Framework*. It combines two key aspects of *Ludic Innovation*: the temporal development and experience of a creative individual and the related technology development potential; both emphasize experiential and developmental concerns.

The first key aspect of *Ludic Innovation* concerns the subjective experience and behavior of a creative individual in different cultural settings and environments across time (e.g., in the case study the different availability of daylight in office spaces in Austria and USA). This aspect is illustrated in the diagram with a circle representing the creative individual or self moving through a channel of doing and undergoing and continuously building an experience repository along the way. In response to barriers (B) encountered in this channel, whose boundaries are defined by those settings, the self gets either to a halt or expands through *combinatory* and *imaginative play*. Halt can refer to pausing or ending an activity or project (e.g., the color mirror explorations or motion tracking explorations in the case study). Expanding refers to cycling through different functions of consciousness and starting a symbol forming process from the virtual center of the self (i.e., the unconscious); the latter process, if successful, can remake past experiences (S_1) in light of current ones (S_2) and turn related barriers (B_2) in means or media for creative expression (e.g., re-visiting the experiences related to color mirror explorations in light of perceived barriers related to motion tracking explorations, which led to *Solar Pink Pong*). Creative work in such a Deweyan sense is always a remaking of past experiences; it builds on prior work and the subconscious maturation of ideas; it is a construction in time. As such, its construction process is symbolized in the diagram with waves radiating from the present self towards past and imagined future situations. This developmental perspective of creative work is key for *Ludic Innovation*; it also builds on the premise of an interactionist model that views creative behavior as "a complex person-situation interaction influenced by events of the past as well as salient aspects of the current situation" (Woodman & Schoenfeldt, 1990).

The second key aspect of *Ludic Innovation* is the related technology innovation potential that can be achieved by an individual or groups through playful technology engagement. This aspect is depicted in the diagram with the *Zone of Proximal Technology Development (ZPTD)*. This zone can also expand through play as described above (e.g., in the case study by make-believe play with a two-year-old child or prototyping with adult engineers) to create "anti-environments" (McLuhan 1988, p. 5) that help to anticipate the "shadows" of future situations (S_3) or events (e.g., a new category of daylight media systems). The idea to describe the technology innovation potential as such a zone is inspired by the Russian psychologist Lev Vygotsky (1978). Vygotsky proposed the zone of proximal development as an alternative approach to assess and support the development of children. Instead of assessing their current achievement level based on performance indicators of independent problem solving (like most traditional testing methods in schools), he proposed comparing the current achievement level with the level that can be reached when the child is guided by adults or collaborates with peers (i.e., the level of potential development); the difference between both performance levels is the "distance" of the zone of proximal development (Kaptelinin et al., 2006, pp. 48-49). Vygotsky characterized the main difference of his approach compared to traditional ones as follows:

The zone of proximal development defines those functions that have not yet matured but are in the process of maturation, functions that will mature tomorrow […] these functions could be 'termed the 'buds' or 'flowers' of development rather than the 'fruits' of development. (Vygotsky, 1978, p. 86)

Vygotsky's zone of proximal development is a well-established concept in early childhood education. As such, I extracted it from its original context and adapted it for the *Ludic Innovation Framework* as an analogy to address similar future-oriented development concerns of emerging technologies. The leading source of development at both ends of the analogy – emerging technology and early childhood – is play. In fact, for Vygotsky (1967) play, particularly make-believe play, which I refer to as imaginative play in the diagram, creates a zone of proximal development:

In play a child is always above his average age, above his daily behavior; in play it is as though he were a head taller than himself. As in the focus of a magnifying glass, play contains all developmental tendencies in a condensed form; in play it is as though the child were trying to jump above the level of his normal behavior. (Vygotsky, 1933/1967)

To sum up, the two key aspects of the *Ludic Innovation Framework* that distinguish it from traditional process models of creative thought emphasize experiential and developmental concerns related to play and innovation; these aspects and their underlying change perspectives bring emerging technologies and early childhood concerns together. The graphic interpretations of those concerns in the diagram are primarily based on Dewey's pragmatism and Vygotsky's cultural-historical psychology, but they are also echoed in Bateson & Martin's (2013) view as behavioral biologists; the latter authors addressed similar developmental concern as a "temporal disjunction between experience and later problem-solving performance" (p. 6) in the context of *playful play* and innovation (see Chapter 2). The potential gap between play experience and beneficial outcome that underlies all three perspectives makes it difficult to directly measure the benefit of play or argue for it as leading source of technology development; in this framework, this benefit and role of play is only suggested by speculative thinking based on the analogy with child development; this analogy is a starting point for discussion and not a scholarly argument. Much clearer, however, seems to be how *Ludic Innovation* can potentially be enabled or cultivated at least in the metaphoric sense of planting "buds" or "flowers" of development. To cultivate *Ludic Innovation* in that sense, requires a "Vygotskian classroom" (Berk & Meyers, 2015, pp. 325, 354) approach. This approach emphasizes assisted discovery with technology experts and peer collaboration; it creates a *Zone of Proximal Technology Development (ZPTD)* through imaginative or make-believe play (e.g., various prototyping activities or tactics) with those experts and peers. As such, this approach was largely practiced in the case study and it raises a fourth and final guiding question (**RQ4**) for the future research on the topic of *Ludic Engineering:*

Can more play elements in technology development and education better train for the unexpected and help to prototype and build more effectively and more often desirable futures?

In response to this question and to conclude this summative reflection on the play element in creative work and innovation, I construct a final speculative *Ludic Innovation* diagram (see Figure 49). In this diagram, my interpretation of Dewey's experience channel, in which the self is in continuous cycle between doing and undergoing, converges with Csikszentmihalyi's flow channel. As a result, it represents an "inside" view or "internal model" of the flow channel as it was inspired by the different development cultures and their views on flow and disruption encountered in the customer discovery program and literature review. This modified flow diagram shows the development perspective of a creative individual (SELF) within the two dimensions of experience (i.e., challenges and skills) and the related dimensions of technology (i.e., opportunities and capabilities) that define their potential (ZPTD). With this diagram, the *Ludic Innovation Framework* does not highlight economic value by itself. Instead, it emphasizes flow rather than disruption as the primary development focus of breakthrough innovation particularly related to technologies for the lived body.

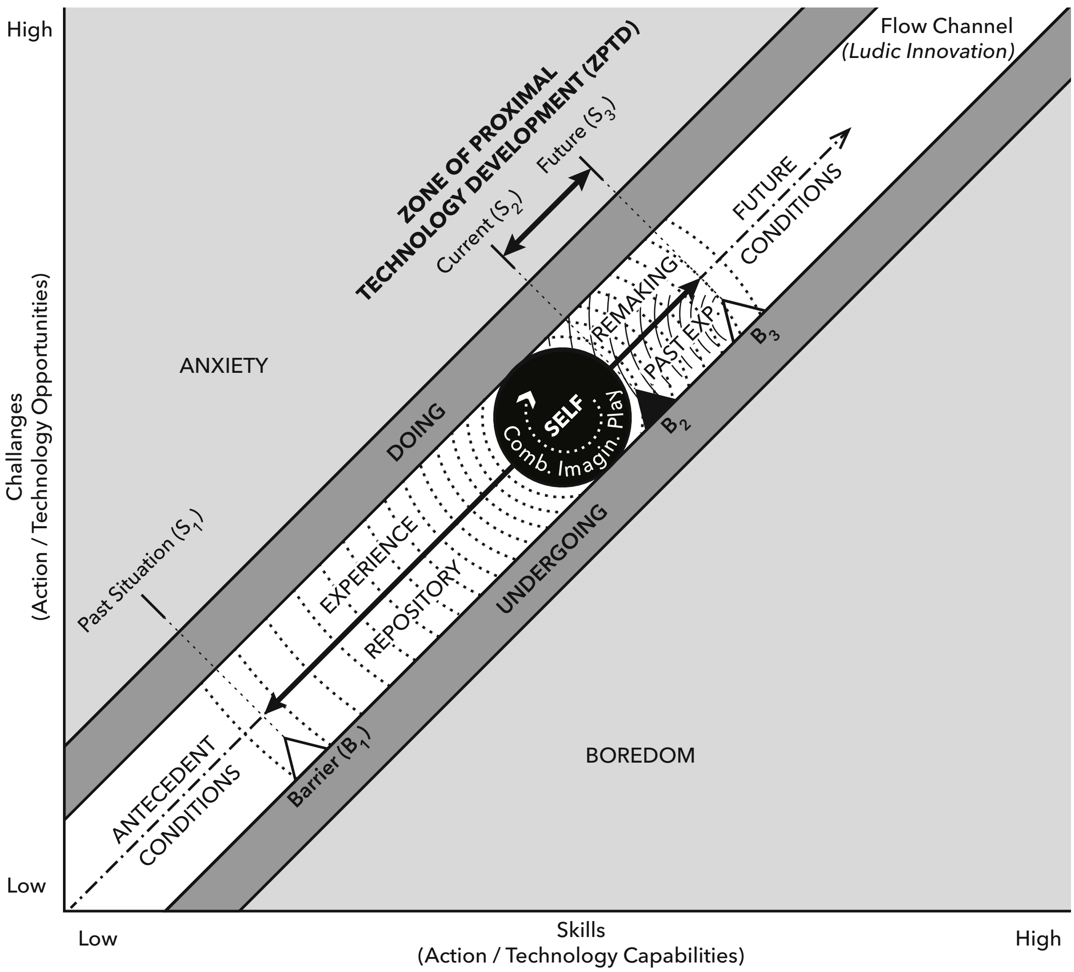

Figure 49: *Ludic Innovation* diagram illustrates the technology development potential (ZPTD) and experience of a creative individual (SELF) by converging Dewey's experience channel of doing and undergoing with Csikszentmihalyi's flow channel; it shows the *Ludic Innovation* process framed by two key dimensions of experience (i.e., challenges and skills) and related dimensions of technology development (i.e., opportunities and capabilities).

7 Conclusion

The conclusion summarizes the wider perspective of the thesis and insights gained by Solar Pink Pong *as a* Ludic Engineering *case study that focuses on "play" as the inventive element in art and engineering. It discusses the limitations of the main outcomes (i.e., experience contribution, technology contribution, explicit knowledge contribution). Finally, it outlines future work and outstanding questions related to further conceptualizing* Ludic Engineering *as an approach and establishing it as a creative practice at the intersection of interactive art and interaction design.*

With this thesis, I have traced a larger convergence of art and ludic (i.e., playful) engineering in light of the *Solar Pink Pong* case study that crossed the intersection of interactive art and interaction design. Although this convergence is often conflicted due to different research cultures and habits of thought in the domains of art and engineering, it presents much unexplored potential particularly for innovating technologies for the lived body as the case study showed. Further exploring this potential and the operational value of "play" (i.e., playful thought and playful behavior) for research and technology development is the primary focus of the thesis.

By tracing this larger art and technology convergence in connection with a specific case study and focus on play, I have sought to provide multidimensional answer to the questions of what "serious" role *Ludic Engineering* can play and how it can be further conceptualized as an approach. I have described *Ludic Engineering* in this context as a playfulness-oriented research and technology-inspired creative practice with a potential that is at least three-fold. First, it can enable new interactive experiences like other forms of interactive art or interaction design. In the case study, this aspect was leveraged by incorporating established practices in art such as public exhibitions and open-ended critique formats that allow the producer (e.g., artist, engineer, etc.) and the consumer (e.g., visitor, user, etc.) to learn from the expressiveness and multifaceted nature of the interactive artwork or system most directly. In the context of the reviewed literature for *Ludic Engineering*, I referred to this aspect as an *experience contribution*. Second, it can "bring new technology into being" (Schön, 1967, p. 1) like other, non-ludic forms of engineering. I referred to this aspect as a *technology contribution* and step towards stating new meanings as opposed to expressing them in a Deweyan sense; this aspect was leveraged in the case study by utility patents that described new, useful, and non-obvious (i.e., surprising) applications of technical components. Third, it can state new meanings, that is, generate new knowledge in fields related to engineering such as human-computer interaction. I referred to this last aspect as an *explicit knowledge contribution*; in the case study, this aspect was facilitated by controlled user studies that isolated some effects of the enabled interactive experiences. With this threefold distinction, I emphasized three intertwined characteristics and equally important contributions that *Ludic Engineering* can make – and made in the case study – that each benefit from play as the inventive element and main driver.

To further conceptualize play as the inventive element in this context, I have constructed a *Ludic Innovation Framework* that is largely based on speculative reasoning in form of diagrams and images. This framework draws an analogy between playfulness concerns in early childhood development and in the development of emerging technologies which are both future-orientated concerns. With this child-technology analogy, however, the framework does not characterize play as "non-rational" or romanticize it as free and detached from societal or technological concerns. Instead, it describes play as a serious symbol forming function (i.e., combinatory and imaginative play) that focuses on the development perspectives of creative individuals or groups engaged in "radical innovation" (Norman & Verganti, 2014) or "breakthrough innovation" (Shteyn & Shtein, 2013, p. xiii). As such, the *Ludic Innovation Framework* brings together diagrammatic elements and views on creativity, innovation, and the human experience by the pragmatist John Dewey, the philosopher-poet Fredrich Schiller, the psychoanalyst Carl Jung, the psychologist Lev S. Vygotsky, the behavioral biologists Patrick Beatson and Paul Martin, and the psychologist and creativity scholar Mihaly Csikszentmihalyi. Based on these views and inspired by the child-technology development analogy, the framework suggests that cultivating *Ludic Innovation* requires adapting a "Vygotskian [technology] classroom" (Berk & Meyers, 2015, pp. 325, 354) approach. This approach emphasizes (1) assisted discovery with technology experts and peer collaboration and (2) creating a *Zone of Proximal Technology Development (ZPTD)* through imaginative or make-believe play; the latter zone refers to the technology development potential that can be expanded through play or playful engagement with technology. In that sense, the core argument or main conclusion of the *Ludic Innovation Framework* remains a speculative question (RQ4) for future research: *Can more play elements in technology development and education better train for the unexpected and help to prototype and build more effectively and more often desirable futures?*

The limitations that apply to this analogy and eclectic conceptualization of *Ludic Innovation* as well as the main outcomes of my thesis (i.e., *experience contribution, technology contribution, and explicit knowledge contribution*) are linked to my practice-based and autoethnographically informed case study research approach. In other words, the contributions of the thesis are limited by a single case study based on my professional orientation and personal view that is not representative of a single field of study as such, but exists at the intersections of four different domains (i.e., art, architecture, design, and engineering). In this regard, I have made the subjectivity and limits of my viewpoints visible by providing a multilayered account with context information that included, among others, my foundation work, related positions of other artists and researchers, and external evaluation milestones in specific domains. Further, my contributions are limited by my social and cultural background as an artist and designer, whose view of art and technology has been shaped as much by the "gadgets" of the western industrialized world as by the related philosophical traditions of thought; in that sense, any McLuhanian "anti-environment" that I have created or commented on, for example, with *Solar Pink Pong* or the *Daylight Media Lab* is still a product of this world represented by mostly white male European and American scholars and practitioners. Finally, the *Ludic Innovation Framework* that brings together various views of creativity and the human experience represents an "internal model" both in the way I experienced creative challenges in the case study and made sense of them in my summative reflection; as such, the framework is a "ludically engineered" artifact, like *Solar Pink Pong*, designed to provoke further discussion rather than a scholarly argument.

With these limitations in mind, the thesis can overall also be seen as a step towards demystifying the play-creativity relationship in the process of inventing technologies for the lived body, with the lived body. This step of demystifying tacit aspects of the creative process aligns with other efforts such as the larger goals of design thinking, particularly those strands of its evolution ("Design Thinking," n.d., para 4) that saw design less as a method and more as a skill that must be learned and practiced like playing a sport or a musical instrument (Lawson, 1980/1990, p. 6). However, to establish *Ludic Engineering* as outlined in this thesis and as advocated for by Myron Krueger (see e.g., 1976; 1983) decades ago, will take more than teaching structured and practical methods of problem solving (see e.g., Kumar, 2012). To create a *Zone of Proximal Technology Development (ZPTD*) following a Vygotskian or Post-Vygotskian classroom approach will require cultivating play without making it a lesson plan (Bodrova & Leong, 2015). Play in that sense is not a teacher-directed activity. It is self-directed and focused on individual discovery. This aspect, however, also underlines the challenges in advocating for this type of playful behavior and playful thought, particularly in education environments in which learning is too often equated with following lesson plans, and creativity with solving puzzles (Shteyn & Shtein, 2013). In a research context, the situation is somewhat similarly challenging; in this case, publication plans and related reward systems can limit playfulness and self-directed discovery, too. In this respect, the domain of art and art education has an advantage as it is typically more receptive to the idea of play and learning through self-directed discovery without prescriptive lesson or publication plans. This inclination of art towards play and self-directed discovery can, at least in light of this case study, be seen as a key argument for better integrating art in a 21st century school curriculum (see e.g., the STEM versus STEAM debate) and for strengthening its role under the roof of a "Digital Bauhaus" (Ehn, 1998; Binder et al., 2008) or an extended umbrella of HCIA (i.e., Human-Computer Interaction Art) that I suggested in the introduction.

Looking ahead to future research on the topic of *Ludic Innovation*, however, it seems less critical to ask *what* classroom interventions are most effective to enhance playful behavior and playful thought; this question risks to generating new lesson plans or method books without addressing the larger methodological or pedagogical concerns of a Post-Vygotskian technology classroom approach. Instead, a more radical shift in formal education (Robinson & Aronica, 2009) and research models as mentioned above will be necessary to better integrate art and promote play for the sake of breakthrough innovation – or likewise the training for unexpected futures (Lester & Russell, 2008, p. 26). Therefore, most critical in this respect is the question of *when* interventions are most effective and, above all, what conditions or social and physical environments best promote playfulness or play experiences at different development stages. (As an educator at the end of the formal education pipeline, I am well aware that "teaching" young adults how to play or be creative can only go so far particularly in classroom settings.) In other words, most critical will be to build almost literally on the child-technology development analogy and study the links between childhood play and adult creativity in the domain of engineering. Also one of the topics for future research suggested by the behavioral biologists Bateson & Martin (2013, p. 128), studying these links in general intends to clarify the nature of the play-creativity relationship and help people to become more creative and innovative. Research in this direction promises to produce more insights and perhaps deliver the arguments needed to most effectively promote *Ludic Innovation* especially in domains that are typically less associated with play and creativity such as engineering.

A potential step in this direction is a research project that I co-initiated while writing the final chapters of this thesis with an interdisciplinary group of six researchers led by neuroscientist Sara Aton. In this project, we plan to study the biological foundation of creativity across different domains (i.e., engineering, natural sciences, performing arts, visual arts); in other words, we plan to explore the neurobiological underpinnings of both creative traits (i.e., lifelong accomplishment and/or potential for creative thinking) and creative states (i.e., being in the moment of one's peak creativity or flow state) by longitudinally studying the behavior, physiology, and performance of individuals working in different domains (i.e., undergraduate and graduate students at the University of Michigan). This research was funded, but has not started yet. It will be another step in a domain that requires a steep learning curve, but that promises to illuminate and further develop some of the speculative ideas in this thesis based on empirical evidence that goes beyond the felt experience. In this case, the experimentation will include monitoring the biology underlying creative processes (i.e., brain activity, cardiovascular activity, eye movements, etc.) below the threshold of consciousness. As "the visual artist" in this project (i.e., co-principal investigator leading the visual art cohort), I am less interested in developing a mechanistic understanding of creativity. I am most interested to better understand the "rhythm" of barriers and flow in a creative process related to reported or observed cycles of doing and undergoing and Dewey's concept of an aesthetic experience and creative production.

However, fully exploring the innovation potential of *Ludic Engineering* for the lived body in this project will require a different effort; it will require to "bring to use" the inclusive augmented reality system, *iGYM*, invented at the end of the *Solar Pink Pong* case study. Making this system available as a platform (i.e., product) to enable new interactive experiences for players with different abilities outside of user studies remains a priority for which yet other strategies and skills are needed; productizing the system will be key for the broader impact of this project as a whole. As such, this next step will also be key for providing the most complete account of the *Ludic Innovation* process in this case study – and for the larger vision of bringing *Ludic Engineering* from the fringes of art and HCI closer to the center of a new field of research and practice.

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Appendix A: Invention Reports

TECHtransfer
UNIVERSITY OF MICHIGAN

File # __________

Invention Report - CONFIDENTIAL

TITLE OF INVENTION (Generic - See Instructions)

Sun-Powered Street Video Game Console

BRIEF SUMMARY (Attach abstracts, manuscripts, additional information - See Instructions)

BACKGROUND
Videogame culture and technology is usually limited to TV or computer screens and the dimmed light conditions of the living room. This limitation promotes the indoor culture of the video game industry or what the PBS documentary â The Video Game Revolutionâ called â the battle of the living roomâ (i.e. Sony, Sega, Microsoft and others fighting about their market share). Physical outdoor activities are for video game players seemingly out of reach of their consoles. As result of this indoor culture, playing video games is today as significant in discussions about childhood development and popular culture as playing on the street was for generations before.

TECHNOLOGY
Researchers at the University of Michigan have developed a new generation of video game console for a full body game, in which a moving sunlight reflection becomes the target and the streetâ s surface the screen. The console that makes this street video game possible resembles a miniaturized satellite and works completely off the grid. It can be mounted, for example, on a utility pole on the street and carries a moving dichroic color mirror that reflects direct sunlight as a colorful (e.g. neon pink) spot on the asphalt. Through motion sensing technology, pedestrians can interact with the spot. They can kick it with their feet or hit it with their handsâ shadows. They can play it back and forth with a partner or bounce it off a boundary such as a curb or road marking. A proof of concept exists already.

APPLICATIONS
Street video game

ADVANTAGES
- Re-invents the street as a public interface for playful interaction
- Combines full body gaming and outdoor play
- Fully sun-powered/off the grid

Wireless Integrated MEMS (WIMS)?_NO_ Software? _No_

INVENTION SUPPORT

Any Federal research grants used? If so, please list agency, federal grant number, and UM Project or Short Code:
N/A

Developed with Corporate, State or Foundation Funds? If so, please list the sponsor and DRDA #:
N/A

Any materials or data from another party? If so, please list the materials and the third party:
N/A

Any third party collaborators? If so, please list name(s) and organization(s):
N/A

Does any contributor have a financial interest in an involved research sponsor, material provider, or potential licensee?
Uncertain

Have you entered into any contracts with third parties related to this invention? If so, please identify these contracts.

Page 1

TECHtransfer
University of Michigan

Invention Report - CONFIDENTIAL

File # __________

No

PUBLICATON DATE(S) (Papers, posters, abstracts, talks, etc. including those that are planned - See Instructions)

Faculty Presentation (Nov 21, 2013), Project presented as part of my 3 year talk in front of Faculty colleagues.
Faculty Show (Jan 10 - Feb 21, 2014), Prototype shown at the Slusser Gallery, Art & Architecture building, University of Michigan. In addition to the show the project will be featured on school website and printed brochures.
Vector Game + Art Convergence Festival (Feb 19-23, 2014) - pending
ISEA2014 (mid-November 2014) - pending

COMMERCIAL POTENTIAL (First listed is primary contact - See Instructions)

Closest known product/technology? Kinect for Xbox (Microsoft), Cyberlight (High End Systems)
Potential Licensees? Video game console manufacturers (e.g. Microsoft, Nintendo, Sony, etc.) and entertainment lighting manufacturers (e.g. High End Systems, Rosco Laboratories, etc.)
If this is software, and it is a modification or improvement to an existing work, or incorporating elements not original to the developer(s), identify that work and its developer(s). No

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Does any contributor have a financial interest in an involved research sponsor, material provider or potential licensee?
___Yes ___No ___Uncertain

File # __________

TECHtransfer UNIVERSITY OF MICHIGAN

Invention Report - CONFIDENTIAL

TITLE OF INVENTION (Generic - See Instructions)

Sun-Powered Â   Laser-Like Projector

BRIEF SUMMARY (Attach abstracts, manuscripts, additional information - See Instructions)

BACKGROUND
Laser projectors are typically used to entertain an audience with light shows or special effects in dark environments or at nighttime events. The coherent nature of laser light and its narrow beam allow the laser projector to draw patterns, letters or even images on walls or other surfaces. However, such laser effects are typically generated by artificial light and electric power sources. There have been no laser effects developed yet for daytime events making use of the light and power of the sun.

TECHNOLOGY
Researchers at the University of Michigan have designed an optical system that turns sunlight into a narrow beam of light similar to that of a laser pointer. This optical system condenses, collimates, and filters sunlight in order to project it as a sharp edged spot over long distances. Using laser-scanning technology, this "sunlight-laser" beam can produce laser-like graphics or animations – outdoors in bright daylight conditions or indoors projected though an opening in a building. Further, it can be used to project enhanced graphics for interactive media such as video games (see Report 6041). There are only concept sketches and mock-ups available so far.

APPLICATIONS
Sun-powered "laser" projector for
- Sunlight "laser" shows
- Commercial outdoor daylight displays or billboards
- Interactive media (such as video games)

ADVANTAGES
- Opens up new artistic and commercial daylight applications for laser technology/effects
- Diameter of "sunlight-laser" beam can easily be scaled up to a few inches and more
- Fully sun-powered/off the grid

Wireless Integrated MEMS (WIMS)? _NO_	Software? _No_

INVENTION SUPPORT

Any Federal research grants used? If so, please list agency, federal grant number, and UM Project or Short Code: N/A
Developed with Corporate, State or Foundation Funds? If so, please list the sponsor and DRDA #: N/A
Any materials or data from another party? If so, please list the materials and the third party: N/A
Any third party collaborators? If so, please list name(s) and organization(s): N/A
Does any contributor have a financial interest in an involved research sponsor, material provider, or potential licensee? Uncertain

File # __________

Invention Report - CONFIDENTIAL

Have you entered into any contracts with third parties related to this invention? If so, please identify these contracts.
No

PUBLICATON DATE(S) (Papers, posters, abstracts, talks, etc. including those that are planned - See Instructions)

No public disclosure planned yet.

COMMERCIAL POTENTIAL (First listed is primary contact - See Instructions)

Closest known product/technology?
Laser Scanners (e.g. United Laser)

Potential Licensees?
Entertainment lighting manufacturers (e.g. United Laser) and electronic display or billboard manufacturers (e.g. Daktronics)

If this is software, and it is a modification or improvement to an existing work, or incorporating elements not original to the developer(s), identify that work and its developer(s).
N/A

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Does any contributor have a financial interest in an involved research sponsor, material provider or potential licensee?
___Yes ___No ___Uncertain

TECHtransfer
UNIVERSITY OF MICHIGAN

File # __________

Invention Report - CONFIDENTIAL

TITLE OF INVENTION (Generic - See Instructions)

Sun-Powered Gobo/Film/Video Projection System or Media Facade

BRIEF SUMMARY (Attach abstracts, manuscripts, additional information - See Instructions)

BACKGROUND
Gobo, film, or video projection systems require powerful artificial light sources and low ambient light to create the best image quality. Natural daylight or direct sunlight interferes rather than supports these projection systems. There have been no outdoor projection systems developed yet, which make use of direct sunlight for the projection itself.

TECHNOLOGY
Researchers at the University of Michigan have designed a system to use sunlight for a daylight projection system (in both front and rear-projection version) that displays static or moving images in black & white, greyscale, or full color. Core of this invention is an optical system that condenses sunlight and filters it through a physical template (e.g. glass gobo) to create a static image on a screen or other surface. Alternatively, sunlight can also be filtered through a moving template (e.g. spinning wheel or film) or a LCD panel to create a moving image. A first proof of concept is planed using a spinning wheel manually operated by a hand-crank like early cinematographs. Only idea sketches are available so far.

APPLICATIONS
Sun-powered gobo/film/video projection system or media facade for:
- Commercial or artistic outdoor displays or billboards
- Outdoor movie systems

ADVANTAGES
- Opens up new artistic and commercial daylight projection systems
- Fully sun-powered/off the grid

Wireless Integrated MEMS (WIMS)? _NO_ Software? _No_

INVENTION SUPPORT

Any Federal research grants used? If so, please list agency, federal grant number, and UM Project or Short Code:
N/A

Developed with Corporate, State or Foundation Funds? If so, please list the sponsor and DRDA #:
N/A

Any materials or data from another party? If so, please list the materials and the third party:
N/A

Any third party collaborators? If so, please list name(s) and organization(s):
N/A

Does any contributor have a financial interest in an involved research sponsor, material provider, or potential licensee?
Uncertain

Have you entered into any contracts with third parties related to this invention? If so, please identify these contracts.
No

TECHtransfer
UNIVERSITY OF MICHIGAN

File # __________

Invention Report - CONFIDENTIAL

PUBLICATON DATE(S) (Papers, posters, abstracts, talks, etc. including those that are planned - See Instructions)

No public disclosure planned yet.

COMMERCIAL POTENTIAL (First listed is primary contact - See Instructions)

Closest known product/technology?
Gobo (e.g. InLight Gobos), DLP front and rear projection systems (e.g. Texas Instruments), video projector (e.g. Epson, BenQ, etc.)

Potential Licensees?
Gobo manufacturers (e.g. InLight Gobos), DLP front and rear projection systems (e.g. Texas Instruments), video projector manufacturers (e.g. Epson, BenQ, etc.), electronic display or billboard manufacturers (e.g. Daktronics)

If this is software, and it is a modification or improvement to an existing work, or incorporating elements not original to the developer(s), identify that work and its developer(s).
N/A

CONTRIBUTORS (See Instructions. First listed is primary contact)

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Does any contributor have a financial interest in an involved research sponsor, material provider or potential licensee?
___Yes ___No ___Uncertain

Page 2

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File # __________

Invention Report - CONFIDENTIAL

Instructions for University of Michigan Invention Report

The Invention Report (IR) records the description and circumstances in which an invention was created or technology was developed.

Title of the Invention
Use a brief title, omitting any confidential information, acronyms, and trademarks (title should be very generic).

Brief Summary
Write or type a general description of the invention. In addition.

(a) Please attach a detailed description of the invention, including a technical description, advantages/improvements over existing methods/devices/materials, and possible modifications;
(b) Please attach any related manuscripts, publications, presentations, posters, etc.

Invention Support
The University is required to report all inventions made with Federal funding to the relevant agency, so it is imperative that you provide details on all federally funded inventions, in particular the agency and the grant number. Please list all other potentially relevant grants, funds, collaborations, or materials received from third parties such that we can do the appropriate reporting to the sponsoring groups and determine if there are any pending license rights to the invention.

Publication Dates
Provide accurate dates and comments to enhance the understanding of critical events and/or make a note that you wish to discuss these issues with us. We are interested in any potential public disclosure (papers, posters, abstracts, talks, etc. including those that are planned) of the invention, to help us and our lawyers evaluate any potential patent protection issues.

Contributors
Contributors are individuals who may have conceived or developed elements of the invention, either independently or jointly with others. If this IR results in a patent application, a patent attorney will determine inventorship based on information from contributors listed in this form. The Contribution % represents the amount that each Inventor contributed to the invention. Fill it in to provide your mutual assessment of each person's relative contribution to the concepts of the invention. The percentages for all UM contributors should add up to 100%. Generally, OTT will use this percentage as an initial basis for a draft Revenue Distribution Plan (RDP). For more information on the RDP process, visit www.techtransfer.umich.edu/resources/inventors/royalties.php. For definitions, including what constitutes being an Inventor, visit www.techtransfer.umich.edu/resources/policies.php#definitions. License revenues, if any, will be distributed according to University policy. The first individual listed will be OTT's primary contact, and agrees to act as conduit of information with the other contributors. Please provide complete addresses (including city, state, zip for home address). Any non-UM affiliation should be stated (e.g., corporate, Department of Veterans Affairs (VA), Howard Hughes Medical Institute (HHMI), other university, or joint appointments). Attach an extra sheet if necessary.

Declaration and Submission
All contributors must review and sign the Declaration, filling in the title of the invention. Please mail and/or e-mail your completed form to the following, and follow up by mailing the original of the first two pages of the IR form if you are submitting by email:

UM Office of Technology Transfer
c/o Patent Administrator
1600 Huron Parkway, 2nd Floor
Ann Arbor, MI 48109-2590
Phone: 734.763.0614
Email: umpatentadmin@umich.edu

Questions
Contact Robin Rasor, Director of Licensing at robinlr@umich.edu or 734.615.8433 and/or see www.techtransfer.umich.edu.

Attorney-Client Privileged Communication – The information in this Invention Report is confidential and should not be disclosed to persons outside the University or to persons not requiring access to this information.

Ver 8.12.09

Appendix B: Utility Patent I

US009547162B2

(12) **United States Patent**
Graf et al.

(10) **Patent No.:** **US 9,547,162 B2**
(45) **Date of Patent:** **Jan. 17, 2017**

(54) **INTERACTIVE PROJECTION SYSTEM**

(71) Applicant: **THE REGENTS OF THE UNIVERSITY OF MICHIGAN**, Ann Arbor, MI (US)

(72) Inventors: **Roland Graf**, Ann Arbor, MI (US); **Surat Kwanmuang**, Bangkok (TH)

(73) Assignee: **The Regents Of The University Of Michigan**, Ann Arbor, MI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/052,950**

(22) Filed: **Feb. 25, 2016**

(65) **Prior Publication Data**

US 2016/0246039 A1 Aug. 25, 2016

Related U.S. Application Data

(60) Provisional application No. 62/120,541, filed on Feb. 25, 2015.

(51) **Int. Cl.**

A63G 31/00	(2006.01)
G02B 19/00	(2006.01)
G02B 26/08	(2006.01)
F21S 9/03	(2006.01)
G09F 19/18	(2006.01)
G02B 26/00	(2006.01)

(52) **U.S. Cl.**
CPC ***G02B 19/0042*** (2013.01); ***F21S 9/035*** (2013.01); ***G02B 26/0816*** (2013.01); ***G09F 19/18*** (2013.01)

(58) **Field of Classification Search**
CPC A63G 31/00; G02B 5/00; G02B 6/0065; G02B 21/00; G02B 21/56; G02B 27/2292; G02B 27/2235; G02B 17/061
USPC 472/59, 61, 130; 353/73, 74, 79–80, 120, 353/121; 359/443, 449, 459
See application file for complete search history.

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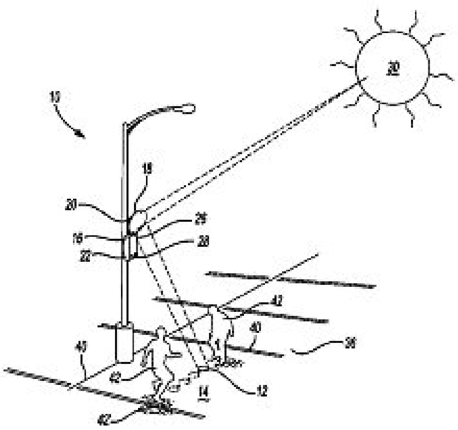
Primary Examiner — Kien Nguyen
(74) *Attorney, Agent, or Firm* — Harness, Dickey & Pierce, PLC

(57) **ABSTRACT**

An interactive projection system for outputting illuminated indicia upon a projection surface. A detection system is operable to detect both stationary and movable features. A control system is operable to determine the position of the stationary and movable features. A reflective device reflects light from a light source (natural and/or artificial) upon the projection surface as the illuminated indicia. A drive system moves the reflective device, thereby moving the illuminated indicia across the projection surface in response to control system thereby simulating the stationary feature on the projection surface as a physical boundary to the illuminated indicia and simulating the movable feature contacting the illuminated indicia.

14 Claims, 3 Drawing Sheets



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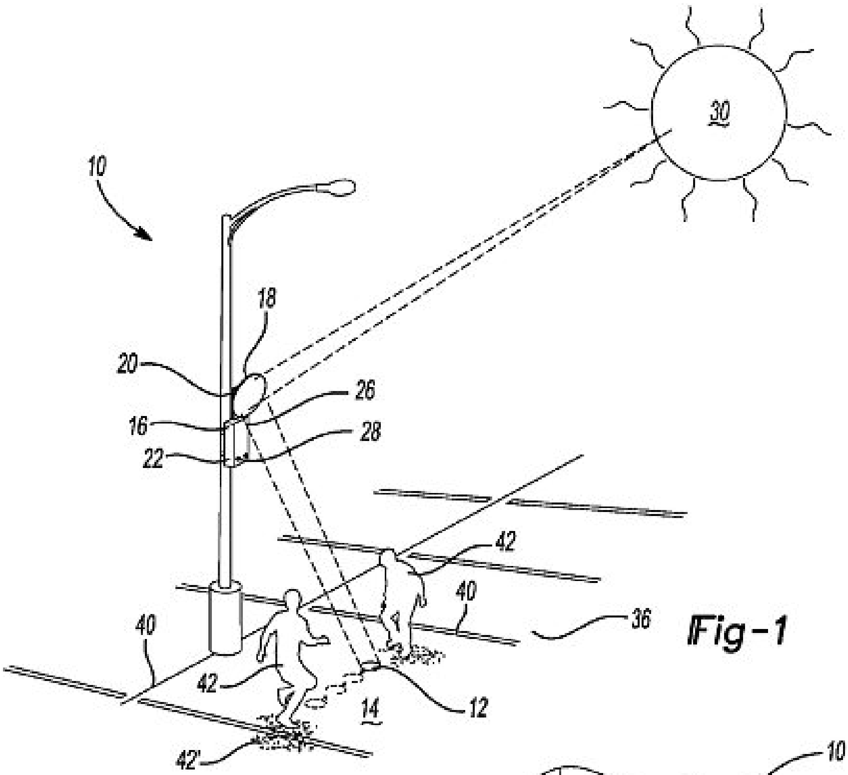
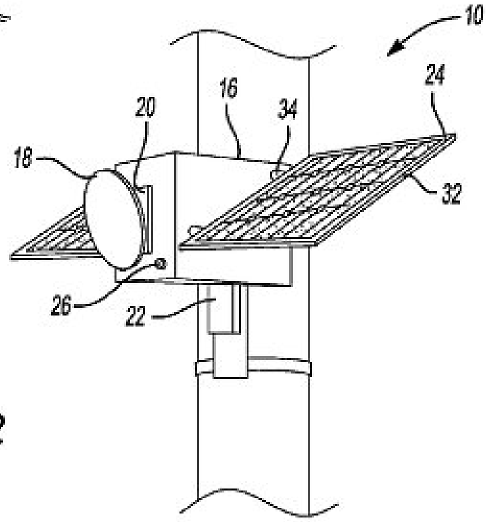


30
10
18
20
26
16
28
22
42
40
36
40
42
14
12
42'

Fig-1



10
24
16
20
34
18
32
26
22

Fig-2

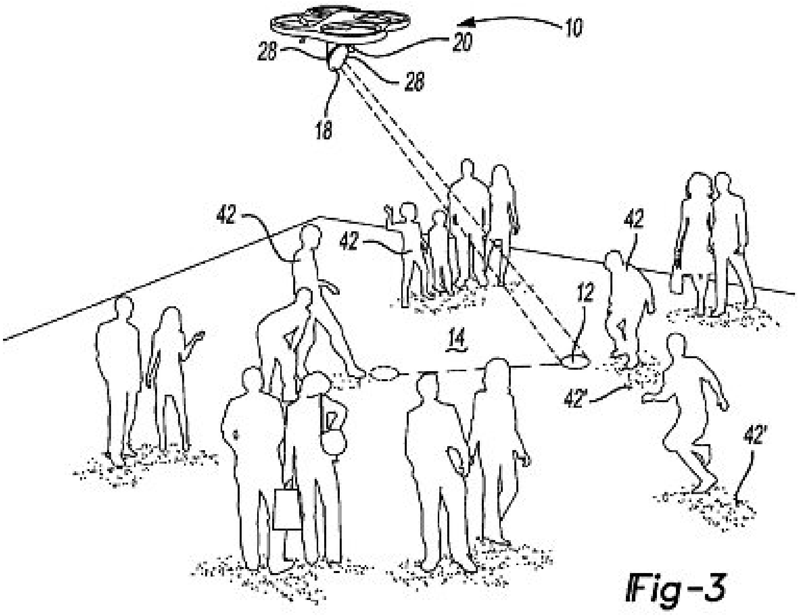


Fig-3

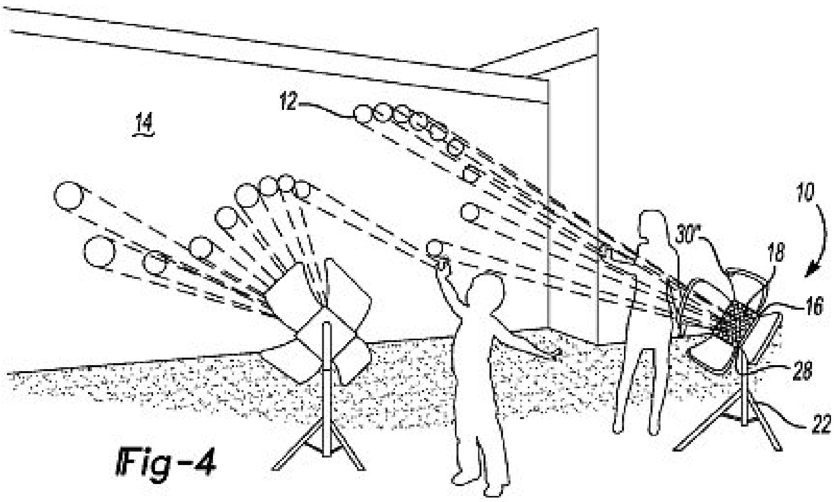


Fig-4

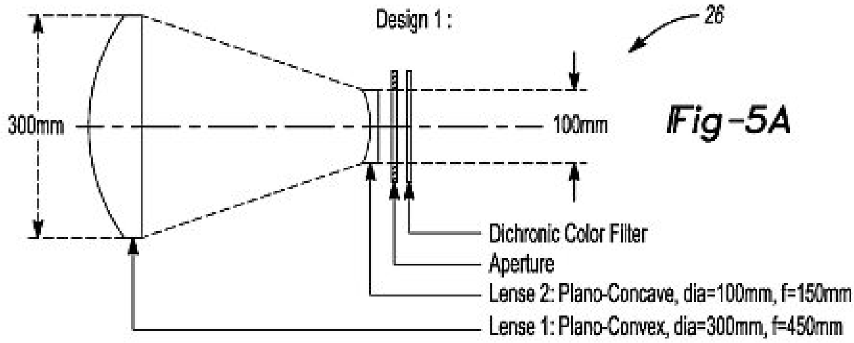


Fig-5A

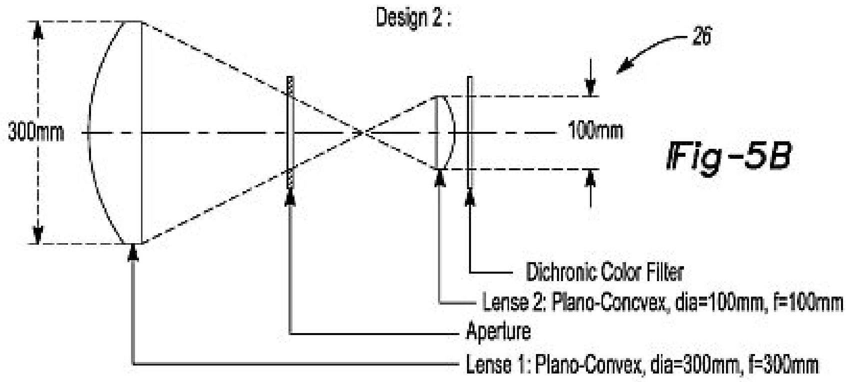


Fig-5B

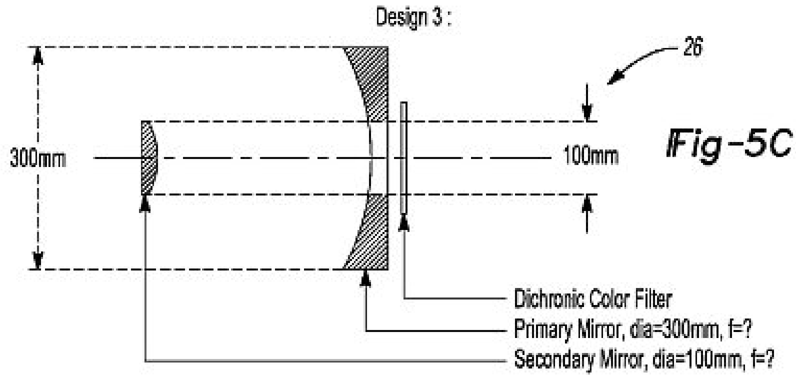


Fig-5C

INTERACTIVE PROJECTION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 62/120,541, filed on Feb. 25, 2015. The entire disclosure of the above application is incorporated herein by reference.

FIELD

The present disclosure relates to an interactive projection system and, more particularly, relates to an interactive projection system employing sunlight and/or artificial light to produce static and/or dynamic images on indoor or outdoor surfaces that can be controlled by body and shadow movement, without the use of separate input devices or wearables.

BACKGROUND AND SUMMARY

This section provides background information related to the present disclosure which is not necessarily prior art. This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

Generally, interactive games or interfaces are limited to use on TV, computer screens, or conventional (digital video projections) and perform best in dimmed light conditions of a living room. To date, daylight or direct sunlight has not yet been consequently explored for the use in display or entertainment systems. In most video game applications, for example, direct sunlight interferes with, rather than supports, video displays and (motion-sensing) systems. On one hand, this latent incompatibility of sunlight with the performance of interactive media systems promotes an indoor media culture. As a result, physical outdoor activities often conflict with video gaming activities. On the other hand, people who do want to use interactive media systems in outdoor environments, for example to play video games (e.g. location based street games) rely on small displays of mobile devices and/or wearable technology with which they often "screen" the physical environment out rather than to fully engage with it.

Accordingly, there exists a need to provide an interactive media experience that is not limited to indoor applications. Moreover, there exists a need to provide an interactive media experience that can naturally co-exist and augment the physical environment in which it is used to create an immersive location-based (or site-specific) interactive experience that is encumbered by any wearable technology. Furthermore, there exists a need to provide an interactive media experience that is capable of employing natural sunlight as the operable light source for the media experience. Still further, there exists a need to provide an interactive media experience that can be used in both sunlight and artificial light applications.

In accordance with the principles of the present teachings, an interactive projection system for outputting illuminated indicia upon a projection surface is provided having advantageous construction and method of use. A detection system is provided that is operable to detect both stationary and movable features. A control system is operable to determine the position of the stationary and movable features from sensors such as, but not limited to, imaging sensors and the position of the light source. A reflective device reflects light from a light source (natural and/or artificial) upon the projection surface as the illuminated indicia. A drive system moves the reflective device, thereby moving the illuminated indicia across the projection surface in response to control system thereby simulating the stationary feature on the projection surface as a physical boundary to the illuminated indicia and simulating the movable feature contacting the illuminated indicia.

In some embodiments of the present teachings, an interactive projection system is provided which enables one or more players to play a full body game, in which one or several moving sunlight reflections (or focused video or laser projections) serve as the target and the street or other outdoor/indoor surface serves as the screen. Through motion sensing technology, players, such as pedestrians or animals, can interact with the projected target as physical beings unencumbered by screens or controllers. The player can "contact" the projected target with their hands, feet, or the associated shadow cast by their body or limb. In some embodiments, the players can play with each other by bouncing it off the hands, feet, or associated shadow, and/or by bouncing it off either naturally occurring physical structures (curbs, road markings, or other delineations) or predefined artificial boundaries. In some embodiments, the interactive projection system is self-powered, such as via solar energy. In the case of solar-powered installation, the control system is also operable to determine the amount of power generation, consumption and storage, thus adjust operation time accordingly.

Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

FIG. 1 is a schematic view of an interactive projection system according to some embodiments of the present teachings;

FIG. 2 is a perspective view of an interactive projection system employing solar energy according to some embodiments;

FIG. 3 is a perspective view of an interactive projection system employing a drone according to some embodiments;

FIG. 4 is a perspective view of an interactive projection system employing a portable structure according to some embodiments; and

FIGS. 5A-5C illustrate a plurality of possible additional lens element arrangements when using sunlight in connection with a detection system.

Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION

Example embodiments will now be described more fully with reference to the accompanying drawings. Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms "a," "an," and "the" may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms "comprises," "comprising," "including," and "having," are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

Spatially relative terms, such as "inner," "outer," "beneath," "below," "lower," "above," "upper," and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the example term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

According to the principles of the present teachings, as illustrated in FIGS. **1-4**, an interactive projection system **10** is provided for outputting one or more illuminated indicia **12** upon a projection surface **14** that can be used in both indoor and outdoor applications. The projection surface can be in any orientations such as horizontal or vertical plane.

It should be understood that interactive projection system **10** may be useful in a wide variety of applications, such as, but not limited to, artistic/aesthetic lighting and display, advertising or information display, interactive outdoor video games (e.g. street video games), physical therapy, sports and recreation, animal entertainment, and the like. Accordingly, in some embodiments, advantages exist including, but not limited to, being completely solar-powered and providing high-intensity daytime displays.

In some embodiments, illuminated indicia **12** can comprise a pong-like member **12'**, being generally circular and projected upon projection surface **14**. However, it should be understood that illuminated indicia 12 can comprise any one of a number of static or dynamic changing depicted shapes or video images, including, but not limited to, geometric shapes (e.g. circular, oblong, elongated, square, rectangular, and the like), animal shapes (e.g. dog, cat, mouse, bird, and the like), sports-related shapes (e.g. football, basketball, tennis ball, and the like), logo or other advertising shapes, or other aesthetic illuminations.

With particular reference to FIGS. **1-3**, in some embodiments, interactive projection system **10** can comprise a housing **16**, one or more reflective devices **18**, one or more reflective device drive systems **20**, a mounting system **22**, a power system **24**, a detection system **26**, and a control system **28**.

In some embodiments, housing **16** can comprise a structure sufficient for containing and/or protecting one or more of reflective device **18**, reflective device drive system **20**, power system **24**, detection system **26**, and control system **28**. Housing **16** can be made of any suitable material capable of withstanding environmental effects, such as metal, plastic, and the like.

In some embodiments, reflective device **18** is supported by reflective device drive system **20** and is movable in every orientation in response thereto. Reflective device **18** is configured to reflect at least a portion of light from a light source **30** to projection surface **14**. To this end, in some embodiments, reflective device **18** can comprise a mirror, such as a dichroic mirror, for reflecting light source **30** to define illuminated indicia **12**. In this way, reflective device **18** can further collect, condense, collimate, focus, and/or filter light from light source **30** to project or display indicia **12** via one or more lens or mirror elements (see FIGS. **5A-5C**)) or other forms of sunlight concentration methods such as LSC (luminescent solar concentrator). Moreover, any light manipulation technology such as, but not limited to, go between optics (GOBOs), filters, dichroic mirrors, films, and LCD panels, DLP devices can be used to further manipulate the illuminated indicia **12**.

In some embodiments, light source **30** is a natural light source **30'** (e.g sun), thereby providing a naturally-occurring light and power source (as will be discussed herein). It should be appreciated that the sun's rays reach the Earth's atmosphere at intensity of over 1,000 W/m^2. Conventional power systems range from 0.75 watts for personal laser pointers to about 10's of watts for laser light show systems to about 100's of watts for projectors. Therefore, harnessing the sun's power results in an outdoor projection system capable of displaying advertising, information, aesthetic accents, or even video games with sufficient intensity to be easily seen even on bright days at practically zero power cost.

In some embodiments, however, light source **30** can comprise an artificial light source **30"**, such as incandescent, halogen, LED, fluorescent, laser, and other conventional illumination sources. Further, the light source can comprise a laser projector or a video projector—the latter in combination with a narrow beam angle projection lens system to achieve high luminosity output. To permit use of interactive projection system **10** in both natural light and artificial light applications, in some embodiments, interactive projection system **10** can comprise both natural light source **30'** and artificial light source **30"** in a hybrid illumination system. In this way, control system **28** can be used to actuate or otherwise operate artificial light source **30"** when natural light source **30'** is unavailable, which may result due to time of day or obstruction of the source (e.g. cloudy day, indoors, and the like). Further, additional artificial light sources can be used to create shadows if sunlight is not available.

In some embodiments, reflective device drive system **20** can comprise a mechanical apparatus operably connected between reflective device **18** and at least one of housing **16** and mounting system **22**. Reflective device drive system **20** can comprise one or more servomotors, stepper motors, brushless motors, pneumatic or hydraulic actuators that control the motion of reflective device **18** through a direct-connection or through a mechanism such as four-bar linkages, belts, chains that is protected from the harsh environment. In this way, reflective device drive system **20** can actuate reflective device **18** to 1) position reflective device **18** in a proper orientation to reflect light from light source **30** to projection surface **14** and 2) to animate illuminated indicia **12** upon projection surface **14** (e.g. to depict movement of illuminated indicia **12** across projection surface **14** and/or to vary a depicted shape of illuminated indicia **12**).

With reference to FIG. **2**, in some embodiments, mounting system **22** of interactive projection system **10** is used to mount housing **16** and the associated structure of interactive projection system **10** upon a mounting surface, such as poles, trees, buildings, or other suitable structure. It should be appreciated that mounting system **22** can define any shape suitable for mounting upon the selected mounting surface. Furthermore, it should be appreciated that mounting system **22** can comprise a portable structure, such as a stand (see FIG. **4**), to permit temporary support of interactive projection system **10**. Still further, mounting system **22** can comprise a movable platform, such as an aircraft, drone, pulley, line, or the like (see FIG. **3**).

Power consuming systems of interactive projection system **10** can be electrically powered by power system **24**. Although power system **24** can be a conventional power system using supplied alternating current (AC), or direct current (DC), in some embodiments, power system **24** comprises one or more solar panels **32** operably coupled to housing **16** and electrically coupled to a power distribution system (not shown) for powering reflective device drive system **20**, detection system **26**, control system **28**, and power storage system. In this way, interactive projection system **10** provides a self-contained assembly that is electrically independent from a local power grid, thereby permitting interactive projection system **10** to be portable and/or installed in locations without requiring connected electrical power.

In this way, power system **24** can further comprise a powered positioning system **34** operably positioning solar panels **32**, housing **16**, and/or reflective device **18** for optimal operation. That is, powered positioning system **34**, such as a geared stepper motor, servomotors, brushless motors, pneumatic or hydraulic actuators can operably actuate solar panels **32** to maximize solar efficiency and can operably actuated reflective device drive system **20** to maximize the reflective capability of reflective device **18** when illuminating indicia **12**. A GPS module can be used with the control system to determine the current location and time to properly position solar panels **32**, housing **16**, and/or reflective device **18** in correct alignment with the sun.

As illustrated in FIGS. **1-4**, detection system **26** of interactive projection system **10** can comprise one or more sensors and/or cameras operable to monitor one or several projection surfaces **14**. Detection system **26** can detect both stationary and moving objects within a predetermined area. Although, in some embodiments, the detection system **26** only detects objects within the corresponding area defined by the projection surface **14**, it should be understood that the detection system **26** can detect objects within a larger or smaller predetermined area, such as a field-of-play area **36** in game-playing scenarios. In this way, detection system **26** can be constrained to only detect objects within the projection surface **14** (that is, the field-of-play area **36** being equal to or smaller than the projection surface **14**) or can be permitted to detect objects outside the projection surface **14** (that is, the field-of-play area **36** is larger than the projection surface **14**).

In some embodiments, detection system **26** can be configured to be operational in bright sunlight applications, which often prove difficult for many motion tracking systems. For instance, during preliminary tests it was determined that the Microsoft Kinect sensor, which is often used for full body gaming, does not perform well in bright daylight. Accordingly, it has been found that a color camera, such as a Point Grey color camera with wide-angle lens, is particularly useful for detecting both stationary and moving objects in the predetermined area.

Detection system **26** can be configured to detect stationary objects and/or features **40** within the predetermined area. The stationary features can be both physical, such as curbs, walls, lines, or other transitional features found in the natural environment, or non-physical, such as artificially defined boundaries or borders. These stationary features, both those that are physically occurring and those that are non-physical but arbitrarily applied to the physical world, can serve as defined boundaries for display of indicia **12**. In the embodiments, such as during a pong-like game play, indicia **12** can be moved about the field-of-play **36** and can "strike" these stationary objects, thereby reversing course or "bouncing" there off. By using at least some of the aforementioned transitional features that naturally occur in the environment, interactive projection system **10** can appear to be aware of and/or respond to the natural environment.

Likewise, detection system **26** can be configured to detect movable objects **42** within the predetermined area. The movable objects can include the physical shape of players, humans, and animals. Moreover, detection system **26** can detect the associate shadow cast by movable objects **42'**, such as the shadow of a hand, foot, head, body, arm, leg, or other feature. Likewise, the system can be programed to detect additional moving sunlight reflections or laser or light points as targets in the playfield. The detection system also converts detections in the camera reference frame to the reference frame of the projection surfaces **14**. It should be recognized that detection system **26** is capable of detecting and tracking a plurality of stationary and movable objects, thereby permitting players, humans, and animals to each have an effect on indicia **12** during use.

Control system **28** can comprise a central processing unit receiving input signals from detection system **28** and outputting signals to one or more of reflective device drive system **20**, power system **24**, and a detection system **26**. In some embodiments, control system **28** can comprise a computational device such as laptop computer or computing module with wired or wireless communications system operably coupled to control system **28** to permit user access, via a public web interface, Bluetooth, Wi-Fi, cellular, or other protocol, to monitor status and/or watch live gameplay over the Internet. In some embodiments, control system **28** can comprise a computer vision module in the form of software running on the computational device or a separate hardware module to process the video stream from detection system **26** to distinguish players and their shadows from the background. Together with the position estimation of the light source position from the control system, a pong-like game program can output the desired reaction position to reflective device drive system **20** to actuate the positioning of reflective device **18** (thereby animating indicia **12**).

In some embodiments, interactive projection system **12** can comprise an audio system for outputting audio (e.g. additional audio feedback such as a "Pong" sound, an annunciation for the system status, public announcement or an advertisement message). In some embodiments, interactive projection system **12** can comprise a plurality of reflective devices **18** to permit a plurality of indicia **12** to be illuminated simultaneously.

Gaming Applications

Humans are physical beings that are adapted to exist naturally in the outdoors. However, many of the popular video games of today require indoor use. However, the interactive projection system of the present teachings can transform a street in bright daylight into an interactive immersive environment.

In this environment, pedestrians can play video games as physical beings unencumbered by screens or controller. Free from input devices and exposed to sunlight, players find both their bodies and shadows present in the game. In some embodiments, of interactive projection system turns a simple sunlight reflection on the ground into the target of a pong-style or hockey-style street game that can be played with the whole body. That is, in some embodiments, interactive projection system **10** builds on the simple screen-based game mechanics of Pong, but enables players **42** to use a more natural interaction behavior similar to playing with a real ball. In fact, it is designed to offer an immersive and location-based gameplay experience in bright daylight without the use of any wearable sensor or head mounted display technologies.

In some embodiments, an illuminated pink circle **12**, generated by sunlight and/or artificial light, moves at a constant speed of 2.5 m/s on the ground **14** and appears to react and/or respond to the natural environment. That is, it bounces back from play field boundaries **40** or anything that the detection system **26** detects as body contours or shadows **42**, **42'** on the ground **14**, thereby mimicking natural reflection of a ball or other object impacting a player or surface. For example, during play, players **42** can kick the spot with their feet or hit it with the shadows of their hands. They can volley it back and forth with a partner **42** or bounce it off a boundary **40**, such as a curb or road marking. The shadow play of the game tends to be one of the preferred ways of interaction with the spot **12**. However, the space in which these interactions occur goes far beyond a conventional screen. It should be understood that the speed of circle **12** can be dependent on the magnitude of the "contact force"—that is, how "hard" a player strikes the circle 12. Moreover, the speed of circle **12** can be dependent on other perceived physical properties, such as friction, weight, resistance, and other motion dynamics and characteristics of bodies in motion.

It should be appreciated that the custom designed dichroic mirror **18** makes the sunlight almost magically appear as a colorful spot **12** on the street like an animated pixel on a screen. Unlike the steady light of a screen or video projector, however, it is the ephemeral nature of daylight that forms the basis of this street video game and blurs the boundaries between interactive media and daylight as a medium.

It has been found that players positively respond to play field boundaries being matched to the natural boundaries of the game location (i.e. walls, curbs, road markings, etc.). This enhances the immersive and location based character of the game. Further, it has been found that increasing the speed and precision of the spot can make the game both more challenging and fun to play.

The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

What is claimed is:

1. An interactive projection system for outputting illuminated indicia upon a projection surface, the projection surface having a stationary feature and a movable feature, the stationary feature defining a perceived spatial limit inhibiting movement of the indicia across the projection surface, the movable feature defining a perceived engaging member contacting the indicia, the interactive projection system comprising:

a detection system directed toward at least a portion of the projection surface, the detection system outputting a detection signal in response to the stationary feature and movable feature;

a control system operable to receive the detection signal and determine a position of the stationary feature and the movable feature, said control system determining a boundary of the projection surface based on the determined position of the stationary feature and the movable feature and outputting a projection control signal in response to the determined boundary,

a reflective device reflecting light from a light source upon the projection surface as the illuminated indicia; and

a reflective device drive system coupled to the reflective device, said reflective device drive system is configured to move the reflective device thereby moving the illuminated indicia across the projection surface in response to the projection control signal thereby simulating the stationary feature on the projection surface as a physical boundary to the illuminated indicia and simulating the movable feature contacting the illuminated indicia.

2. The interactive projection system according to claim **1**, wherein the detection system comprises one or more detection sensors operable to detect a stationary physical feature on the projection surface.

3. The interactive projection system according to claim **2** wherein the stationary physical feature is chosen from the group consisting essentially of a curb, a wall, a physical delineation.

4. The interactive projection system according to claim **1**, wherein the detection system comprises one or more detection sensors operable to detect a stationary non-physical feature on the projection surface.

5. The interactive projection system according to claim **4** wherein the stationary non-physical feature is an artificially-defined border.

6. The interactive projection system according to claim **1**, wherein the detection system comprises one or more detection cameras operable to detect a movable shadow of a user.

7. The interactive projection system according to claim **1**, further comprising:

a power supply system electrically coupled with at least the control system, the detection system, and the reflective device drive system.

8. The interactive projection system according to claim **7** wherein the power supply system is a solar power supply system.

9. The interactive projection system according to claim **8**, further comprising:

a power positioning system coupled to the solar power supply system, the power positioning system is configured to move the solar power supply relative to the sun.

10. The interactive projection system according to claim 1 wherein the reflective device reflects light from the sun upon the projection surface as the illuminated indicia.

11. The interactive projection system according to claim 10 wherein the reflective device drive system is configured to move the reflective device relative to the sun.

12. The interactive projection system according to claim 1 wherein the light source is an artificial light source.

13. The interactive projection system according to claim 1 wherein the light source is chosen from the group consisting essentially of incandescent, halogen, LED, fluorescent, laser, and video or laser projector.

14. The interactive projection system according to claim 1 wherein the reflective device selectively reflects light from the sun and artificial light upon the projection surface as the illuminated indicia.

* * * * *

Appendix C: Commercial Assessment

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EARLY COMMERCIAL ASSESSMENT FOR DISCUSSION

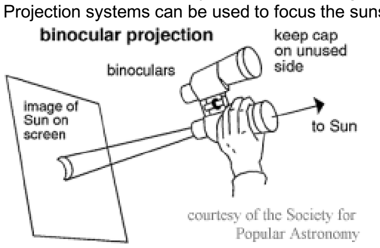
Confidential – Do Not Distribute

IR#	6080, 6081, 6082	Manager Initials	KM
Date Received by Fellow	22 January 2014	Fellow Initials	
Original Title	System and methods for sun-powered outdoor projection system		
Improved Title (if necessary)	Sun-powered outdoor projection system or interactive video game		
Classifications	Application Categories: *Physical Science: Instrumentation* Technology Taxonomy: *Physical Science: Instrumentation: Optical*		
Keywords	Sun-powered, interactive videogame		
Stage of Development	Working prototype for PinkPong video game		
Pending Disclosures	Previous • 21 Nov 2013 – Talk presented to UM faculty colleagues • 10 Jan through 21 Feb 2014 – Prototype (for PinkPong game) to be shown at Slusser Gallery and featured on university website and printed material • Video uploaded to internet ~3 months ago (link) Pending • 19-23 February 2014 – Vector Game + Art Convergence Festival presentation • November 2014 – International Symposium on Electronic Art		

SECTION 1. TECHNOLOGY DETAILS

State of the art

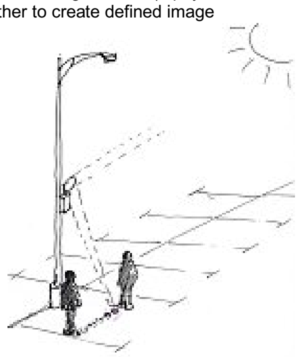
- At the Earth's atmosphere, solar intensity is ~1 kW/m^2 [(3)]
    - A high-end conventional laser pointer is on the order of ~ 1 W/m^2 [(4)]
    - Harnessing this power could create an impressive, energy efficient projection system with adequate intensity to be visible during daylight
- Projection systems can be used to focus the suns rays for observation of solar events[1,2]



Disclosed technology

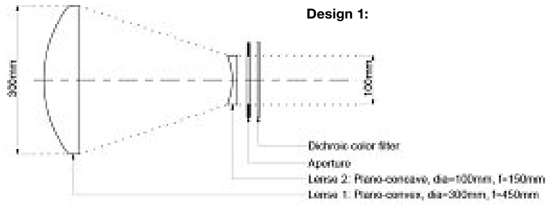
- Sunlight can be collected, condensed, collimated, and filtered to project an image or images
    - Easily visible even in bright conditions outdoors

- Can be projected indoors (from outdoor source)
- Sharp edges and long projection distances
- Filter through GOBO (a physical filter to project light in a defined shape/pattern), LCD filter, or other to create defined image

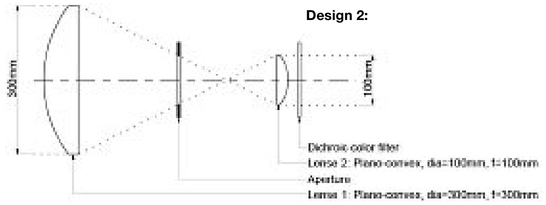


- Static or dynamic image projection
  - Project moving images
  - Respond to user interaction
- Can control sharpness and strength of beam with optics

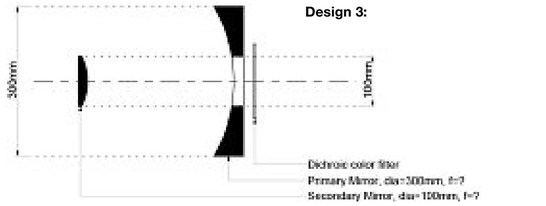
Design 1:



Design 2:



Design 3:



Sources (with hyperlinks)
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2. http://www.skyandtelescope.com/observing/objects/sun/3309106.html?page=2&c=y
3. http://www.starhop.com/library/pdf/studyguide/high/SolInt-19.pdf
4. http://www.wickedlasers.com/inferno

SECTION 2. POTENTIAL APPLICATIONS

- Interactive outdoor games
- Outdoor advertising
- Outdoor projection/movie systems
- Laser light shows
- Ambient lighting for architectural/landscaping

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SECTION 3. MARKET OVERVIEW

Market:
Established/Existing __
Emerging _x_
Future __

- Digital display signage market[1]
  - 2011 global revenue estimated at $1.1 billion (~$400 million for display alone)
    - Promising growth prospects
    - Projected to grow to $2.5 billion (~$850 million) by 2017
  - Drivers
    - Convergence of technology
    - Focus on content creation
    - Increasing affordability
  - Restrains
    - Weak economy
    - Elongated sales cycles
  - Lots of vendors are launching green initiatives
    - Save money
    - Value-added selling point
    - Enhance brand image
- Global LED lighting market[2]
  - Worth $9 billion in 2012
    - Expected to grow to $36 billion by 2017
    - Driven in a large part by outdoor and residential applications
  - Outdoor applications currently comprise 10 percent of market
    - Expected to provide the greatest growth opportunity
    - Reach 13.5 percent by 2017
- Video games in the US[3]
  - 114 million people play video games
    - Expected to make $10 billlion worth of purchases in 2013
  - Growth is being driven by emergence of non-traditional markets
    - Interactive, active games like Wii Fit and EA Sports Active are key examples
    - Active games can also be used for health maintenance or treatment

Sources

1. Frost and Sullivan. “Global digital signage systems market.” 2012.
2. Frost and Sullivan. “World LED lighting markets (2013 update). December 2013.
3. Packaged Facts. “The adult videogamer market in the U.S.” Janaury 2009.

SECTION 4. COMPETITION

Marketed Products

- PT-AR100U PRojector (Panasonic)
  - 280 Watt lamp
  - 1080p projection resolution
  - “Comfortable viewing in various lighting conditions”
  - ~$1300 per unit
  - https://www.panasonic.com/business/projectors/PT-AR100U.asp
- Inferno laser pointer (Wicked Lasers)
  - 750 mW laser
  - $400 per unit
  - Personal use laser
  - http://www.wickedlasers.com/inferno
- Luminance RGB 5000 (CT.Lasers)

  - 5 W overhead laser show system
  - http://www.ctlasers-store.com/luminancergb_p/luminance5000.htm
- Xbox Kinect (Microsoft)
  - Interactive gaming system
  - Sense/track movement without any other sensors
  - $100 per unit
  - http://www.xbox.com/en-US/kinect

SECTION 5. KEY COMMERCIALIZATION CHALLENGES

- This product can only be used during sunny periods.
  - What is the best way to market the device to as to allay concerns over that?
  - Are there any available workarounds or companion technologies that can be packaged with this one to address those concerns?
- What resolution can be achieved when using the disclosed technology as a projection system? Is it comparable to current HD projection technology?
- Does the 10 m projection radius of the videogame also apply to other projection sytems? What is the limit of those systems?
- Are there any added value-features that can be incorporated into PinkPong system to further differentiate it from traditional games (kick the can) and interactive video games (Wii, Kinect, etc.)?
- Are there any safety concerns with focused and/or reflected sunlight? How can those be mitigated?

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SECTION 6. MARKETING SUMMARY

The sun's rays reach the Earth's atmosphere at an intensity of over 1,000 W/m^2. Conventional system powers range from 0.75 watts for personal laser pointers to ~10's of watts for laser light show systems to 100's of watts for projectors. Harnessing the sun's power could create a next-generation outdoor projection system capable of displaying advertising, information, aesthetic accents, or even video games with sufficient intensity to been easily seen even on bright days at practically zero power cost. Such a system would be, self-sufficient, off-grid, and customizable for a variety of uses.

Sun-powered versatility
By using an appropriate configuration of lenses, condensers, and collimators this technology harnesses the power of the sun to display moving or static images. Go between optics (GOBOs), filters, dichroic mirrors, film, and LCD panels are among options available for manipulate the display image(s). This self-powered system represents a powerful, versatile, and customizable solution for a variety of applications in outdoor display, landscape architecture, advertising, and entertainment.

Applications
* Artistic/aesthetic lighting and display
* Advertising or information display
* Interactive outdoor videogames

Advantages
* Completely solar-powered
* High-intensity daytime display
* Interactive videogames, advertising, or display system

Sun-powered interactive videogame provides hours of outdoor fun
Solar PinkPong – the next-generation street video game; R. Graf

SECTION 7. KEY COMPANIES

Company Name, Country	Brief Description and Rationale for Interest	Business Development Contact (ONLY if readily available)
CT. Lasers Connecticut, USA	FDA/CDRH certified laser light show equipment manufacturer. Connecticut Lasers is one of the nations top suppliers for Laser light show components, Laser light show projectors, Laser advertising systems and Laser light show equipment.	Phone: (203) 889-1319 (Leave a voice mail. We ALWAYS return phone calls) [emphasis theirs]
The Active Gaming Company Massachusetts, USA	Sale numbers not available. Maker of simple interactive video games aimed mostly at children	
Emoshape UK	UK tech startup focused on creating interactive technological experiences for its users. Created a interactive screen that could project a ball that users could manipulate without any other special equipment or interface	
Barco Belgium	Barco NV is a Belgium-based technology company which specializes in the design and development of professional display and visualization equipment and systems for a variety of markets, such as medical imaging, media and entertainment, infrastructure and utilities, traffic and transportation, defense and security, education and training and corporate audio/video. $1.5 billion in annual sales but listed as a tier III display company by Frost and Sullivan so may be looking for new technology to assert themselves in this field.	
Daktronics South Dakota, USA	Daktronics, Inc. is a supplier of electronic scoreboards, electronic display systems and related marketing services, digital messaging solutions, software and services for sporting, commercial and transportation applications. The Company offers a complete line of products, from small indoor and outdoor scoreboards and electronic displays to multi-million dollar video displays systems. $500 million in annual sales.	
Digital View Ltd Hong Kong	Hardware manufacturer for display systems. Another tier III display company according to Frost and Sullivan. $8.4 million in 2012 sales.	

SECTION 8. RELEVANT PATENT & PUBLICATION SEARCH RESULTS

Patent Details	Relevant Excerpts / Hyperlink(s)
US20120315819A1 29 May 2012 Flashlight activity game Inventor: K Gandy	A **flashlight activity game** is disclosed that is played with a common or custom flashlight. The flashlight activity game allows a **first player to hide a detector that a second player must find with a flashlight**. The flashlight may also have a focusable or diffuser lens to allow younger children to have a broader beam of light and older children to have a narrower beam to equalize the challenge for all players. The detector emits a flashing light and/or sounds when the detector is located with light from a flashlight. Multiple people can also play where the detector is placed by one person and two or more people compete to find the detector first. The detector is **self-powered** to allow for hours of play without charging or replacement of batteries.
US6364315 2 May 2000 Outdoor game kit with radio frequency transmitters and receivers Inventor: J Velke III	A game kit for playing a variety of **outdoor games**, comprising a plurality of animal-shaped game pieces, wherein **each of the game pieces has at least one light-emitting device** and at least one sound-emitting device; a plurality of radio frequency receivers, wherein each of the receivers is encased within an animal-shaped game piece and is operable to activate the light-emitting device and the sound-emitting device; at least one radio frequency transmitter adapted to be worn by a player and operable to activate the radio frequency receivers; and a container for storing and transporting the game kit components. Each of the receivers is activated when a player wearing a transmitter enters a predetermined detection zone around each of the receivers, thereby causing the light-emitting device to emit light and the sound-emitting device to emit sound. The game kit preferably includes other components, such as a flag, a game book, a stopwatch, and balloons.
US7252394 10 March 2004 Laser projection display and illumination device with MEMS scanning mirror for indoor and outdoor applications Inventor: Y-C Fu Assignee: Advanced Numicro Systems	**A projection display system includes a light source emitting a light beam, and a reflecting mirror system** for scanning the light beam over an image to illuminate the image. The light source can be solid state such as a laser diode. The reflecting mirror system can be one or more MEMS scanning mirrors that rotate to raster scan the light beam over the image. The image can be an advertisement located on a wall, a screen, a sign, or a billboard. The image can also be a semi-transparent image that is **projected onto a medium to produce a larger image**.
US7416306 4 June 2004 Laser projector Inventors: K Yamamoto, K Mizuuchi, Y Kitaoka, K Kasazumi Assignee: Matsushita Electric Industrial CO	A **reflection-type laser projector** (100) projects modulated laser beams outputted from a laser projection unit (40), on a screen, wherein a reflector (112) as a constituent of the screen (110) has reflection characteristics of reflecting, among the incident light, only laser beams of three colors of red, blue, and green, which are projected from the laser projection unit (40) and light in the neighboring wavelength band, and transmitting

	light in other wavelength bands, thereby **preventing pictures on the screen (110) from becoming hard to be seen due to effects of indoor illumination or light from outdoors.**
Publication Details	**Relevant Excerpts / Hyperlink(s)**
Baranowski et al. "" *Pediatrics*. **2012**. 129(3): e6437-642. Link	RESULTS: **There was no evidence that children receiving the active video games were more active in general, or at anytime, than children receiving the inactive video games**. The outcomes were not moderated by parent perceived neighborhood safety, child BMI z score, or other demographic characteristics. CONCLUSIONS: These results provide no reason to believe that simply acquiring an active video game under naturalistic circumstances provides a public health benefit to children.
AG LeBlanc et al. "Active video games and health indicators in youth: A systematic review." *PLOS One*. Link	Controlled studies show that AVGs (Active Video Games) acutely **increase light- to moderate-intensity physical activity; however, the findings about if or how AVG lead to increases in habitual physical activity or decreases in sedentary behaviour are less clear**. Although AVGs may elicit some health benefits in special populations, there is not sufficient evidence to recommend AVGs as a means of increasing daily physical activity.
Other Sources	**Relevant Excerpts / Hyperlink(s)**
R Stross. "Exergames don't cure young couch potatoes." *New York Times*. 23 June 2012. Link	**But exergames turn out to be much digital ado about nothing, at least as far as measurable health benefits for children**. "Active" video games distributed to homes with children do not produce the increase in physical activity that naïve parents (like me) expected. That's according to a study undertaken by the Children's Nutrition Research Center at Baylor College of Medicine in Houston…

Appendix D: CHI Play Paper

iGYM: An Interactive Floor Projection System for Inclusive Exergame Environments

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[4] Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI, USA

{rolgraf, pbenawri, amycarss, carichnd, henryli, nebeling, hunseok}@umich.edu

ABSTRACT

In traditional sport settings, players with mobility disabilities typically do not have opportunities to engage in physical play with their peers without mobility aids and vice versa. In this paper, we present an interactive floor projection system, *iGYM*, designed to enable people with mobility disabilities to compete on par with, and in the same physical environment as, their peers without disabilities. At the core of *iGYM* are the concept of peripersonal circle interaction and adjustable game mechanics, which enable individualized game calibration and wheelchair-accessible manipulation of virtual targets on the floor. Based on a pilot study, we determined three adaptation levels designed to make the system *(I)* accessible, *(II)* more playable, and *(III)* more balanced. We conducted a user study with 12 children testing the effects of these levels. Findings indicate that higher adaptation levels were not always preferred. Player preferences were multifactorial and also based on their desire to challenge themselves. Perceptions of fairness were often formed regardless of whether players used wheelchairs or not.

Author Keywords

Adaptive sport; inclusive exergame; interactive floor; game balancing; peripersonal space.

CSS Concepts

- **Human-centered computing~Accessibility technologies**
- Human-centered computing~Mixed / augmented reality

INTRODUCTION

Adaptive sports, and more recently exergames, have successfully enabled people with mobility disabilities to enjoy the benefits of physical play. For example, wheelchair basketball, tennis, quad rugby and power soccer provide many benefits beyond physical fitness including an increased sense of empowerment, normalcy, and acquisition of social capital [29]. However, adaptive sports typically do not address the physical and social barriers [39, 45] that limit the opportunities, particularly for young people with mobility disabilities, to engage in physical play activities with their non-disabled peers [32]. Likewise, exergames for people with mobility disabilities often focus on improving their rehabilitation outcome, but do not address their needs for recreational exercise and social inclusion in communities. Further, many popular exergame platforms (e.g., Nintendo Wii or Xbox Kinect) or custom-designed exergame interventions for players with disabilities are screen-based [23, 24, 35], which is impractical for co-located play scenarios [44] similar to adaptive sports or sport activities in general.

Figure 1. Two children competing on iGYM's interactive floor. The projected circles around their bodies can be expanded – through body movement or with a kick button – to manipulate a virtual target into the opponent's goal. The scores are displayed at the center of the playfield.

CHI PLAY '19, October 22–25, 2019, Barcelona, Spain

ACM ISBN 978-1-4503-6688-5/19/10…$15.00
DOI: https://doi.org/10.1145/3311350.3347161

In this paper, we propose to use projected augmented reality (AR) in the form of an interactive floor system to facilitate co-located physical play experiences for people with mobility disabilities and their non-disabled peers (see Figure 1). Interactive floor systems and their potential to facilitate whole-body interactions and co-located games have been studied mostly for people with cognitive disabilities [22, 46, 47] or non-disabled people [8, 20, 33]. Further, many interactive floor systems have been deployed commercially (e.g., most notably interactive floor projections in shopping malls or museums), but no system has been developed and implemented yet for people with mobility disabilities in inclusive traditional sport settings.

Our main contribution is a wheelchair-accessible projected AR sport system, *iGYM*, designed to enable people with different abilities and mobility aids to engage in realistic manipulation of virtual targets on an interactive floor. Our current implementation of *iGYM* is an air hockey inspired multiplayer game. Two key design features of *iGYM* are: ***(1)* peripersonal circle interaction**, a projected circle on the floor visualizing each player's peripersonal space boundaries with which they can manipulate a virtual target on the floor by body movement, limb extension or pressing a kick button to simulate limb extension; ***(2)* adaptable game mechanics** using physics simulation to create a realistic ball game environment, which allows balancing players' individual differences in response time or mobility by controlling game mechanics such as the circle size and puck speed and customizing them for each player.

We evaluated the effectiveness of *iGYM* to accommodate different abilities and mobility aids in this game. In a pilot study, we first identified three adaptation levels to adjust the peripersonal circle interaction for a variety of match-ups between players using power wheelchairs, players using manual wheelchairs, and players without wheelchairs. Each level uses an increased adaptation condition of the peripersonal circle interaction. In condition CI, the presence of the peripersonal circle makes the game accessible for players with varying mobility. Condition CII improves the game's playability by providing players who use wheelchairs with a way to momentarily expand their peripersonal circle using a kick button. Condition CIII employs a game balancing model in addition to providing a kick button for players who use wheelchairs.

We then conducted a user study with 12 children (9-16 yrs. old) including five players using power wheelchairs, three players using manual wheelchairs, and four players without wheelchairs. *iGYM* enabled fast paced 1-on-1 competitions in different match-ups. Findings suggest that playing the game in adaptation level *CIII*, the most adapted and balanced condition, was slightly preferred. Most players preferred matches in which the kick button enhanced the playability for players using wheelchairs (condition *II+III*) over matches without the kick button (condition *I*). Preferences, however, were multifactorial and also based on players' interest in challenging themselves, and perceptions of fairness were often formed regardless of whether players used wheelchairs or not.

RELATED WORK

Our proposed system builds on prior work on adaptive sports, exergame accessibility, game balancing, co-located games on interactive floors, and peripersonal space.

Adaptive Sports

Through adaptive sports, people with disabilities learn compensatory strategies and transform their perceptions of self by building strength, flexibility, stamina, and an improved outlook on life [38]. Adaptive sports also create a unique opportunity for technological innovation. Wheelchair sports in particular have been a driving force for innovation in adaptive sports technology and practice [9]. An example is Power Soccer, a competitive team sport for users of motorized wheelchairs, who are unable to propel themselves in manual wheelchairs or perform the feats of upper-body strength that manual wheelchair sports require [35]. Power Soccer is most related to the play opportunities and experiences that our proposed system seeks to provide. It enables co-located physical play by optimally using all the resources at hand [43]. For example, in Power Soccer, players use a foot guard as an intermediary object or tool to kick an oversized soccer ball, which is an input modality that shares some similarities with our proposed peripersonal circle interaction. However, power soccer has yet to explore opportunities for greater social integration in which people with disabilities can play together with their peers without disabilities.

Exergame Accessibility

Active video games or exergames encourage physical activity by enabling players to use bodily movements to control the gameplay. The emerging body of literature exploring the design of exergames accessible to players with disabilities typically focuses on at least one of three different aspects: the games' socialization, entertainment, and rehabilitation outcomes [21]. The latter is the primary focus of the majority of studies that explore exergames as a way of improving motor skills and cardiovascular outcomes. Fewer studies focus on entertainment or socialization aspects in correlation with accessibility concerns of player with disabilities [23, 24, 35]. A particular related sub-category of exergames for players with disabilities are wheelchair-based movement games [15, 18] in which the wheelchair movement and position becomes part of the element that controls the game. A common limitation of such exergame interventions is that regardless of their system input accessibility, their system output is typically screen-based limiting the playfield to a virtual space disconnected from the physical space surrounding the players. In other words, these games preference single player scenarios or scenarios in which multiple players face the same screen, which restricts co-located play opportunities [43] that allow players to engage with each other in shared physical space, for example, by augmenting it with minimal visual aids like *iGYM.*

Game Balancing

Balancing games helps to keep players in the state of Flow [10] by balancing their abilities with the challenges that they encounter [30]. Jackson and Csikszentmihalyi [28] argue that for the experience of Flow, the perception of a challenge is more important than the apparent objective challenge. For example, a stronger tennis player can enjoy competing against a weaker player by choosing to change their focus from winning the game to setting goals for improving different aspects of their game. This balances the challenge for the optimal experience. Jackson and Csikszentmihalyi, therefore, make a basic distinction between person-centered and environment-centered challenge adjustments [28]. This distinction also inspired Altimira et al's [1] internal and external adjustment dimensions for balancing exertion games, which seem particularly relevant for game adaptations in traditional sport settings.

Particularly related to our design goal of having people with disabilities compete on par with their peers without disabilities is Wheelchair Revolution, a competitive motion-based dancing game [17]. This game allows explicit and hidden balancing approaches to accommodate players' different skills and abilities in a screen-based setting. Such balancing approaches, which are also known as player balancing [7] and typically involve altering game mechanics to provide hindrance or assistance to one of the players, have been shown to be particularly important for making exergames accessible and fair for players with mobility disabilities. For example, Hwang et al. [26] found an increase of perceived fun and fairness, and reduction in "blowout" races with large score differentials when an algorithm was used to balance differences in pedaling ability among children with cerebral palsy competing in a screen-based racing game. Prior research also indicates that players in social play settings are more likely to accept explicit game balancing assistance because it promotes playing together with friends [14]. Little is known, however, about the effects of similar game balancing strategies in a traditional sport setting on the performance or experience of players with disabilities competing with peers without disabilities and vice versa.

Co-located Games on Interactive Floors

Interactive floors encourage physically active behavior by enabling co-located physical play. A systematic review of co-located augmented play spaces [13] places interactive floors in the category of interactive screen environments. The most widely used commercial deployment of interactive floors comes in the form of ceiling mounted projection and motion-monitoring systems. Müller et al. [41] provide a technical review of the most common interactive floor systems and propose a novel interactive laser floor system, which we also consider as a possible direction for our future system. Studies on interactive floors show their potential to facilitate co-located and collaborative games. Most of those studies focus on non-disabled players [8, 20, 33] or players with cognitive disabilities [22, 46, 47], but not on players with mobility disabilities in inclusive settings.

Particularly related to the spatial and technical configuration of our proposed system is the FUTUREGYM project [46], a large-scale interactive floor projection system in a school setting meant to provide social skill training for children with cognitive disabilities. This project follows the paradigm of spatial augmented reality and projects only minimal visual aids on the floor, which leverages its ability to function even with the light levels of a typical exercise environment. It uses multiple projectors and large ceiling heights, which helps prevent occlusion. However, it does not provide the design features to enable co-located physical play experiences for people with mobility disabilities and their non-disabled peers.

Further, related to our air hockey inspired game with peripersonal circle interaction is a recent demonstration of a German glass flooring system manufacturer [2]. This demonstration shows a similar multiplayer sport environment making use of interactive floor tiles. However, the tracking in this system can only sense the players' feet and the circle does not dynamically adapt to the player's peripersonal space boundaries.

Peripersonal Space

The concepts of peripersonal space and body schema have direct implications for the design of the peripersonal circle feature. According to these concepts, guiding the movement of the body through space and manipulating objects requires an integrated neural representation of the body (i.e., the body schema) and of the space around the body (i.e., the peripersonal space) [25]. Further, and key for the better understanding of the two input modalities of our peripersonal circle feature (i.e., extending limbs and pressing a push button), are studies showing that peripersonal space boundaries can be modulated both by extending limbs or using tools. Examples of tool use include navigating with a cane, playing tennis with a racket [4], using a computer mouse [3], or using a wheelchair as a full-body tool [16]. We believe that interactive environments, such as our proposed interactive floor, provide similar opportunities for peripersonal space boundary modulation and full body illusions, in which the peripersonal space representation shifts from the physical body to a subjectively experienced virtual body [42].

THE IGYM SYSTEM

In this section, we describe the design process and the main system components of *iGYM.* An earlier version of *iGYM* with a preliminary user study was presented in [19], following which we developed new features for the *iGYM* system, introducing a more structured approach to the adjustable game mechanics based on three player-driven adaptation levels. We also developed an automatic adaptation approach based on a new game balancing model and a single-player training mode. We evaluated these new aspects in a new user study with 12 children.

Design and Development Process

The complete design and development process from low to high fidelity prototypes was informed by interviews with health professionals in a customer discovery program following the Lean LaunchPad approach [5] and casual observations of physical therapy sessions of people with mobility disabilities. Further, it was informed by constant usability and playtesting, first by our research team members, and then by "tissue testers" [43] ranging from 4-12 years old. Our design and development strategy was to first assure the overall quality of our prototype before conducting pilot playtests with players using mobility aids to minimize frustration from unwanted or unresolved functionality issues.

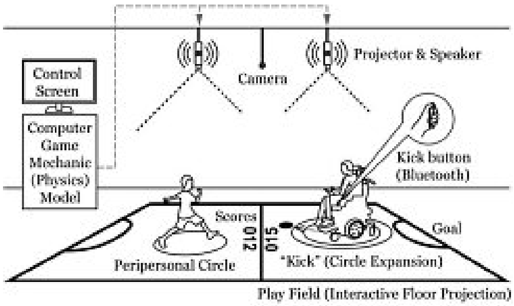

Figure 2: iGYM concept. Players' peripersonal circles can be expanded to "kick" a target on the interactive floor via limb movement or kick button activation.

Peripersonal Circle Interaction and Kick Button

The *iGYM* concept is shown in Figure 2. *iGYM* projects a circle on the floor around each detected player that enters the playfield. The center of each of these peripersonal circles is initially obtained by the weighted average of coordinates of all the pixels constituting the shape of the detected player. The size of each circle is refined via the trimming and dilation process performed on the detected player shape. As a result, the circle's center travels, and the perimeter expands or contracts based on the player's movement representing the peripersonal space boundary. For example, the player's arm extension or kicking motion increases the area of active pixels of the detected player and expands the circle projection around the body accordingly. This responsive circle can be used to directly manipulate (e.g., "kick") a virtual target such as a puck on the floor.

For players who may not be able to easily extend their arms or perform a kick, we introduced a wireless controller with a kick button to expand their peripersonal circle representation and achieve the same effect (Figure 3). This

Figure 3: Two examples of kick button activation; knee (left player) and index finger (right player).

Figure 4. Researcher demonstrating the kick button controller prototype based on a modified Bluetooth wireless mouse.

kick button can be attached to the body (e.g., hand, finger, torso, or leg mounted) or to the mobility aid. Our current controller prototype is a modified Bluetooth wireless mouse that allows plugging in switches with different form factors (Figure 4). For our study, we used two different switches with an activation surface of 2.5cm and 3.5cm diameter. Both switches provide an auditory click and tactile feedback. Players could choose between these two switches and their mounting position. The smaller switch could be attached to the index finger of players using manual wheelchairs with athletic pre-wrap in such a way that they could activate the switch while pushing the wheelchair hand rims, and a larger button could be placed in the hand of players using power wheelchairs or body-mounted with hook-and-loop strips.

Adjustable Game Mechanics

The game mechanics in *iGYM* are based on a set of adjustable game parameters and physics simulation, which together allow realistic and fast-paced interaction with a virtual target on the floor bouncing off playfield boundaries as well as the players' peripersonal circles. *iGYM* supports manual balancing of players' individual differences in response time or processing speed by allowing game mechanics' parameter customization for each player and each side of the playfield individually (see Table 1).

We used this feature to develop a competitive game for two players inspired by air hockey. In this game, the playfield is divided into two parts, each dedicated to one player, who

Global Parameters	**Default***
Target diameter (m)	0.36
Individual Parameters for each Player & Playfield Side	
Min target speed (m/s)	0.08
Max target speed (m/s)	5.86
Goal size for scoring (m)	2.1
Playfield friction (m/s^2)	0.33
Playfield boundary elasticity for target contact (%)	90
Individual Parameters for Kick Button	
Max diameter of expanded peripersonal circle (m)	2.52
Max speed of peripersonal circle expansion (m/s)	20
Max hold time of expanded peripersonal circle (s)	1.5

Table 1: Key parameters for game calibration. *Parameter baseline used in adaptation condition *CI* + *CII*.

can score and defend goals similar to playing air hockey or soccer. Some of the key parameters that are used for game play adjustment and player balancing are listed in Table 1.

For example, the maximum speed of the target and the size of the goal set the overall pace and difficulty of the game. Playfield friction determines how fast the target decelerates on each side of the playfield. Applying a higher friction setting on one side would make the target move slower when it enters that region. The elasticity parameter determines the deceleration of the target on each side of the playfield when it contacts the peripersonal circle or playfield boundary. Related to the kick button are the parameters that set the speed with which the peripersonal circle expands, the maximum size it expands to, and the maximum hold time or duration it can be kept expanded (e.g. to defend a goal).

Game Balancing Model

We also developed a game balancing model in iGYM that can be automatically trained in a short single-player session against the system (a pre-test). A simple linear performance model is adopted to estimate the expected player score (PS) as a function of two game parameters: goal size (GS) and peripersonal circle (PC) size. In our linear model, the player score performance PS is estimated by three coefficients a, b, and c using an equation $PS = aGS + bPC + c$ for a given GS and PC parameter set. Each user plays a short 4-minute single player game with various GS and PC parameter settings while the system records the current player's score for a specific parameter setting (GS, PC). When a single player game completes, linear model parameters a, b, and c are extracted by solving a least square problem [37]. By adjusting peripersonal circle size, the system then increases or counterbalances each player's reach advantage based on their performance.

Spatial and Technical Configuration

iGYM has been implemented in a large common space of a university studio building with ceiling heights (6.8m) and light levels (~270 lux) similar to those of a school gym (see Figure 3). Two ceiling mounted projectors with integrated loudspeaker (Epson Pro G7100 XGA 3LCD, 1024x768 pixels, 6500 lumens) create a 6.3 x 4.2 m large projection area on the floor. For better projection visibility, the floor is covered with a white skid resistant PVC covering. A ceiling mounted camera (StereoLabs ZED camera, 1280x720 pixel) monitors the players' movements. It captures graphic frames and streams them to the host computer (Intel Core i7-6700 CPU @ 3.40GHz * 8) at a constant rate of 35 frames per second (fps). The system output is reduced to minimal visual projections on the floor such as court lines, markings, scores, targets, and the peripersonal circle feature, enhanced by some sound effects. As a result of this system configuration, players are less likely to obscure a projection and occlusion is in general less noticeable.

PILOT STUDY TO EXPLORE GAME PARAMETERS

To develop an appropriate study design and select adaptation parameters for our system, we conducted pilot playtests with 9 participants between 7 and 19 years old, including 7 people with mobility disabilities (5 power wheelchair users, 2 manual wheelchair users) and 2 players without disabilities.

Playtests were conducted over three separate days. We formed three groups of players *(1)* using the same, *(2)* using different, and *(3)* using no mobility aids. Players were paired up to compete against each other in these constellations in 10-minute-long playtest sessions. During a warm-up phase, game parameters such as circle expansion speed and goal size were determined based on our observations, while the preferred mounting position and form factor of the kick button were chosen in consultation with each player.

For the pilot study, we collected observational and informal interview data from players and their caregivers. Interview questions focused on the usability of the peripersonal circle interaction feature in conjunction with the kick button and the pace of the game. To complement our field observation data, we also recorded quantitative measures such as the ball speed to determine the overall pace of the game and the "kicking power."

Observations

In general, our pilot study showed that *iGYM's* air hockey game was accessible for all participants. Our main observations relate to the peripersonal circle interaction and kick button, the target speeds, and goal size adaptation.

Peripersonal circle interaction and kick button

The peripersonal circle interaction feature was accessible and intuitive to use for all players, especially when the target was in front of the players. Some wheelchair users struggled when the target was behind their backs. Two power wheelchair users and one player without disabilities highlighted independently the peripersonal circle feature and the kick button as their *"favorite parts"* and the elements that make the game *"fair"*. For the kick button, we determined that the two switch form factors (2.5cm and 3.5cm) were sufficient to accommodate all pilot participants using wheelchairs. The primary mounting positions were hands, legs, and knees. The click and hold function of the kick button enabled wheelchair users to perform similar gameplay behavior as their peers without disabilities. For example, it enabled the players to push the button for a kick or hold it down to keep the peripersonal circle expanded to block an opponent's kick and defend the goal.

Adjustable game mechanics

iGYM's game mechanics created a realistic air hockey inspired game experience and helped to set its overall pace. We adjusted various parameters to test their effects, including the target speed, playfield friction, and playfield boundary elasticity. However, slowing down or increasing the speed for each player or playfield side individually seemed to disrupt the game's flow and was deemed less practical. Further, speed parameter adjustments seemed less significant as a potential player balancing approach compared to the effects of adjusting the size of the peripersonal circle or the size of the goal. While adjusting the peripersonal circle size was perceived as providing assistance, adjusting the goal size was mostly perceived as changing the difficulty level for players. We decided to focus on peripersonal circle adjustments by keeping the goal size constant to better isolate and understand the effect of the peripersonal circle. This addressed our immediate goal of exploring system adaptations that enable players with different abilities to compete with each other.

The Three Adaptation Levels

We developed three adaptation levels: *(CI)* circle without kick button, *(CII)* circle with kick button, *(CIII)* circle with kick button and balancing model. The first two adaptation levels were directly based on our pilot observations. *CI* is meant to provide every player basic game accessibility and virtual target manipulation ability through the same peripersonal circle representation on the playfield. However, the kick button was not available and game parameters were not customized in this level. *CII* gave players using mobility aids access to the kick button to enable circle expansion and gameplay behavior similar to that of players without disabilities. Finally, *CIII* employed the game balancing model to balance players' skills and physical abilities by automatically adapting their circle size (i.e., controlling their reach advantage) based on their performance in single player pre-tests.

STUDY

To explore our system's effectiveness based on the determined three adaptation levels, we conducted a two-day user study involving six sets of three 1-on-1 matches each played with a different adaptation level.

PID	Sex/Age	Diagnosis	Mobility Aids used	Kick button Position*
P1	M, 12	Cerebral palsy	Power wheelchair	Handheld
P2	M, 12	Spina bifida	Manual wheelchair	Finger
P3	M, 14	Merosin deficient congenital muscular dystrophy	Power wheelchair	Handheld
P4	F, 14	N/A	N/A	N/A
P5	M, 16	Duchenne muscular dystrophy	Power wheelchair	Handheld
P6	F, 9	N/A	N/A	N/A
P7	M, 11	Cerebral Palsy	Manual wheelchair	Finger
P8	M, 12	Muscular dystrophy	Power wheelchair	Handheld
P9	M, 10	Spinal Muscular Atrophy	Power wheelchair	Power chair desk
P10	F, 15	Spinal Muscular Atrophy 3	Manual wheelchair	Finger
P11	F, 16	N/A	N/A	N/A
P12	M, 11	N/A	N/A	N/A

Table 2. Participant profiles showing mobility aids used and respective kick button position during playtests. *Kick button was only used in adaptation condition *CII + CIII*.

Research Questions

Our evaluation addressed four primary research questions:

Q1: *Overall, how did players perceive the nature or benefit of the game?* We were interested to understand how players perceived the overall nature of the game and system and what elements they liked most about it.

Q2: *How did players feel about presence or absence of a kick button?* We hypothesized that players using wheelchairs would feel an unfair disadvantage when playing without kick-button.

Q3: *What adaptation level did players prefer most?* We hypothesized that adaptation level *III* would be preferred.

Q4: *How did players feel about competing against people of different abilities?* We wanted to understand how players with different disabilities and mobility aids experience playing against each other in a competitive sport setting.

Participants

We recruited a total of 12 participants (8 male, 5 female) in the age range of 9 to 16 years old from a local pediatric rehabilitation center through flyers and word of mouth (see Table 2). Our primary selection criteria were that participants be between 8-17 years of age, able to see, hear, and have response capability to play and evaluate the game regardless of what mobility aid they used.

Our sample included 8 participants with mobility disabilities, 5 who used power wheelchairs for mobility and 3 who used manual wheelchairs. The remaining 4 participants did not have mobility disabilities and participated without mobility aids. Eight participants were active in sports (6 in adaptive sports). Though none mentioned hockey, game mechanics were clear to all participants. Players participated in pairs and were given the option to bring a friend or sibling to play against. However, with our sample, we were unable to produce all possible permutations of player pairs. All participants received US $20 compensation for their time.

Procedure

Participants and their parents completed assent forms and pre-study questionnaires before being introduced to *iGYM*. The introduction consisted of a brief demonstration of the peripersonal circle and the interaction (circle expansion) available within the game, as well as the rules and general concepts of the game (score; defend; do not cross the centerline). Participants competed head-to-head in three 5-minute matches, one in each adapted condition. They were not told that game parameters would be changed, only that they would play three matches against each other. The order of the adaptation levels for 1-on-1 matches were randomized using all possible permutations for different player pairs so as to avoid ordering bias.

Prior to their match in the *CIII* condition, participants completed a 4-minute round in a single-player mode. Based on their scores from this single player round, the Game Balancing Model generated system parameters to be used in the *CIII* condition. The player not participating in the single-player round used the time as a rest period and was taken to a space out of direct view of the playfield.

Data Collection

Five research team members had fixed roles during the study to maintain protocol and guide children and parents through data collection. Data was collected in four stages:

1) Pre-study questionnaire (before 1-on-1 matches)

The questionnaire consisted of 11 questions in two blocks focusing on: (A) demographics and information on disabilities, and (B) frequency and social nature of participants' physical activity and video gaming habits.

2) Observation data (during each match)

One researcher documented observation data during each match pertaining to strategy and movement on the playfield and emotions expressed during playtests (e.g. gestures or facial expressions of joy).

3) Ratings and rankings (after each match)

After each 1-on-1 match players were separated and asked to rate their level of agreement with statements about fun, fairness and competitiveness of the game on a 5-point Likert scale. After matches two and three, they were also asked which of the previous matches they preferred in order to determine preferences across the three adaptation conditions. Informed by our experience of collecting this data from children during the pilot study, we reduced cognitive load by simplifying survey questions and presenting the Likert scale using smileys on whiteboards.

4) Post-study interview (after the 3 matches)

Semi-structured interviews were used to probe earlier responses and to gather feedback on participants' experience with the system. Data from stages 1) and 2) and 3) provided context for 4) and our later analysis. Post-study interview questions included:

1. Which of the matches was your favorite? Why?
2. Which parts of the game did you enjoy most?
3. Which parts not? How would you change them?
4. How well did the circle and kick button work?
5. Your opponent was on foot and you in a wheelchair (and vice versa). Did this affect how you played?

Analysis

Survey data and match scores per adaptation level were entered into a spreadsheet as context for our analysis of interview and questionnaire responses. For instance, score data allowed us to draw parallels between match preference and performance, and observation data helped us understand player behavior while playing against people with different abilities. Likert-scale ratings from questionnaires on fun, fairness, and challenge were analyzed using median and mode. Due to low statistical power we focused on qualitative analysis. Two members of the research team independently used thematic coding to analyze questionnaire and interview data. The study team unified codes and correlated these with observations and scores from each match using affinity diagramming.

RESULTS

We present our results along with our four research questions.

Overall, how did players perceive the nature or benefit of the game?

Players drew system comparisons to soccer, hockey, and air hockey, which suggested that the system was indeed perceived as being analogous to traditional sports. One player stated, *"I liked me being the hitter thing. You know how in normal air hockey you go like that with the thing [arm motion of sliding air hockey paddle toward puck]? Well, you're actually the thing!"* (P7, player using manual wheelchair). In terms of gameplay, players described the game as fun, competitive, fast-paced, and strategic, and expressed their appreciation for these attributes. One player noted, *"I just like a challenge. I like for it to be as fair as possible."* (P3, player using power wheelchair), while another mentioned *"I liked when it gets going faster, like a volley. That's what makes regular air hockey enjoyable - the back and forth."* (P11, player without wheelchair). Further, five of the participants who used wheelchairs (P2, P3, P5, P7, P9) reported that they had prior experience with adaptive sports, and expressed appreciation for the fact that unlike other adaptive sports, *iGYM* did not require special equipment to be played adaptively, *"[In other adaptive sports] sometimes you can't reach the [ball or puck] because you're so low in a wheelchair, but [with this] that's not the case. It adapts it for you and it's easier. It's basically adapted for everyone, even people with no physical disabilities."* (P7, player using manual wheelchair).

How did players feel about presence or absence of a kick button?

Interview responses indicated that the kick button worked well as an equalizer, provided better control, and reduced wheelchair movement to an extent that the game seemed more comfortable to players, *"I noticed first I was going in circles a lot more often because I was trying to get the circle from going into my goal, then the button really helped me with these issues."* (P1, player using power wheelchair). Players stated that in presence of a kick button, they adopted the strategy of staying near their goals to prevent opponent goals and own goals, and also hitting the kick button very frequently, which they described as "spamming." Spamming was best exemplified by P5 (player using power wheelchair) who stayed inside the goalie crease for the entirety of their two-player match against P6 (player without wheelchair). By spamming the kick button, P5 covered their goal almost completely, and P6 seemed discouraged due to lack of goals scored.

What adaptation level did players prefer most?

CIII was the most preferred adaptation level for 5 out of 12 players (P3, P5, P10, P11, P12) due to higher perceived fairness and competitiveness. Four of them (P5, P10, P11, P12) specifically noted small score differentials as an indicator of fairness, and suggested preference towards matches that gave both opponents an equal chance of winning, "*[CIII] felt like the most fair and competitive. The first [match, in condition CII] we could do offensive things but we hadn't really figured out defense, and every time we tried to defend we would just score on ourselves. Then the middle game [CIII] we were able to like actually both attack and defend, and then in the last game [CI] she was pretty much only able to defend.*" (P11, player without wheelchair). This was also reflected in actual score differentials produced in that condition, which were the lowest out of all three adaptation levels for 4 out of 6 player pairs (2 ties and 2 matches with a 3-goal score differential) (see Table 3). Interview responses suggest that players noticed whether they won or lost in each match, but winning or losing did not seem to have a strong effect on preference for the adaptation level. "Blowout" matches with large score differentials were not preferred by any participant due to lower perceived fairness.

Player Pairs		**Preferred level**	**CI Scores, CII Scores, CIII Scores**	**Score differential**	**Minimum score differential**
P-M	P1 (P)	*CII* (L)	10-14, 17-23, 14-28	4 6 14	*CI*
	P2 (M)	*CI* (W)			
P-N	P3 (P)	*CIII* (W)	9-13, 15-6, 11-8	4 9 3	*CIII*
	P4 (N)	*CII* (L)			
P-N	P5 (P)	*CIII* (T)	12-10, 12-12, 29-9	2 20 0	*CIII*
	P6 (N)	*CI* (L)			
M-P	P7 (M)	*CII* (L)	14-12, 13-16, 12-22	2 3 10	*CI*
	P8 (P)	*CI* (L)			
P-N	P9 (P)	*CII* (W)	4-15, 7-3, 7-10	11 4 3	*CIII*
	P12 (N)	*CIII* (W)			
M-N	P10 (M)	*CIII* (T)	8-17, 20-14, 15-15	9 6 0	*CIII*
	P11 (N)	*CIII (T)*			

Legend

Win (W)	Players using power wheelchairs (P)
Tie (T)	Players using manual wheelchairs (M)
Loss (L)	Players without disability (N)

Table 3. Overall preferred adaptation level and score differentials for participants.

In terms of overall preference, adaptation level *CIII* was closely followed by *CII* (chosen by 4 out of 12 players). The perceived fun and fairness scores were similar between adaptation levels *CI* and *CIII* for participants, with equal median and mode values for fun (median = 5, mode = 5) and fairness (median = 4.5, mode = 5), which were higher than those for *CII*. Players were, however, split regarding opinions about the fairness of adaptation level *CI*. While some participants liked the challenge and strategic gameplay that was required for playing without a kick button, others deemed it to be highly unfair for the player using a wheelchair.

How did players feel about competing against people with different abilities?

Players liked that *iGYM* allowed them to play with people of different abilities, *"I liked the fact that it was a competition. I'm very competitive, and most sports, being in a wheelchair, I can't do with other kids because my wheelchair restricts my mobility."* (P1, power wheelchair user). Most players said they had not often engaged in physical activities with people of different mobilities prior to this study. Regardless of whether or not they had a mobility disability, most initially said mobility differences did not affect their strategy or approach to the game.

On further probing, some participants described making what we recognize as internal adjustments to achieve fairness in the game, *"I feel like playing against anyone I would try to adapt my skill level to theirs. I was making sure that sometimes she was able to score and not necessarily being as offensive as I could have been."* (P11, non- wheelchair user). This was also exemplified in the P9 vs. P12 match when it was observed that P12 would wait to kick the puck until P9, a power wheelchair user, was facing forward. Additionally, P4 played with their hands in their pockets and did not utilize the circle effectively. When questioned about this adjustment, P4 stated that no adjustments were made, but observations indicate that P4's nonchalant playing style likely affected the score differential.

DISCUSSION

iGYM was designed to enable co-located play in an inclusive traditional sport setting. The pilot study showed the system was accessible to people using wheelchairs. Target speed calibration risked disrupting the game flow and had little effect on the playability (i.e. the ability to score and defend goals) compared to adaptations related to the peripersonal circle size and kick button. A subsequent study then used three adaptation levels to study the effects in isolation, assessing the performance and experience of players with different abilities and mobility aids in 1-on-1 competitions. In this section, we discuss the findings of our system adaptation efforts in the context of inclusive play and address the larger implications of designing an interactive system for inclusive play in traditional sport settings.

The Nature of the Game and Perception of Inclusive Play

Overall, players perceived the game as being a competitive, fun, and inclusive sport activity. Most notable was how players, particularly wheelchair users, expressed their perception of the game as being physical, inclusive, and adapted even for people without physical disabilities. In other words, the system was seen as enabling a "non-disability specific" play activity. A similar perspective was expressed by five other players, all wheelchair users, who made system comparisons to adaptive sports. Some indicated that adapting equipment for players with disabilities can lead to exclusion of non-disabled players. This finding indicates that adaptation measures can potentially be seen as barriers to inclusive play. Further, it does seem to validate our initial design goal of providing an adapted sport experience similar to wheelchair sports, but in an inclusive setting allowing peers without disabilities to equally participate and enjoy the game.

The Kick Button Effect

The availability of a kick button was a deciding factor for most players' perceptions of fun and fairness, and it helped to minimize score differences. It seemed to have a strong effect on the game play and game behavior of players using wheelchairs, which was noticed both by players who used a kick button and their opponents without one. Activating the kick button increased not only the peripersonal circle size commonly used to defend a goal, but also the puck speed. It had a visible, "empowering effect" that can perhaps be best compared with a "powerful" kick in soccer, where power is a key measure for the kicking success [34]. As a result, the kick button was a clearly preferred design feature for most players. However, not having a kick button promoted more active movement of wheelchair users, which was considered more challenging. For this reason, it seemed to be the preferred condition of several players who were not necessarily seeking *the* fairest game, but just *a* fairer game that provided the right challenge for them. This finding supports the importance of paying particular attention to person-centered [28] or internal [1] adjustment preferences when designing or providing interactive adaptation measures in a sport setting.

The Peripersonal Circle Interaction Quality

The quality of the peripersonal circle interaction appeared to be threefold: First, it provided each player the same peripersonal space boundary representation on the playfield (i.e., the same visible adaptation mechanism). Second, it provided each player a very similar input modality (i.e., a circle that can only travel, expand or contract; the expansion being incremental and non-incremental as the only difference). Third, individual circle size adjustments effectively compensated for response time differences due to movement restrictions of wheelchair players.

Adaptation Level Preferences

The three adaptation levels, *CI*, *CII*, and *CIII*, provided three peripersonal circle interaction versions, which helped to isolate the effects of the kick button and balancing model and in return indicated different qualities and benefits of each adaptation level. Overall findings suggest that: *CI* made the game more accessible, *CII* more playable, and *CIII* more balanced. The sample size, however, is too small to make generalizations beyond an overall preference for the matches using the kick button (*CII+CIII).* Further, some "blowouts" matches might have resulted from a limitation of our current balancing model (CIII) that does not work well when the player's play-style changes over time within or after the training session. For example, some players did not play well in the beginning but got more accustomed as the 4-minute training continued while the level of difficulty increased. This could have led to cases where the system underestimated the player's performance for the parameters tested in the earlier training and overcompensates by providing easy parameters for that player in 1-on-1s.

Most surprising was the preference of a few players using wheelchairs towards *CI*, which was the least adapted level, lacking both the kick button and balancing model. We think this preference implies that *CI* with the peripersonal circle adaptation alone is in fact already accommodating many ability differences that can typically result from wheelchairs' movement restrictions, such as side-turns, which might affect player experience. Such movement restrictions and the need to address them in direct competitions with players without disabilities are also discussed by Gerling [17] as a key challenge for "accommodating extreme ability differences." This finding suggests the importance of equally accessible and very functionally similar input modalities to level the playing field in sport settings. Preference of a particular adaptation level might also be indicative of individual differences such as inherent competitiveness, which might bias player preference toward a more difficult or easier condition. This could be accommodated in real world applications by providing the option of playing with or without a kick button.

Competition Among People with Different Abilities

The notion of fairness in an inclusive competitive play setting was particularly interesting to explore. Perceptions of unfairness were observed regardless of whether a mobility aid was being used. P8, a power chair user, mentioned, *"The other games [CII, CIII] didn't seem as fair. It was about me being in a power chair and he was not, I have the advantage in that case."* (P8, player using power wheelchair). In other words, in some cases our system appeared over-balanced for wheelchair users and in other cases for players without wheelchairs. This might imply that the system design was not perceived as an advantage for either player group. Further, it could imply that notions of fairness are also informed by individual attributes such player competitiveness or cooperativeness. Marker et al. [37] highlight both cooperation and competition as key aspects that impact player motivation and behavior, which have yet to be examined more in social exergame interventions.

LIMITATIONS AND FUTURE WORK

Individual player preferences and social factors such as cheering spectators (friends or family members), playing against a friend or family member, and the effects of internal balancing by some players to ensure fairness may have affected gameplay. However, since these moderating factors were not the focus of our investigation, we did not explicitly control for them. Further, we conducted the study without running a competition with ranking or incentives for winning. A more stringent, competitive atmosphere might highlight different aspects of the gameplay that were undetectable in the current study design.

While the formal study design was necessary to isolate effects, it limited the ways in which players could engage with *iGYM*. After the study sessions, participants were given extra time to play without restrictions on the number of players on the field or added pressure of observation. This seemed to modify the gameplay. It prompted multiplayer matches, participation using mobility aids other than wheelchairs (such as crutches), and children playing with their parents. These observations introduced interesting new dimensions of unrestricted play that we plan to further explore through a "play day", where players will be invited to participate in open play sessions.

Our study focused on inclusive play for children because of the potential developmental benefits to this age group, for which social and physical barriers are often experienced on a daily basis. That said, the system design could be extended to adults and more than two players. Our future design goal is to further develop the system for multiplayer games on a larger scale.

On a technical level, our current implementation uses a user-specific but static parameter set for adapting game mechanics after a pre-test. We want to develop a version that continually adapts game mechanics even during the game. This is in principle possible by reinforcement learning based parameter tuning that treats recent game segments as pre-tests.

On a theoretical level the literature on peripersonal space as it relates to exergames and accessibility concerns is largely unexplored. Mueller et al.'s framework for designing exergames [39] might help to connect this literature with further research on designing inclusive exergames. Adding to this framework, we suggest introducing the lens of the "intermediate body" for the subjectively experienced virtual body that players access in the form of our peripersonal circle or other forms of peripersonal space boundary simulations.

CONCLUSION

We have presented a prototype of an interactive floor projection system designed to enable co-located physical play experiences for people with and without mobility disabilities. Playtests exploring three different adaptation levels showed that our peripersonal circle interaction and kick-button feature were key to achieving system accessibility and playability of a fast-paced game. Findings suggest most players, regardless of mobility aid, preferred matches in which the kick button enhanced the playability for the player using a wheelchair (*CII+CIII)* over matches without the kick button (*CI*). Preferences, however, were multifactorial and also based on players desire to challenge themselves, and perceptions of fairness were often formed regardless of whether players were using wheelchairs or not. Our design features and related findings have theoretical and practical implications for creating novel, inclusive exergame opportunities in traditional sport settings.

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Appendix E: Utility Patent II (Application)

Atty. Docket No. 10109-19001P

PERIPERSONAL BOUNDARY-BASED
AUGMENTED REALITY GAME ENVIRONMENT

BACKGROUND OF THE DISCLOSURE

Field of the Disclosure

[0001] The disclosure relates to augmented reality game environments.

Brief Description of Related Technology

[0002] Through adaptive sports, people with disabilities learn compensatory strategies and transform their perceptions of self by building strength, flexibility, stamina, and an improved outlook on life. Some adaptive sports are wheelchair sports. An example is power soccer, a competitive team sport for users of motorized wheelchairs, who are unable to propel themselves in manual wheelchairs or perform the feats of upper-body strength that manual wheelchair sports require. Power soccer successfully builds on the players' capacities using their respective mobility aids and can serve a wide range of ages and abilities. Power soccer enables co-located physical play by optimally using all the resources at hand. However, power soccer has yet to explore opportunities for greater social integration in which people with disabilities play together with their non-disabled peers.

[0003] Active video games, or exergames, encourage physical activity by enabling players to use bodily movements to control the gameplay. The design of exergames for players with disabilities typically focuses on at least one of three different aspects: the games' socialization, entertainment, and rehabilitation outcomes. Exergames provide a way of improving motor skills and cardiovascular outcomes. Several game controllers and exergaming platforms are commercially available, i.e., Nintendo Wii, Sony Playstation3 Move, Microsoft Xbox Kinect. A common limitation of exergames is that, regardless of system input accessibility, system output is always screen-based. In other words, much like conventional videogames, these games present single player scenarios or other scenarios in which multiple players face the same screen, which limits co-located play opportunities.

[0004] A sub-category of exergames for player with disabilities are wheelchair-based movement games, in which the wheelchair movement and position, as opposed to only the player's body movement, becomes part of the element that controls the game. As in the case of adaptive sports, wheelchair-based movement games can further be divided into games for power wheelchair users and games for manual wheelchair users. One example is Wheelchair Revolution, a competitive motion-based dancing game. Wheelchair Revolution provides players the option to use both a foot-based game input (i.e., a pressure sensing mat) and a wheelchair-based game input (i.e., kinect motion-monitoring system), with time and score balancing being used to account for individual player skills and abilities. However, the foot-based and wheelchair-based input modalities have very different characteristics that seem to emphasize player's differences. Further, the game forces both players to face a screen in front of them and stay within the close range of a motion monitoring system or on a pressure-sensing mat, which limits their range and degree of freedom, which would be impractical for co-located play.

[0005] Adaptive sports, and more recently exergames, have successfully enabled people with motor disabilities to enjoy the benefits of physical play. For example, wheelchair basketball, tennis, quad rugby and power soccer, provide many benefits beyond physical fitness. The benefits include an increased sense of empowerment, normalcy, and acquisition of social capital. However, adaptive sports typically fail to address the physical and social barriers that limit the opportunities for certain individuals, such as those with motor disabilities, to engage in physical play activities with their non-disabled peers. Likewise, exergames for people with motor disabilities often focus on improving a rehabilitation outcome, while failing to address needs for recreational exercise and social inclusion. Further, many popular exergame platforms (e.g., Nintendo Wii and Xbox Kinect) are screen-based, which is impractical for co-located play scenarios similar to adaptive sports or sport activities in general.

[0006] Interactive floors encourage physically active behavior by enabling co-located physical play. Interactive floors are typically deployed in the form of ceiling mounted projection and motion-monitoring systems. Interactive floors have been applied in connection with non-disabled players and players with cognitive disabilities, but not in connection with players with motor disabilities in inclusive settings.

SUMMARY OF THE DISCLOSURE

[0007] In accordance with one aspect of the disclosure, a method of providing an augmented reality game environment within a game space includes obtaining, by a processor, sensor data for the game space, determining, by the processor, a position of a player in the game space based on the sensor data, generating, by the processor, player image data of a peripersonal boundary of the player based on the determined position of the player for rendering a representation of the peripersonal boundary in the game space, the peripersonal boundary being disposed about, and spaced from, the determined position, obtaining, by the processor, player data for the player via an input modality, the player data being indicative of a player directive to modulate the peripersonal boundary, adjusting, by the processor, a size of the peripersonal boundary as a function of the player data, and updating, by the processor, the player image data based on the adjusted size of the peripersonal boundary.

[0008] In accordance with another aspect of the disclosure, a system for providing an augmented reality game environment within a game space includes a projection system to render images in the game space, a sensor system to capture sensor data for the game space, a processor coupled to the sensor system to receive the captured sensor data and to the projection system to control rendering of the images, a memory coupled to the processor and in which player detection instructions and image generation instructions are stored. The processor is configured via execution of the player detection instructions to determine a position of a player in the game space based on the sensor data. The processor is configured via execution of the image generation instructions to generate player image data of a peripersonal boundary of the player based on the determined position of the player and to direct the projection system to render the images in accordance with the player image data, the peripersonal boundary being disposed about, and spaced from, the determined position. The processor is further configured via the execution of the player detection instructions to obtain player data for the player via an input modality, the player data being indicative of a player directive to modulate the peripersonal boundary. The processor is further configured via the execution of the image generation instructions to adjust a size of the peripersonal boundary as a function of the player data and update the player image data based on the adjusted size of the peripersonal boundary.

[0009] In connection with any one of the aforementioned aspects, the systems, devices, and/or methods described herein may alternatively or additionally include any combination of one or more of the following aspects or features. The adjusted size of the peripersonal boundary includes an expansion of the peripersonal boundary, the expansion increasing a reach of the player to interact with a target object of the game space. The player data includes a controller signal from a controller, the controller signal being indicative of an actuation of the controller by the player. Adjusting the peripersonal boundary includes accessing a data store to obtain a player parameter, such that the function by which the peripersonal boundary is adjusted takes the player parameter as an input. The player parameter calibrates a speed of expansion of the peripersonal boundary. The player parameter calibrates a maximum size of expansion of the peripersonal boundary. The player parameter calibrates a duration of expansion of the peripersonal boundary. The player parameter calibrates an elasticity of the peripersonal boundary in connection with non-player-induced interaction of the peripersonal boundary with a target object. The input modality includes a sensor system such that the player data includes further sensor data. Adjusting the size of the peripersonal boundary includes determining, by the processor, that the further sensor data is indicative of an outward thrust of a limb of the player. The method further includes determining, by the processor, a position of a simulated object of the augmented reality game environment within the game space, generating, by the processor, object image data of the simulated object for rendering a representation of the simulated object in the game space, and updating the object image data based on a simulated interaction of the simulated object and the adjusted size of the peripersonal boundary. The method further includes rendering, by the processor, a visible representation of the player image data. The method further includes projecting, via a projection system, a representation of the player image data on a floor on which the game space is defined and on which the player moves. The adjusted size of the peripersonal boundary includes an expansion of the peripersonal boundary, the expansion increasing a reach of the player to interact with a target object of the game space. The system further includes a controller configured to be actuated by the player, wherein the player data includes a controller signal from the controller, the controller signal being indicative of an actuation of the controller by the player. The processor is further configured via the execution of the image generation instructions to access a data store to obtain a player parameter, such that the function by which the peripersonal boundary is adjusted takes the player parameter as an input. The player parameter calibrates a speed of expansion of the peripersonal boundary, a maximum size of expansion of the peripersonal boundary, a duration of expansion of the peripersonal boundary, or an elasticity of the peripersonal boundary. The sensor system provides the input modality such that the player data includes further sensor data. The processor is further configured via the execution of the player detection instructions to determine that the further sensor data is indicative of an outward thrust of a limb of the player. The processor is further configured via the execution of the image generation instructions to determine a position of a simulated object of the augmented reality game environment within the game space, generate object image data of the simulated object for rendering, via the projection system, a representation of the simulated object in the game space, and update the object image data based on a simulated interaction of the simulated object and the adjusted size of the peripersonal boundary. The projection system is mounted above the game space such that the images are rendered on a floor on which the game space is defined and on which the player moves.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

[0010] For a more complete understanding of the disclosure, reference should be made to the following detailed description and accompanying drawing figures, in which like reference numerals identify like elements in the figures.

[0011] Figure 1 is a schematic, perspective view of an augmented reality game environment generated by an exergame system in accordance with one example.

[0012] Figure 2 is a block diagram of a system for providing an augmented reality game environment in accordance with one example.

[0013] Figure 3 is a flow diagram of a method providing an augmented reality game environment in accordance with one example.

[0014] Figure 4 is a flow diagram of a player detection and image generation procedure implemented by the method of Figure 2 in accordance with one example.

[0015] Figures 5 and 6 are photographs of an augmented reality game environment in accordance with one example.

[0016] Figure 7 is a perspective view of a controller for the augmented reality game environment in accordance with one example.

[0017] Figures 8 and 9 are photographs of optional mounting arrangements for the controller of Figure 7.

[0018] Figure 10 is a photograph of a controller in a mounting arrangement in accordance with another example.

[0019] The embodiments of the disclosed systems, devices, and methods may assume various forms. Specific embodiments are illustrated in the drawing and hereafter described with the understanding that the disclosure is intended to be illustrative. The disclosure is not intended to limit the invention to the specific embodiments described and illustrated herein.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0020] Methods and systems for providing an augmented reality game environment, such as an exergame environment, are described. In some cases, the game environment may be interactive, involving multiple players. The game environment may be configured to present an inclusive environment, in which players of differing levels of mobility, skill, or capability can participate. In some case, the game environment may be or include an exergame environment, in which the players interact with a virtual target object. For example, the virtual target object may be a virtual ball or puck. Interaction with the ball may then involve directing the virtual ball into a virtual goal or net, as in soccer or hockey.

[0021] In some cases, the disclosed systems are or include an interactive floor projection system. The projection of a game space on a floor facilitates co-located physical play experiences for people with motor disabilities and their non-disabled peers. The interactive floor systems facilitate whole-body interactions and co-located games. Individuals with motor disabilities thus have opportunities to participative in inclusive recreational sport settings.

[0022] The disclosed methods and systems are configured to generate a peripersonal boundary for each player within a game space of the game environment. The peripersonal boundary acts as an interaction modality of the game environment. In some cases, the peripersonal boundary provides the mechanism by which a player manipulates or otherwise interacts with a target object or other aspect of the game environment. The peripersonal boundary may be a circle or other shape projected or otherwise rendered, e.g., on the floor, to simulate a player's peripersonal space boundary. The player can adjust (e.g., expand) the peripersonal boundary, e.g., through body movement or with a controller (e.g., a push button controller). The adjustment may be directed to manipulating a virtual physical target, e.g., rendered on the floor.

[0023] The peripersonal boundary may be one of multiple aspects of the disclosed methods and systems that are configured for, and/or directed to, allowing people with motor disabilities to compete on par with, and in the same environment as, their non-disabled peers. For instance, with the controller, players in power wheelchairs with less upper body strength, for example, can expand the boundary in the same way as players who are capable of extending or otherwise moving their arms or legs in order to kick the simulated target.

[0024] The disclosed methods and systems may include additional or alternative player balancing features, including, for instance, parameters directed to game calibration. The game calibration may be implemented on a respective basis for each player. For instance, calibration may be specific to each player and/or to each side of the game space (e.g., playfield). The calibration may be implemented to address player differences in response time, processing speed, and/or other characteristics. Examples of player-customizable game mechanic parameters include the speed of the target, friction applied to the target movement, as well as the sizes of the goal and the player's peripersonal circle representation.

[0025] Although described below in connection with examples involving a ball or puck, the disclosed methods and systems are not limited to soccer-like or other exergame or other game environments involving a ball, a puck, goals, or nets. The disclosed methods and systems are well-suited for use in connection with a wide variety of game environments, including environments that do not involve a target object.

[0026] Figure 1 depicts one example of a game environment provided by the disclosed systems and methods. In this case, the game environment resembles a hybrid of soccer and air hockey. Two or more players attempt to manipulate a moving, virtual target object, e.g., a virtual ball or puck, into an opponent's goal. The players may include individuals with or without mobility challenges, including users of power wheelchairs, manual wheelchairs, a walker, and non-disabled players. The game environment is designed such that the game is accessible and playable for all participants, regardless of how they were paired up. To that end, one or more player or other game parameters may be adjusted, including, for instance, one or more speed-related parameters. For example, the speed at which the target object moves may be customized or otherwise adjusted. The speed may be adjusted to accommodate different levels of player skill and other player characteristics, such as a player's respective information processing speed. Alternative or additional examples are described below.

[0027] The system includes a ceiling mounted video projection system. The video projection system is configured to render an interactive floor. This and other aspects of the system are directed to (1) affordability and robustness, (2) ease of implementation and potential for scalability, (3) versatility and flexibility of computer software based system implementation, (4) high display speed and accuracy, and (5) good visibility in the typical light levels of exercise environments.

[0028] The system generates a peripersonal boundary on the interactive floor for each player. In this example, the peripersonal boundary is or includes a circle disposed around, and spaced from, each player's body. The peripersonal boundary dynamically adapts to the player's body movement and can be used to manipulate the simulated target on the floor. The peripersonal boundary thus moves as the player moves. Each peripersonal boundary is displayed or rendered on the floor via the projection system. Other shapes, such as non-circular shapes, may be used.

[0029] The peripersonal boundaries may be expanded to manipulate a virtual target. In this example, the manipulation of the target object simulates a kick of a soccer ball, e.g., into the opponent's goal. The expansion is effectuated through player limb movement and/or with a controller, e.g., a push button controller. In the former case, a leg may be kicked outward. The latter case may accommodate players unable to perform a kicking motion. The scores are displayed at the center of the playfield.

[0030] The peripersonal boundary feature may provide cognitive and other development benefits for certain individuals. Guiding the movement of the body though space and manipulating objects requires an integrated neural representation of the body (i.e., the body schema) and of the space around the body (i.e., the peripersonal space). Furthermore, the various input modalities of the peripersonal boundary feature (e.g., extending limbs and pressing a push button) demonstrate that peripersonal space boundaries can be modulated both by extending limbs or using tools. The interactive game environment provided by the disclosed systems and methods presents similar opportunities for peripersonal space boundary modulation and full body illusions, in which the peripersonal space representation shifts from the physical body to a subjectively experienced virtual body.

[0031] Figure 2 depicts a system 200 for providing an augmented reality game environment within a game space. The system 200 may provide the game environment example shown in Figure 1 and/or other game environments. The game space may be defined or provided on a medium. In this case, the medium is or includes a floor. The medium may vary. For instance, other tangible surfaces, such as a display screen of a head-worn display, may be used. Alternatively or additionally, the game space may be provided via, or otherwise include or involve, floating images, such as holographic images.

[0032] The system 200 includes a projection system 202, a camera 204, and a computer system 206 having a processor 208 and one or more memories 210. Fewer, additional, or other components may be included. In the example of Figure 1, the system includes one or more controllers 212.

[0033] The projection system 202 is configured to render images in the game space. In some cases, the projection system 202 is mounted above the game space such that the images are rendered on a floor on which the game space is defined and on which the player(s) move, For instance, the projection system 202 may be ceiling mounted. In this case, the projection system 202 includes one or more projector mounts 214. In one example, two ceiling mounted projectors with an integrated loudspeaker (e.g., Epson Pro G7100 XGA 3LCD, 1024x768 pixels, 6500 lumens) are provided to create a 6.3 x 4.2 meter large projection area on the floor. The projection area may define or establish the game space.

[0034] The configuration of the projection system 202 and, thus, the game space, may vary. The game space may or may not be defined on a floor. For example, the projection system 202 may be or include a wearable device, such as head-mounted display. In those and other cases, the game space may be three-dimensional rather than two-dimensional. The projection system 202 may include any number of projectors. For better projection visibility, the floor may be covered with a white skid resistant PVC or other covering.

[0035] The image data rendered by the projection system 202 may vary in accordance with the game space and environment. In the soccer/air hockey example, the image data is rendered to present court lines, markings, scores, one or more targets, and the peripersonal boundary of each player. Any number of visual projections may be provided on the floor. Reducing or minimizing the number of projections may be useful, insofar as players are less likely to obscure a projection. As a result, occlusion is reduced or eliminated.

[0036] The camera 204 is configured to capture sensor data for the game space. The sensor data is captured to monitor the players' movements. In the example of Figure 2, the camera 204 captures graphic frame data (or other camera or sensor data) and streams the frame data to the computer 206. For example, the camera 204 may send the frame data at a constant rate of 35 frames per second, although other frame rates may be used. The camera 204 may be or include a ceiling mounted camera, such as a StereoLabs ZED camera, 1280x720 pixel camera. In this example, the camera 204 includes one or more camera mounts 216. Other types of optical or non-optical sensors may be used, including, for instance, depth sensing cameras, laser-based sensor systems, as well as other radar- and lidar-based systems. Sonar-based and other non-electromagnetic sensor systems may alternatively or additionally be used.

[0037] The processor 208 is coupled to the camera 206 to receive the captured camera or other sensor data. The processor 208 is also coupled to the projection system 204 to control rendering of the images in the game space. The processor 208 may be or include a general-purpose processor, such as a central processing unit (CPU). In one example, the processor 208 is or includes an Intel Core i7-6700 CPU having eight cores. The processor 208 may include any number of processing cores or processors. The configuration of the processor 208 may vary. For instance, the processor 208 may be or include one or more graphic processing units (GPUs) or digital signal processors (DSPs). The GPU(s) and/or the DSP(s) may be integrated with the CPU(s) to any desired extent.

[0038] The memory 210 is coupled to the processor 208. The memory 210 may include one or more memory units. For instance, the memory 210 may include any number of addressable memory integrated circuit (IC) chips, such as random access memory (RAM) chips. The memory 210 may be integrated with the processor 208 to any desired extent. For instance, the memory 210 may be or include an on-board memory unit of a processor IC chip.

[0039] One or more instruction sets are stored in the memory 210 for execution by the processor 208. In this case, player detection instructions 218 and image generation instructions 220 are stored in the memory 210. The instructions 218, 220 may be integrated to any desired extent. Fewer, additional, or other instructions or instruction sets may be stored on the memory 210. For instance, interface instructions may be provided to generate a user interface on a display of the computer 206. The interface may be directed to customizing or configuring the system 200 via user selection of one or more parameters for the game environment.

[0040] The processor 208 is configured via execution of the player detection instructions 218 to determine a position of a player in the game space based on the camera or other sensor data. The camera or other sensor data may be processed in accordance an object detection procedure specified via the player detection instructions 218. An example procedure is described below in connection with Figure 4. The manner in which the player position is determined may vary.

[0041] The processor 208 is configured via execution of the image generation instructions 220 to generate player image data of a peripersonal boundary of the player based on the determined position of the player. The processor 208 is then configured via execution of the image generation instructions 220 to direct the projection system 202 to render the images in accordance with the player image data. The peripersonal boundary is disposed about, and spaced from, the determined position for the player.

[0042] The processor 208 is further configured via the execution of the player detection instructions 218 to obtain player data for the player via an input modality. The player data is indicative of a player directive to modulate the peripersonal boundary. In some cases, the player directive is or includes a limb movement, such as a leg kick or other outward thrust of a limb. The limb movement may be detected via further camera or other sensor data. The input modality in such cases thus includes or involves the camera 204. The processor 208 may thus be further configured via the execution of the player detection instructions 218 to determine that the further camera data is indicative of an outward thrust of a limb of the player. Other limb movements may be detected, including, for instance, an arm motion.

[0043] With some players, the input modality includes or involves one of the controllers 212 associated with the player. Each controller 212 is configured to be actuated by a respective player such that the player data may include a controller signal from the controller 212. The controller signal is thus indicative of an operational state of the controller. In such cases, the player directive is or includes actuation of the controller 212. For example, a push button of the controller 212 may be pressed by the player. The controller 212 may be worn, held, or otherwise accessible to the player. In some cases, the controller 212 is or includes a transceiver for wireless communications (e.g., Bluetooth communications) with the computer 206. Other wireless protocols may be used.

[0044] Each controller 212 may be or include a push-button device. In some cases, the controller 212 may be a handheld device. The controller 212 may have a housing similar to a computer mouse device, in which case the controller 212 may be actuated with a squeezing motion. Alternatively or additionally, the controller 212 may be a wearable device. For example, the controller 212 may include a strap to secure the controller 212 to a side of a knee or leg of the player. The controller 212 may then be actuated by a player via inward motion of the knees. Further details regarding an example of the controller 212 are provided in connection with Figure 7.

[0045] Other input modalities may be used. For instance, an audio signal indicative of the player directive may be captured via a microphone. A player with limited mobility may then be able to speak or otherwise generate a sound to modulate the peripersonal space. Alternatively or additionally, a player with limited mobility may use an input modality involving eye gaze tracking. A head-mounted or other camera may generate data indicative of pupil position, which may then be used to detect a player directive to modulate the peripersonal boundary.

[0046] The processor 208 is further configured via the execution of the image generation instructions 220 to adjust a size of the peripersonal boundary as a function of the player data. For example, when a player executes a leg kick, the player data indicative of the leg kick is used by the processor 208 to expand the peripersonal boundary of the player. Similarly, when a player actuates the controller 212, the player data indicative of the actuation is used by the processor to expand the peripersonal boundary of the player. In either case, the processor 208 updates the player image data based on the adjusted size of the peripersonal boundary.

[0047] In some cases, the adjustment includes an expansion of the peripersonal boundary. An example of an expansion is shown in Figure 1. In that way, the expansion may increase a reach of the player to interact with a target object of the game space. Alternative or additional adjustments may be implemented. For example, the shape of the peripersonal boundary may change. For instance, the peripersonal boundary may extend outward in a direction of a leg kick and/or a direction in which the player is oriented. Thus, the expansion or other adjustment may or may not be uniform or symmetrical.

[0048] In game environments involving a target or other object in addition to the peripersonal boundaries, the processor 208 is further configured via the execution of the image generation instructions 220 to determine a position of a simulated object of the augmented reality game environment within the game space. The processor 208 generates object image data of the simulated object for rendering, via the projection system 202, a representation of the simulated object in the game space. Then, during the game, the processor 208 updates the object image data based on a simulated interaction of the simulated object and one of the peripersonal boundaries. For example, the ball or other object may be redirected when the ball overlaps with the peripersonal boundary. The redirection may be intensified if the object interacts with an expanded or otherwise adjusted peripersonal boundary.

[0049] The computer 206 may include a number of components, peripheral devices, or other elements. In the example of Figure 2, the computer 206 includes a data store 222, a display driver 224, a controller driver 226, and a wireless communications interface 228. The data store 222 may be used to store parameter and other data for configuring the game environment. The display driver 224 may be configured to generate image data signals (e.g., pixel signals or other display control signals) to the projection system 202 based on the image data generated by the processor 208. The controller driver 226 may be configured to generate data indicative of user interaction with each controller 212. The wireless communications interface 228 may be or include a Bluetooth or other driver to support wireless communications with the computer 206, such as wireless communications with the controller(s) 212.

[0050] The processor 208 may be further configured via the execution of the image generation instructions 220 to access the data store 222 to obtain one or more player parameters. One or more characteristics of the peripersonal boundary may be customized by the parameter(s). The function by which the peripersonal boundary is adjusted may thus take the player parameter as an input. The nature of the player parameter(s) may vary. Examples include parameters that calibrate a speed of expansion of the peripersonal boundary, a maximum size of expansion of the peripersonal boundary, a duration of expansion of the peripersonal boundary, and an elasticity of the peripersonal boundary. Further details regarding examples involving these and other examples are provided below.

[0051] The processor 208 may be or include any number or type of processing cores, processors, processing units (e.g., a central processing unit or graphical processing unit), or processing systems. The processor 208 may be or include one or more general processors, digital signal processors, application specific integrated circuits, field programmable gate arrays, servers, networks, digital circuits, analog circuits, combinations thereof, or other now known or later developed devices for analyzing and processing data.

[0052] The memory(ies) 210 may be or include any number or type of computer-readable memories, media, or other devices on which data is stored. The memory(ies) 210 may be or include a main memory, a static memory, or a dynamic memory. The memory(ies) 210 may include, but may not be limited to computer readable storage media such as various types of volatile and non-volatile storage media, including but not limited to random access memory, read-only memory, programmable read-only memory, electrically programmable read-only memory, electrically erasable read-only memory, flash memory, magnetic tape or disk, optical media and the like. In one case, The memory(ies) 210 may include a cache or random access memory for a processor. Alternatively or additionally, The memory(ies) 210 may be separate from the processor, such as a cache memory of a processor, the system memory, or other memory. The memory(ies) 210 may be or include an external storage device or database for storing data. Examples may include a hard drive, compact disc ("CD"), digital video disc ("DVD"), memory card, memory stick, floppy disc, universal serial bus ("USB") memory device, or any other device operative to store data. The memory(ies) 210 may be operable to store instructions executable by a processor. The functions, acts or tasks illustrated in the figures or described herein may be performed by the programmed processor executing the instructions stored in the memory(ies) 210. The functions, acts or tasks may be independent of the particular type of instruction set, storage media, processor or processing strategy and may be performed by software, hardware, integrated circuits, firmware, micro-code and the like, operating alone or in combination. Likewise, processing strategies may include multiprocessing, multitasking, parallel processing and the like.

[0053] Figure 3 depicts a method 300 of providing an augmented reality game environment within a game space. The method 300 may be implemented by the above-described processor 208 (Figure 2) and/or another processor. For instance, the method 300 may be implemented via execution of the above-described instructions stored on the memory 210 and/or another memory.

[0054] The method 300 may begin with one or more acts directed to configuring the game environment. For example, a user interface may be generated to provide a user with an opportunity to customize one or more game parameters. The user interface may alternatively or additionally be directed to initiating the game environment and/or starting a game.

[0055] Upon starting the game, camera or other sensor data is obtained in an act 302 for the game space. The camera or other sensor data may captured via one or more cameras or other sensor systems as described above. The camera data may be provided or configured as frame data in some cases. The manner in which the camera data is obtained may vary. For instance, obtaining the camera data may include receiving raw or other data from the camera, processing the raw data, accessing raw or other data from a memory, and/or other steps.

[0056] In an act 304, a position of each player in the game space is determined based on the camera or other sensor data. The position may be a centroid of an area in which one or more objects are detected via analysis of the camera or other sensor data. One example of an object detection technique that may be implemented is described in connection with Figure 4. Other object detection techniques may be used, including, for instance, techniques that rely on sensor data from radar-, lidar-, and sonar-based sensor data.

[0057] In some cases, the act 304 may also include determining a position of one or more simulated objects of the augmented reality game environment within the game space. The object may be or include a simulated ball or puck, as described above. The determination may or may not be made separately (e.g., at a different time in the sequence or method 300) than the player position determination.

[0058] Player image data of a peripersonal boundary of each player is generated in an act 306 based on the determined position of the player. The player image data is directed to rendering a representation of the peripersonal boundary in the game space. As described above, the peripersonal boundary is disposed about, and spaced from, the position determined for the player. The representation may be rendered on a floor or other surface or medium. The image data may be configured such that the representation is or includes a real or virtual image. The player image data may be two- or three-dimensional image data.

[0059] In some cases, the act 306 also includes generating object image data of the simulated object. The object image data is used for rendering a representation of the simulated object in the game space. The object image data may or may not be generated separately (e.g., at a different time in the sequence or method 300) than the player image data.

[0060] In an act 308, player data is obtained for one or more of the players via an input modality. The player data is indicative of a player directive to modulate the peripersonal boundary of the player. The input modality may vary. For instance, the input modality may be or include the camera(s). The player data may thus include or be based on camera data indicative of a kick or other limb movement. The input modality may be or include a handheld, worn, or other controller with a push button or other technique to capture and/or generate the player data (or signal or data underlying the player data). The player data may thus include a controller signal from a controller, the controller signal being indicative of an actuation of the controller by the player. Still other input modalities may be used, including, for instance, sound-based modalities and other visual modalities, such as pupil tracking.

[0061] A size of the peripersonal boundary is adjusted in an act 310 as a function of the player data. In some cases, the peripersonal boundary expands as a function of the player data. The expansion may or may not be uniform or symmetrical. For instance, the peripersonal boundary may expand in a direction in which the kick or limb movement is oriented. The expansion may increase a reach of the player to interact with a target object of the game space.

[0062] In act 312, the player image data is updated based on the adjusted size of the peripersonal boundary. The player image data for rendering of the peripersonal boundary is updated to reflect the expanded or otherwise adjusted size of the peripersonal boundary.

[0063] The updated player image data is rendered into a visible representation in an act 314. Rendering the updated player image data may include providing the image data to a display driver, a projection system, and/or other display system, such as a head-worn display system. The image data may be processed in accordance with one or more graphics and/or display procedures. Rendering the image data may also include one or more acts relating to the generation of pixel control or other signals for the projection system.

[0064] Adjusting the peripersonal boundary in the act 310 may include an act 316 in which a data store is accessed to obtain one or more player parameters. The parameter(s) may then be applied in an act 318 as input(s) to the function by which the peripersonal boundary is adjusted. Various player parameters may be used, including, for instance, parameters that calibrate a speed of expansion of the peripersonal boundary, a maximum size of expansion of the peripersonal boundary, a duration of expansion of the peripersonal boundary, and/or an elasticity of the peripersonal boundary in connection with non-player-induced interaction of the peripersonal boundary with a target object. In cases in which a simulated object is present in the game environment, the act 312 may include updating the object image data. The update may be based on a simulated interaction of the simulated object and the adjusted size of the peripersonal boundary.

[0065] The act 310 may also include determining, in an act 320, that further camera or other sensor data is indicative of a kick or other outward thrust of a limb of the player. The determination may alternatively be part of a procedure in which the player data is obtained in the act 308.

[0066] The method 300 may include fewer, additional, or alternative acts. For instance, the method 300 may include one or more acts directed to adjusting the player parameters. The parameter adjustments may be useful for balancing the game environment, thereby making the environment more accessible and/or interactive for certain players.

[0067] The order of the acts of the method 300 may differ from the examples described above. For instance, one or more of the acts may be implemented concurrently.

[0068] Figure 4 depicts a method or procedure 400 for determining player position and generating and updating image data for a peripersonal boundary around the determined position. The procedure 400 may be implemented as part of, or in connection with, the method 300 of Figure 3, and/or another method. The procedure 400 may be implemented by the processor 208 (Figure 2) and/or another processor. The procedure 400 may by implemented via execution of the above-described instructions and/or other instructions.

[0069] The procedure 400 may begin with an act 402 in which a background image is captured by a camera, such as a ceiling-mounted camera. The act 402 may be implemented before players have entered the game space. Once the game environment is initiated (e.g., a game has started), a new video frame image is captured (e.g., by the same camera) in an act 404. Processing of the image data is then conducted in an act 406. In some cases, the processing includes a comparison of the color of each pixel in the new video frame with the background image data. A change detection routine is then implemented in an act 408. In some cases, each pixel having a color difference larger than a threshold difference is marked or otherwise identified. Clusters of identified pixels are then found in an act 410. Clusters having sizes smaller than a threshold size may be eliminated or discarded. For each remaining cluster, a circle or other boundary is found or otherwise determined in an act 412 such that all of the pixels in the cluster are contained within the boundary. The boundary corresponds with the peripersonal boundary for one of the players. In some cases, minimum and maximum sizes for the boundary are provided. The act 412 may also include generating the image data to draw or otherwise render the boundary for projection on the floor. A decision block 414 then determines whether a player directive to expand the peripersonal boundary is received. The player directive may be or include limb motion or an actuation of a controller button. If yes, control passes to an act 416, in which any boundary(ies) dedicated or otherwise associated with the controller or player are expanded. Otherwise, or eventually, control returns to the act 404 for a another iteration of the procedure 400, starting with a new video frame image.

[0070] Other procedures may be used to project or otherwise render a circle or other boundary on the floor or other medium around each detected player that enters the playfield. For instance, a procedure that uses the weighted average of all the pixels constituting the shape of the detected player may be used. The center of each peripersonal boundary may be initially obtained by the weighted average of coordinates of all the pixels constituting the shape of the detected player. Alternatively or additionally, trimming and/or dilation may be implemented on the detected player shape. The size of each circle may be refined via the trimming and dilation process performed on the detected player shape. The center and size of each circle may then be corrected to compensate for perspective distortion that depends on the position of the detected player. As a result, the center of the circle or other boundary travels, and the perimeter expands or contracts based on the player's movement representing the peripersonal space boundary. For example, players' arm extension or kicking motion increases the area of active pixels of the detected player and expands the circle projection around the body on the floor accordingly. This responsive circle can be used to directly manipulate, for example, a virtual ball or puck target on the floor. Likewise, a player using mobility aids can use a wireless push controller to expand the peripersonal circle representation and achieve the same effect. The push button controller may be attached to the body (e.g., hand, finger, torso, or leg mounted) or a mobility aid. The controller may be a modified Bluetooth wireless mouse that allows plugging in switches with different form factors, as shown in Figure 7. In one example, the controller includes switches with an activation surface of 2.5cm and 3.5cm diameter. Both switches provide an auditory click and tactile feedback.

[0071] Individualized Game Calibration. The disclosed methods and systems may have an adjustable game mechanic (physics) model established via a number of parameters that allow realistic and fast-paced interaction with a target such as a virtual ball or puck. Further, the physics model and parameters allow player differences to be balanced in response time or processing speed or other ways. To that end, game mechanic parameter calibration may be implemented or customized for each player and/or each side of the playfield individually. In the above-described soccer game, the playfield may be divided into two parts, each dedicated to one player. Examples of parameters to be used for game play adjustment and player balancing are listed in Table 1 below.

Table 1

Global Parameters	**Default***	**Max.**
Diameter of the target (m)	0.36	0.94
Individual Parameters for each Player & Playfield side		
Minimal speed of the target (m/s)	0.1	0.9
Maximal speed of the target (m/s)	11.5	13.8
Goal size for scoring (m)	2.8	4.2
Friction on the playfield (m/s^2)	0.25	1.7
Elasticity of playfield boundary for the contact with the target (%) **	100	100
Elasticity of peripersonal circle boundary for the contact with the target **	100	100
Individual Parameters for Push Button Controller		
Max diameter of peripersonal circle when expanded (m)	3.2	4.2
Speed of peripersonal circle expansion (m/s)	20	20
Max hold time of expanded peripersonal circle (s)	3.1	3.1

*Parameter baseline used in default environment
**The speed changes to a certain percentage of the original one

[0072] The maximum speed of the target and the size of the goal set the overall pace and difficulty of the game. Playfield friction determines how fast the target decelerates on each side of the playfield. Applying a higher friction setting on one side would make the target move slower when it enters that region. The elasticity parameter determines the deceleration of the target on each side of the playfield when it contacts the peripersonal circle or playfield boundary. Related to the push button controller are the parameters that set the speed with which the peripersonal circle expands, the maximum size it expands to, and the maximum hold time or duration it can be kept expanded (e.g., to defend a goal). Additional, fewer, or alternative parameters may be used.

[0073] The adjustment of the parameters on an individual basis and/or other aspects of the disclosed systems and methods provide a high level of accessibility for people of different mobility levels, including players using various mobility aids, such as power wheelchairs, manual wheelchairs, and walkers. Furthermore, in tests of the disclosed systems and methods, players of a wide range of ages were accommodated (e.g., between seven and 19 years old). Participants included five power wheelchairs users, two manual wheelchairs users, one person using a walker, and two people without disabilities.

[0074] Figures 5 and 6 depict examples of how the increased level of accessibility allows players with different mobility levels to play against, and interact with, each other. The parameters were used to calibrate the game environment, thereby making the game more playable and enjoyable for each of the participants. Examples of player combinations tested were:

1. Manual wheelchair user vs. Manual wheelchair user
2. Power wheelchair user vs. Power wheelchair
3. Power wheelchair user vs. Manual wheelchair user
4. Power wheelchair user vs. Non-disabled player
5. Manual wheelchair user vs. Non-disabled player

[0075] Another aspect of the disclosed systems and methods that improves accessibility involves different mounting positions of the controller (e.g., push button controller). The controller may be configured such that the controller is disposed in a hand-, torso-, or leg-mounted position. Other positions may be used, including positions on a mobility aid, such as a walker handle. The configuration of the controller may include or involve varying the size of the switch. For example, the activation surface of the controller may vary (e.g., 2.5 cm and 3.5 cm). For example, the smaller switch was mounted on the index finger of participants using manual wheelchairs in such a way that they could activate the switch while pushing the wheelchair handrims. One participant using a walker had the switch mounted on the right handle. Most participants using power wheelchairs used the larger switch with their right hand, which was placed on their lap while the left hand controlled the wheelchair's joystick. One power wheelchair user participant had the switch mounted on his right knee and activated it by pressing both knees together. For the knee switch mounting position, a larger activation surface may be useful.

[0076] Figure 6 shows examples of two different mounting positions for the controller. The player on the left has the controller in a knee-mounted position. The player on the right has the controller in an index finger position.

[0077] Figures 7-10 show further examples of optional mounting arrangements for the controller. In Figure 7, the controller includes a strap (e.g., a hook and loop strap) for securing the controller to a finger or other body part or object. Figure 8 depicts the controller of Figure 7 with the strap secured to a wheelchair platform. Figure 9 depicts the controller of Figure 7 with the strap wrapped around one or more fingers of a player. Figure 10 depicts a controller with an alternative finger mounting arrangement in which the controller is actuated by pressing the controller against a wheelchair rim or other object.

[0078] The following aspects of examples of the disclosed systems and methods were found in the test to increase playability and utility.

[0079] The peripersonal circle expands uniformly which allowed each player to develop different movement and target manipulation strategies based on player skills and respective mobility aids. For example, some wheelchair users activated the push button controller while moving sideways across the playfield to kick or defend a goal while others made more turns and confronted the target and opponent heads on.

[0080] The simple and unambiguous click and hold function of the push button controller enabled participants with mobility aids to perform similar gameplay behavior as their non-disabled peers. It enabled player to push the button for a kick or hold it down to keep the peripersonal circle expanded, which seemed intuitive to use, for example, to block an opponent's kick or defend the goal. The push button controller and the peripersonal circle feature make the game fair.

[0081] The intuitive use of the peripersonal circle feature simulated a realistically physical play experience when the target was in front of the participants.

[0082] In some cases, if two or more players are in close proximity to each other, their peripersonal circles may merge into one larger circle. This effect may be eliminated by incorporating player ID tracking, thereby enabling competitive multiplayer team sport scenarios. On the other hand, this effect may encourage new forms of collaborative behaviors, such as players inviting other players to join their peripersonal circle to cover more surface area, for example, to more effectively defend a goal.

[0083] The tests exhibited the degrees to which the game environment is affected by adjustments to the parameters. Different parameters achieved different levels of player balancing. Most effective were the parameters relating to changing the size of the goal and the maximum size of the peripersonal circle as well as its expansion speed (i.e. “kicking” power). Changing the maximum target speed, playfield friction or elasticity parameters helped to set the overall pace of the game, but was often less comprehensible and more difficult to use for manually balancing player’s individual abilities. Further, some participants had the tendency to adapt their gameplay to their opponent. For example, one participant started by playing easy and got more competitive as the game went on. Another participant tried to teach the opponent by showing how to best play the game. These cooperation and self-balancing behaviors reminded one of a soccer pick-up game in which player with different abilities seek to find a competitive yet mutually satisfying way to play together. These interactions may be useful and beneficial apart from the goal of achieving a balanced game environment through physics model adjustments. The disclosed systems and methods may thus provide an inclusive environment for individuals with mobility limitations.

[0084] Other aspects of the game environment also promote an inclusive sports experience, including, for instance, the virtual nature of the target object. The virtual nature of the object avoids a sports experience in which players may get embarrassed when hit by a ball, as in walker soccer.

[0085] The disclosed systems and methods are designed to build on players’ ability to see, hear, and have response capability to play and evaluate the game regardless of if they use a mobility aid, or what kind of mobility aid they use. Significant improvements in accessibility and playability of the game (e.g. ability to score and defend goals) are achieved relative to other activities. The peripersonal circle interaction and individualized game calibration may be useful with other types of participants. The benefits are not limited to manual wheelchair users and power wheelchair users.

[0086] The peripersonal boundary provides a universal design element for fast-paced manipulation of virtual targets on interactive floors. The use of a circle presents the risk of accidently manipulating the target behind a player’s back. Other non-uniform, scalable, peripersonal space representations, in which the players have no or less active space behind their backs, may be used to address that risk.

[0087] The probably most significant finding underlying the accessibility of the game environment was the unexpectedly high target speeds with which the game was playable. The general significance of the target speed is that it defines the pace of a game and a player’s performance. In the tests, the target speed turned out to be a useful measure, because it connects to other findings related to the relative success of different player balancing efforts and social factors. For example, when the playtests were designed, it was anticipated that the maximum target speed would be one of the parameter that has to be calibrated most to address players' individual abilities. Instead, it was found that the maximum target speed parameters in all playtest categories could be left relatively close to the upper speed threshold of the system for both players on the field. More actual player balancing was achieved by changing the goal size and the size of the peripersonal circle as well as its expansion speed (i.e. kicking power) for player using the push button controller. These alternative system balancing measures were one of the reason, why the maximum target speed parameters were largely left untouched and ended up being higher than anticipated.

[0088] Related to our development goal of inclusive exergames is the notion of fairness, which was evident in the test results. Fairness was a reason why the players found the peripersonal circle feature and the push button controller appealing to use. The game's perceived fairness from the player's side seems to also align with the game's fair "optic" from the observer and spectator's side, which shows every player with the same peripersonal circle represented on the playfield.

[0089] The disclosed systems and methods are not limited to the examples described above. Alternative features may be incorporated, including, for instance, tracking a player identification code (ID) to enable multiplayer games with more than two players, and full integration of the push button controller as a wearable and/or chair-able input device . In some cases, the controller may be integrated into the joystick of power wheelchairs. Still other options involve a floor-projected user interface that enables players to start or change games or balance certain parameters such as their "kicking power" automatically or by player direction.

[0090] In some cases, the disclosed methods and systems may include further or alternative interaction scenarios. For instance, the target itself may include a structural component, such as a robotic disc, as well as an image-based component, e.g., a projected circle around the disc. The projection may be achieved through, e.g., laser projection. The circle may be used for directly manipulating the disc without touching the disc. This scenario provides another example of object manipulation, and may be useful game environments having slower moving objects and/or robots.

[0091] The disclosed methods and systems provide an interactive floor projection system that enables co-located physical play for people with motor disabilities and their non-disabled peers.

Playtests indicated that the peripersonal circle interaction feature was useful for system playability at overall higher than anticipated target speeds for all 10 participants. Regardless of what type of, or if, a mobility aid was used, the peripersonal circle feature provided all players equal access, kicking power, and similar target manipulation opportunities. Further, the sizes of the peripersonal circle and goal were a more significant variable for player balancing than adapting the maximum target speeds; and social factors such as players' self-balancing behavior and their relationships had also significant impact on the gameplay. Our design features and related findings have theoretical and practical implications for creating novel, inclusive exergame opportunities.

[0092] The disclosed methods and systems provide physical play opportunities for people with motor disabilities that include co-located play with non-disabled peers. The disclosed methods and systems provide an interactive floor projection system for inclusive exergames, which enables people with motor disabilities to compete on par with, and in the same environment as, their non-disabled peers. Multiple system features, e.g., player balancing and peripersonal circle interaction, enable individualized game calibration and fast-paced manipulation of virtual targets on the floor. Playtests were conducted with various participants, including users of power wheelchairs, manual wheelchairs, a walker, and non-disabled players. The playtests showed overall playability with similar high target speeds. Adapting the maximum target speeds was less significant for addressing players' individual abilities than changing the sizes of their peripersonal circles or goals.

[0093] The present disclosure has been described with reference to specific examples that are intended to be illustrative only and not to be limiting of the disclosure. Changes, additions and/or deletions may be made to the examples without departing from the spirit and scope of the disclosure.

[0094] The foregoing description is given for clearness of understanding only, and no unnecessary limitations should be understood therefrom.

What is Claimed is:

1. A method of providing an augmented reality game environment within a game space, the method comprising:

obtaining, by a processor, sensor data for the game space;

determining, by the processor, a position of a player in the game space based on the sensor data;

generating, by the processor, player image data of a peripersonal boundary of the player based on the determined position of the player for rendering a representation of the peripersonal boundary in the game space, the peripersonal boundary being disposed about, and spaced from, the determined position;

obtaining, by the processor, player data for the player via an input modality, the player data being indicative of a player directive to modulate the peripersonal boundary;

adjusting, by the processor, a size of the peripersonal boundary as a function of the player data; and

updating, by the processor, the player image data based on the adjusted size of the peripersonal boundary.

2. The method of claim 1, wherein the adjusted size of the peripersonal boundary comprises an expansion of the peripersonal boundary, the expansion increasing a reach of the player to interact with a target object of the game space.

3. The method of claim 1, wherein the player data comprises a controller signal from a controller, the controller signal being indicative of an actuation of the controller by the player.

4. The method of claim 1, wherein adjusting the peripersonal boundary comprises accessing a data store to obtain a player parameter, such that the function by which the peripersonal boundary is adjusted takes the player parameter as an input.

5. The method of claim 4, wherein the player parameter calibrates a speed of expansion of the peripersonal boundary.

6. The method of claim 4, wherein the player parameter calibrates a maximum size of expansion of the peripersonal boundary.

7. The method of claim 4, wherein the player parameter calibrates a duration of expansion of the peripersonal boundary.

8. The method of claim 4, wherein the player parameter calibrates an elasticity of the peripersonal boundary in connection with non-player-induced interaction of the peripersonal boundary with a target object.

9. The method of claim 1, wherein:

the input modality comprises a sensor system such that the player data comprises further sensor data;

adjusting the size of the peripersonal boundary comprises determining, by the processor, that the further sensor data is indicative of an outward thrust of a limb of the player.

10. The method of claim 1, further comprising:

determining, by the processor, a position of a simulated object of the augmented reality game environment within the game space;

generating, by the processor, object image data of the simulated object for rendering a representation of the simulated object in the game space; and

updating the object image data based on a simulated interaction of the simulated object and the adjusted size of the peripersonal boundary.

11. The method of claim 1, further comprising rendering, by the processor, a visible representation of the player image data.

12. The method of claim 1, further comprising projecting, via a projection system, a representation of the player image data on a floor on which the game space is defined and on which the player moves.

13. A system for providing an augmented reality game environment within a game space, the system comprising:

a projection system to render images in the game space;

a sensor system to capture sensor data for the game space;

a processor coupled to the sensor system to receive the captured sensor data and to the projection system to control rendering of the images; and

a memory coupled to the processor and in which player detection instructions and image generation instructions are stored;

wherein the processor is configured via execution of the player detection instructions to determine a position of a player in the game space based on the sensor data;

wherein the processor is configured via execution of the image generation instructions to generate player image data of a peripersonal boundary of the player based on the determined position of the player and to direct the projection system to render the images in accordance with the player image data, the peripersonal boundary being disposed about, and spaced from, the determined position;

wherein the processor is further configured via the execution of the player detection instructions to obtain player data for the player via an input modality, the player data being indicative of a player directive to modulate the peripersonal boundary;

wherein the processor is further configured via the execution of the image generation instructions to adjust a size of the peripersonal boundary as a function of the player data and update the player image data based on the adjusted size of the peripersonal boundary.

14. The system of claim 13, wherein the adjusted size of the peripersonal boundary comprises an expansion of the peripersonal boundary, the expansion increasing a reach of the player to interact with a target object of the game space.

15. The system of claim 13, further comprising a controller configured to be actuated by the player, wherein the player data comprises a controller signal from the controller, the controller signal being indicative of an actuation of the controller by the player.

16. The system of claim 13, wherein the processor is further configured via the execution of the image generation instructions to access a data store to obtain a player parameter, such that the function by which the peripersonal boundary is adjusted takes the player parameter as an input.

17. The system of claim 16, wherein the player parameter calibrates a speed of expansion of the peripersonal boundary, a maximum size of expansion of the peripersonal boundary, a duration of expansion of the peripersonal boundary, or an elasticity of the peripersonal boundary.

18. The system of claim 13, wherein:

the sensor system provides the input modality such that the player data comprises further sensor data;

wherein the processor is further configured via the execution of the player detection instructions to determine that the further sensor data is indicative of an outward thrust of a limb of the player.

19. The system of claim 13, wherein the processor is further configured via the execution of the image generation instructions to:

determine a position of a simulated object of the augmented reality game environment within the game space;

generate object image data of the simulated object for rendering, via the projection system, a representation of the simulated object in the game space; and

update the object image data based on a simulated interaction of the simulated object and the adjusted size of the peripersonal boundary.

20. The system of claim 13, wherein the projection system is mounted above the game space such that the images are rendered on a floor on which the game space is defined and on which the player moves.

ABSTRACT OF THE DISCLOSURE

A method of providing an augmented reality game environment within a game space includes obtaining, by a processor, sensor data for the game space, determining, by the processor, a position of a player in the game space based on the sensor data, generating, by the processor, player image data of a peripersonal boundary of the player based on the determined position of the player for rendering a representation of the peripersonal boundary in the game space, the peripersonal boundary being disposed about, and spaced from, the determined position, obtaining, by the processor, player data for the player via an input modality, the player data being indicative of a player directive to modulate the peripersonal boundary, adjusting, by the processor, a size of the peripersonal boundary as a function of the player data, and updating, by the processor, the player image data based on the adjusted size of the peripersonal boundary.

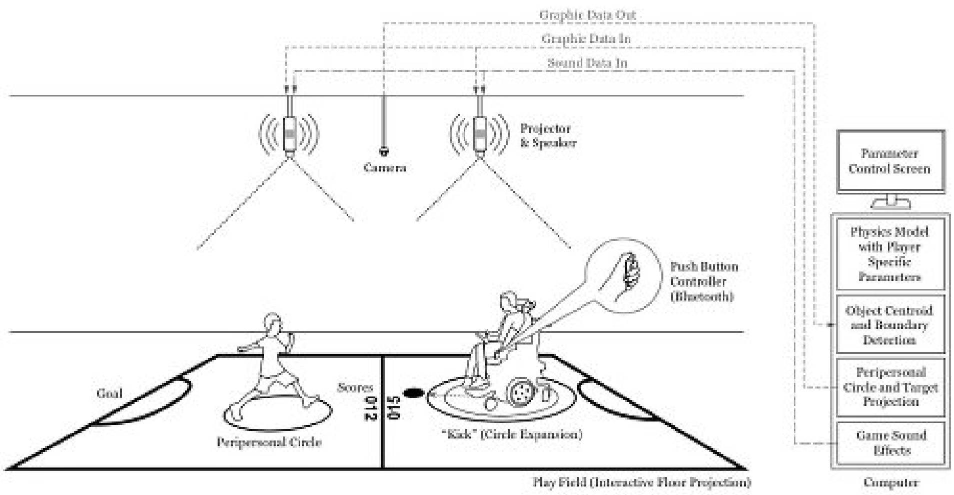
Graphic Data Out
Graphic Data In
Sound Data In
Projector & Speaker
Camera
Parameter Control Screen
Physics Model with Player Specific Parameters
Object Centroid and Boundary Detection
Peripersonal Circle and Target Projection
Game Sound Effects
Computer
Push Button Controller (Bluetooth)
Goal
Scores
012
015
Peripersonal Circle
"Kick" (Circle Expansion)
Play Field (Interactive Floor Projection)

FIG. 1

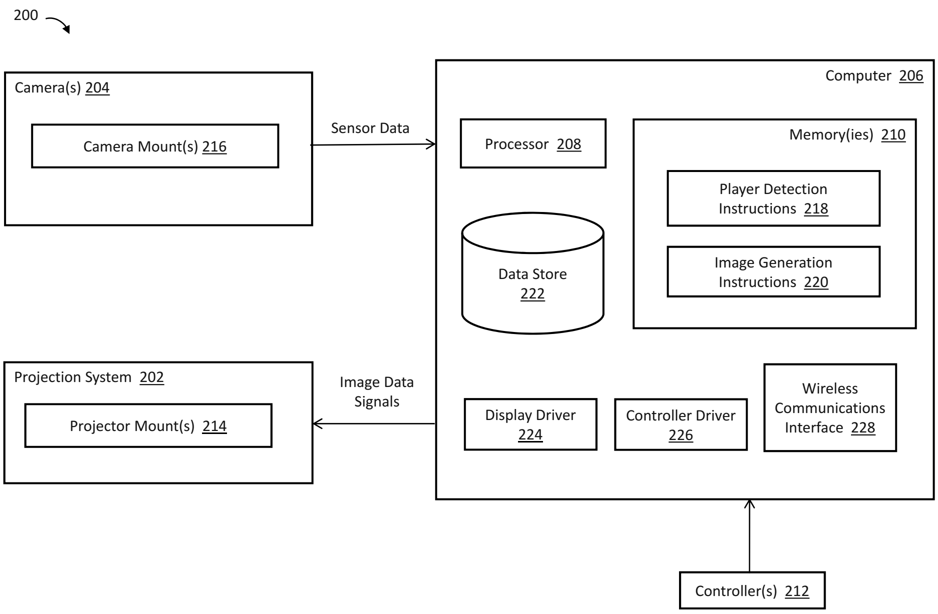
200
Camera(s) 204
Camera Mount(s) 216
Sensor Data
Computer 206
Processor 208
Memory(ies) 210
Player Detection Instructions 218
Image Generation Instructions 220
Data Store 222
Projection System 202
Projector Mount(s) 214
Image Data Signals
Display Driver 224
Controller Driver 226
Wireless Communications Interface 228
Controller(s) 212

FIG. 2

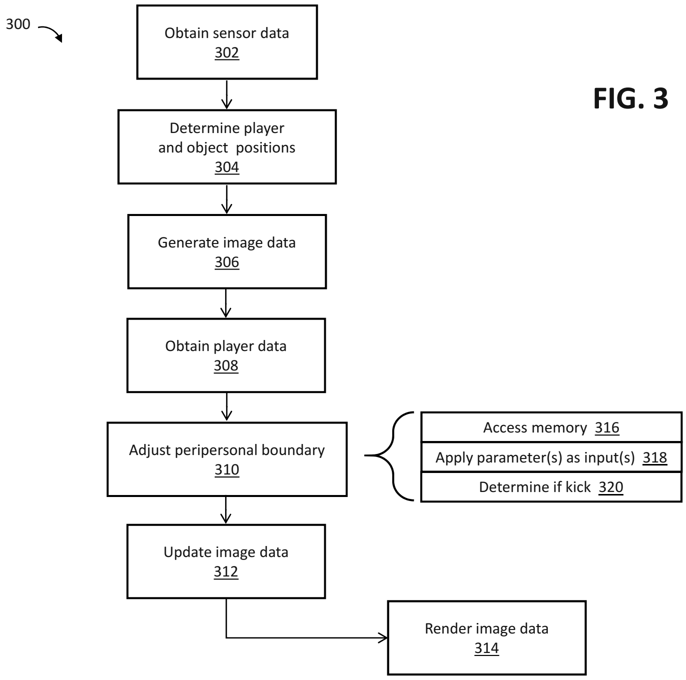
300
Obtain sensor data 302
Determine player and object positions 304
Generate image data 306
Obtain player data 308
Adjust peripersonal boundary 310
Access memory 316
Apply parameter(s) as input(s) 318
Determine if kick 320
Update image data 312
Render image data 314

FIG. 3

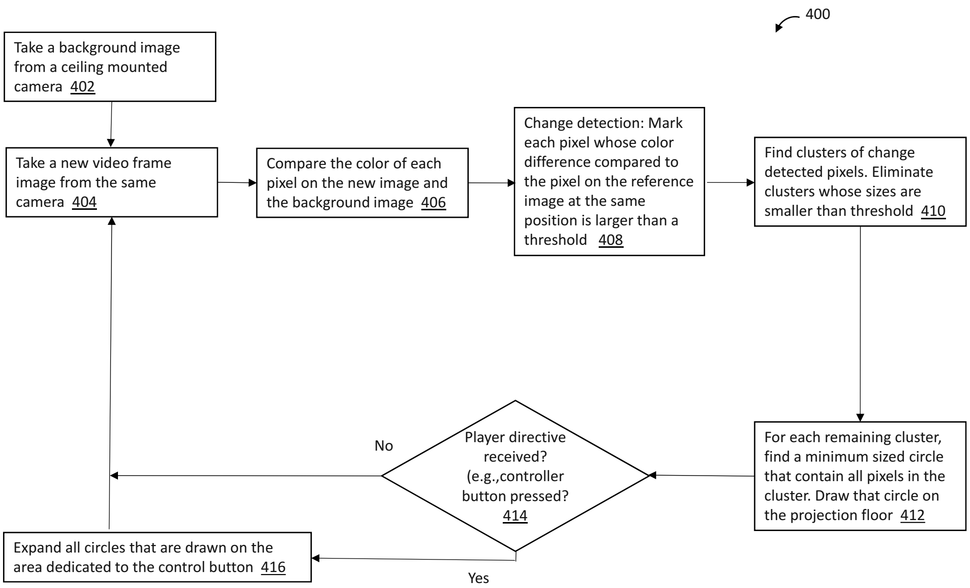
400
Take a background image from a ceiling mounted camera 402
Take a new video frame image from the same camera 404
Compare the color of each pixel on the new image and the background image 406
Change detection: Mark each pixel whose color difference compared to the pixel on the reference image at the same position is larger than a threshold 408
Find clusters of change detected pixels. Eliminate clusters whose sizes are smaller than threshold 410
For each remaining cluster, find a minimum sized circle that contain all pixels in the cluster. Draw that circle on the projection floor 412
Player directive received? (e.g.,controller button pressed? 414
No
Yes
Expand all circles that are drawn on the area dedicated to the control button 416

FIG. 4


600
014

FIG. 5

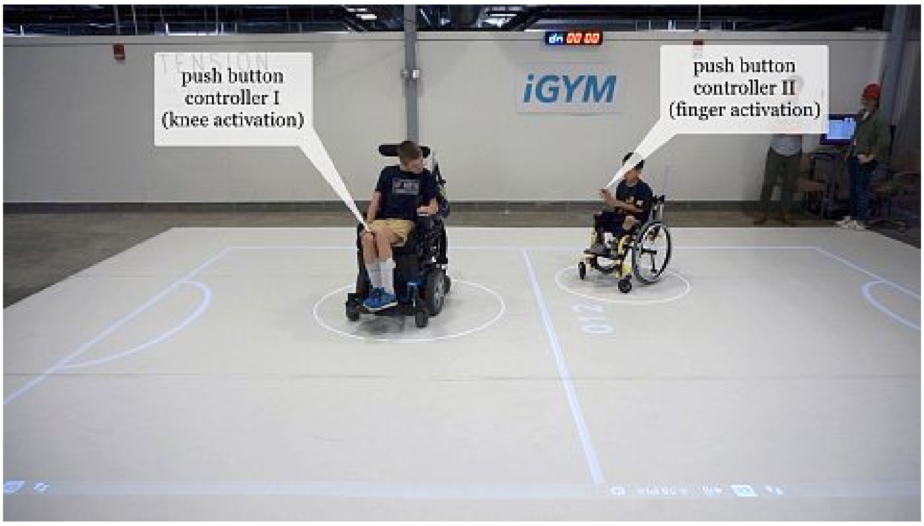
push button
controller I
(knee activation)
iGYM
push button
controller II
(finger activation)

FIG. 6

FIG. 7

FIG. 8

FIG. 9

FIG. 10

Appendix F: Curriculum Vitae

ROLAND GRAF

CURRICULUM VITAE

Associate Professor
Stamps School of Art & Design
University of Michigan
Ann Arbor, MI, USA

www.igym.solutions
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roland@assocreation.com
+1.734.649.5812

EDUCATION

2020 (expected) **Dr. techn. (Doctor of Science)**
Vienna University of Technology, Austria. Concurrent enrollment: WU Vienna University of Economics and Business and University of Vienna
Dissertation: *From Pink to Pong: Tracing a Convergence of Art and Ludic Engineering*
Advisor: Christine Hohenbüchler (Head of the Institute of Art and Design)

2000–03 **Periods of study**
Academy of Fine Arts Vienna, Austria; Ecole d´ Architecture Montpellier, France

2002 **Dipl. Ing. (Master of Science in Architecture equivalent)**
Vienna University of Technology, Austria. Advisor: William Alsop

PROFESSIONAL EMPLOYMENT

2011–Present **Associate Professor** (promotion/tenure in 2017)
University of Michigan, Stamps School of Art & Design
MFA Faculty Advisor and Studio Leader of the MDes in Integrative Design cohort 2018-20 (thematic focus: *Equity and Access in Education)*

2007–11 **Assistant Professor** (Univ. Ass.)
Department of Spatial and Sustainable Design, Institute for Architecture and Design, Vienna University of Technology

2004–07 **Senior Exhibition Designer**
BWM Architects, Vienna, Austria
Designed exhibitions for public museums, trade shows, and art fairs. Clients included: Eggenberg Palace, Graz; The Vienna Museum; *XAL, etc.*

2003–04 **Paramedic** (alternative civilian service)
Green Gross Ambulance Service, Vienna, Austria

2002 **Architectural Project Manager**
PPAG Architects, Vienna, Austria
Managed the initial design and launch of the award-winning experimental igloo and street furniture project *Enzi* for the MuseumsQuartier Wien

PROFESSIONAL ACTIVITIES

2018–Present **Creator and Principal Investigator**
Created *iGYM,* an inclusive augmented reality play and exercise system for children with different abilities. Initiated and lead a U-M cross-campus research team with faculty and students from the School of Information, School of Kinesiology, Stamps

School of Art & Design, and the College of Engineering. Develop productization plans with the U-M Tech Transfer Venture Center. (Co-PI's: Michael Nebeling and Hun-Seok Kim)

2015–Present **Creator and Principal Investigator**
Created *Internet of Shoes (IoS),* a sensory networking platform. Lead a U-M cross-campus research collaboration on prototyping novel ways of human connectedness with embedded wireless technologies. Work on productization with U-M Tech Transfer Venture Center. (Co-PI's: Prabal Dutta and Brad Campbell)

2014–2017 **Director and Principal Investigator**
Established *Daylight Media Lab*, a U-M Art & Technology research collaboration with material scientists and engineers exploring sunlight as a medium for interactive outdoor experiences. Outcomes: patent applications, the award-winning street video game *Solar Pink Pong,* and interaction modalities inspiring the *iGYM* project.

2007–16 **Freelance Product Designer**
Created products for the German retailer *Magazin* and the Danish furniture manufacturer *Fredericia*. Product launches: *Feldmark Eiche Table* (2016), *Slim Jim Table* (2011), *Koerfgen Bench* (2010), and *Feldmark Table* (2007).

1997–Present **Artist and Co-founder**
Co-founded the artist group *Assocreation* in Vienna, Austria in 1997. Established *Assocreation's* studio in Michigan, USA in 2011. Direct *Assocreation's* work, which includes urban interventions, happenings, objects, and interactive installations (see awards and exhibitions below).

AWARDS AND HONORS (selected)

2019 ***ACM CHI Play Best Paper Award*** for the *iGYM* study (top 1% of submissions)

U-M Ideas Lab: Predicting Human Performance. Invited to a three-day workshop event with 25 selected experts from various disciplines to develop new cutting-edge interdisciplinary research proposals for the U-M Bioscience Initiative.

PLAY_STREET, Winner with *Red Crossing*. International competition to re-imagine the urban street as a play space as part of the 2019 Winnipeg Design Festival PROTO. (with Nick Tobier and Jennifer Low)

2018 ***U-M Academic Innovation Award*** for online course development that examines the present and possible futures of AR/MR/VR (with Michael Nebeling, Steve Oney)

2017 ***LitKNIT Gateways, shortlisted*** (5 out of 80 entries) for the Smart Oxford Playable City Commission, UK. (with Nick Tobier and Michael Rodemer)

2016 ***19th Japan Media Arts Festival, Excellence Award*** in the Entertainment Division for *Solar Pink Pong* (3 out of 700 entries). The National Art Center, Tokyo, Japan. Head of the Jury: IIDA Kazutoshi (Game Creator and Professor, Ritsumeikan University), HIGASHIIZUMI Ichiro (Designer and Creative Director), KUDO Takeshi (Curator, Aomori Museum of Art), UKAWA Naohiro (Artist and Professor, Kyoto University of Art and Design), YONEMITSU Kazunari (Game Designer)

	New Technological Art Award 2016 (NTAA), Nomination for *Solar Pink Pong* (20 out of 478 entries). Ghent, Belgium. Head of the Jury: Martin Honzik (Head of Department Prix/Festival Ars Electronica) and Peter Weibel (Director, ZKM Karlsruhe)
2015	***Customer Discovery Program*** to explore the commercialization potential of *Solar Pink Pong*. Five-week long I-Corps workshop at the Grand Valley State University sponsored by the U-M Center for Entrepreneurship, Michigan, USA.
2014	***The Rogers Edge Award*** for accomplishments in creative work and research, Stamps School of Art & Design, University of Michigan, USA.
2013	***Community Service Award*** in recognition for the service to the homeless community of Washtenaw County, Ann Arbor, Michigan, USA.
2006	***Diwali Art Commission, Finalist*** with *Moon Ride*. ArtReach (Events) Ltd, Leicester City Council, Leicester, UK.
2005	***Adolf Loos National Prize for Design*** for the street furniture *Enzi,* Design Austria. (with PPAG Architects)
2004	***Atelierstipendium*** *(studio space award) "Making it 2 – die sprache der straße"* for *Assocreation* sponsored by Vienna's 5th municipal district, Vienna, Austria.
2003	***Special Award, Kunsthalle Wien*** for my master thesis *Common Ground bodenlos*, Kunsthalle Wien-Project Space, Vienna, Austria. (with Michael Bieglmayer)
2001	***Prix Ars Electronica 2001, Award of Distinction*** in the Category of Interactive Art for *Bump*. Ars Electronica Center and ORF studio Linz, Austria. Jury: Masaki Fujihata (Media Artist and Professor, Keio University, Japan), Ulrike Gabriel (Media Artist, Germany), Peter Higgins (Designer, UK), Hiroshi Ishii (Computer Scientist, Professor, MIT, USA), Joachim Sauter (Media artist and designer, Professor, Berlin University of the Arts, Germany)
	Telematikpreis for *Bump*. University of Essen and Berlin University of the Arts, Germany.
1999	***Europan 5: New Housing Landscape, Site: Turko, Finnland, 2nd Prize*** for *Housing for Homeworkers*, Biennial European Architecture competition. (with Michael Bieglmayer, Mladen Jadric, and Urban Fish Architects)

PATENTS

2019	US Utility Patent, Title: *Peripersonal Boundary-Based Augmented Reality Game Environment*. Inventor: Roland Graf et al. (Application No.: 62/826,814)
	US Utility Patent, Title: *Sensory Networking Device and Methods of Use*. Inventor: Roland Graf et al. (**Granted**, Patent No.: US10433394)
2017	US Utility Patent, Title: *Interactive Projection System*. Inventor: Roland Graf et al. (**Granted**, Patent No.: US9547162)
2011	Austrian Utility Patent, Title: *Möbel mit abnehmbaren Stützbeinen*. Inventor: Roland Graf (**Granted**, Patent No.: AT509473)

GRANTS AND SPONSORSHIPS (selected)

2020 — *U-M Bioscience Ideas Lab Progam:* "Biological signatures of creative work and problem solving: A cross-disciplinary approach". Co-Principal Investigator with: Sara Aton (PI), SangHyun Lee, Taraz Lee, Anita Gonzalez, and Margit Burmeister. ($ 790,000)

2018 — *The U-M Exercise and Sport Science Initiative Award (ESSI):* "A projection-based augmented reality system for inclusive recreational sports and performance tracking". Principal Investigator. Co-PI's: Michael Nebeling and Hun Seok Kim. ($ 150,000)

U-M Office of Research, Faculty Grants and Awards Program: "Red Crossing". Co-PI with Nick Tobier. ($ 18,000)

U-M AR/VR Initiative: Lenovo computers and AR smartphones. (value $ 5,500)

2017 — *U-M Microsoft AR/VR Initiative*: Microsoft HoloLens, commercial suite for developers. (value $ 4,500)

2016 — *Play Everywhere Challenge, Winner* (50 out of 1000+ submissions): *"Brightmoor Runway"* (with Nick Tobier and Michael Flynn). National competition developed by KaBOOM in collaboration with the Robert Wood Johnson Foundation, the U.S. Department of Housing and Urban Development, the National Endowment for the Arts, etc. to envision community-driven solutions that integrate play into everyday life and unexpected places. ($ 40,000)

U-M Office of Research, seed funding to multi-unit, faculty-led teams (MCubed 2.0): "Next Generation Outdoor Interactive Media Systems" with Edwin Olson and Jason Corso. ($ 15,000)

2015 — *U-M Office of Research, Faculty Grants and Awards Program:* "Internet of Shoes". ($ 11,250)

Undergraduate Research Opportunity Program (UROP) and Supplementary Research Funding: "Daylight Media Lab". ($ 1,700)

2014 — *Stamps School of Art & Design, Faculty Research Seed Grant Funding*: "Daylight Media Lab". ($ 25,600)

2013 — *U-M Office of the Vice President for Research, Faculty Grants and Awards Program*: "Solar Pink Pong". ($ 11,250)

2012 — *The Austrian Research Promotion Agency (FFG)*, Vienna, Austria: "Moon Ride". (EUR 5,000)

Instructional Development Fund, U-M *Center for Research on Learning and Teaching*: "Design and Build Portable Shelter: Ann Arbor's Camp Take Notice." ($ 500)

2010 — *Istanbul 2010: European Capital of Culture*: "Bump: Asia / Europe". (EUR 26,700)

The Arts and Culture Division of the Federal Chancellery of Austria: "Bump: Asia / Europe". (EUR 7,000)

2008	*Republic of Austria Federal Ministry for Europe, Integration and Foreign Affairs (BMEIA), Europalia*: "Red Carpet". (EUR 4,400)
2006	*The Arts and Culture Division of the Federal Chancellery of Austria*: "Moon Ride". (EUR 10,000)
	The Arts and Culture Division of the Federal Chancellery of Austria: "Real Estate". (EUR 3,700)
2004	*Emanuel und Sofie Fohn-Stipendienstiftung (Stipend for highly talented students)*: "Airlines". (EUR 2,000)
2003	*Bienal de Valencia, Alsop Architects*: "Common Ground". (EUR 43,500)
	The Arts and Culture Division of the Federal Chancellery of Austria: "Bump: Fabrica / MuseumsQuartier Wien". (EUR 15,000)
2000	*Kapsch AG (The Kapsch Group: International Road Telematics, Information Technology and Telecommunications Company):* "Bump: CeBIT 2000 Hannover / Burgtheather Wien". (ATS 477,560)
1999	*Robert Bosch AG*: "Bump: Linz / Budapest". (ATS 120,000)
	The Arts and Culture Division of the Federal Chancellery of Austria: "Bump: Linz / Budapest". (ATS 120,000)
	Federal Ministry of Science, Research and Economy: "Bump: Linz / Budapest". (ATS 100,000)

PEER REVIEWED PUBLICATIONS

2019	**Roland Graf**, Pallavi Benawri, Amy E Whitesall, Dashiell Carichner, Zixuan Li, Michael Nebeling, and Hun Seok Kim, "iGYM: An Interactive Floor Projection System for Inclusive Exergame Environments," *In Proceedings of the 2019 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '19)*, ACM, New York, NY, USA, 31–43. **(Best Paper Award)**
	Roland Graf, Sun Young Park, Emma Shpiz, and Hun Seok Kim. 2019. IGYM: A Wheelchair-Accessible Interactive Floor Projection System for Co-located Physical Play. *In Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (CHI EA '19)*. ACM, New York, NY, USA, Paper LBW1615, 1–6.
2015	**Roland Graf** and Surat Kwanmuang. 2015. Solar Pink Pong: Street Video Game. *In Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '15)*. ACM, New York, NY, USA, 417–418.

SOLO EXHIBITIONS

2009	*"Assocreation – taste it!"*. The Vienna Künstlerhaus, k/haus galerie, Austria. Curated by Peter Bogner (Director, Künstlerhaus) and Irene Korom. Opening remarks: Dr. Paul Maringer.
2008	*"Feldmark by Roland Graf"*. Exhibition organized by Magazin as part of "Passagen 2008: Interior Design Week", Cologne, Germany.

2003	*"Bump, Assocreation"*. Fabrica Gallery, Brighton, UK. Curated by Matthew Miller and Liz Whitehead.

GROUP EXHIBITIONS AND URBAN INTERVENTIONS (selected)

2019	*Red Crossing.* Participatory public performance. Group Exhibition "PROTO-", Winnipeg Design Festival, Winnipeg, Manitoba, Canada. Juried by Luis Callejas, Liz Wreford, and Marianne Amodio. (with Nick Tobier/Everyday Places)
	Bump. Documentation. Group exhibition "ARS on the WIRE, 40 Years Ars Electronica", Ars Electronica, Linz, Austria. Curated by Gerfried Stocker.
	Red Crossing. Participatory public performance. Group Exhibition "Formations", The Prague Quadrennial of Performance Design and Space 2019, Prague, Czech Republic. (with Nick Tobier/Everyday Places)
	Pipa Vista. Urban intervention and workshop series. Instituto Acaia and Parque Villa Lobos, São Paulo, SP, Brazil. (with Instituto Acaia and Stamps School MDes C4)
2018	*Brightmoor Runway.* Permanent urban intervention. Brightmoor, Detroit, Michigan, USA. (with Nick Tobier and Michael Flynn)
2017	*Flint Runway.* Temporary urban intervention. Group Exhibition "Flint Free City Festival", Michigan, USA. (with Nick Tobier and Michael Flynn)
	Austria Power Machine. Interactive installations. Group Exhibition "With brain, heart and muscle power! Austrian Pavilion at the EXPO 2017 in Astana, Kazakhstan. (with BWM Architects)
	Internet of Shoes. Objects and Documentation. Group Exhibition "Reach: A Stamps Faculty Exhibition", Ann Arbor Stamps Gallery, Michigan, USA. Curated by Srimoyee Mitra.
	Energy Race. Interactive installation. Centennial Ceremony and Exhibition, Chulanlongkorn University, Bangkok, Thailand.
2016	*Rolling Shadows*. Interactive Installation and happening. Group exhibition "CreateWorld 2016: The Creativity of Things", Queensland College of Art, South Brisbane, Australia.
	Solar Pink Pong. Interactive installation. Group exhibition "Update_6 / New Technological Art Award", Zebrastraat Ghent, Belgium. Juried by Martin Honzik (Head of Department Prix/Festival Ars Electronica) and Peter Weibel (Director, ZKM Karlsruhe).
	Internet of Shoes. Interactive Installation. Group exhibition "ISEA2016 Hong Kong Cultural R>evolution – 22nd International Symposium on Electronic Art", Hong Kong, China. Curated by Dr. Olli Tapio Leino and Tobias Klein (School of Creative Media, City University of Hong Kong).
	Solar Pink Pong. Interactive installation. Group exhibition "19th Japan Media Arts Festival". The National Art Center, Tokyo, Japan. Organized by the Japan Media Arts Festival Executive Committee.

	Arising from the Surface. Urban Interventions and independent filmmaking project. Mumbai, India. Assisted by Smruti Swarup Puhan and supported by the University of Michigan India Initiative. (with Robert Platt)
2015	*Red Carpet* and *Dumpster Swimming Pool*. Installation. Group Exhibition "Sommer Spiele" (Summer Games), GrazMuseum, Graz, Austria. Curated by Otto Hochreiter und Christina Töpfer.
	Solar Pink Pong. Interactive installation. Group exhibition "FILE 2015: Electronic Language International Festival", Sao Paulo, Brazil. Curated by Paula Perissinotto and Ricardo Barreto.
	Solar Pink Pong. Interactive installation. Group exhibition "Arts Track at TEI 2015 – the 9th International Conference on Tangible, Embedded and Embodied Interaction" at Stanford University, CA, USA. Curated by Wendy Ju (Stanford University) and Arts Track Chairs Elizabeth Goodman (UC Berkeley) and Younghui Kim (Hongik University).
2014	*Sewer Foamies*. Installation and happening. Group exhibition "Cheriton Light Festival", Folkestone, UK. Commissioned by Strange Cargo Arts Company Ldt., Cheriton, Folkestone, United Kingdom.
	Solar Pink Pong. Interactive Installation. Group exhibition "ISEA 2014: LOCATION – The 20th International Symposium on Electronic Art", Dubai, UAE. Curated by Janet Bellotto and Joshua Watts (Zayed University, College of Arts and Creative Enterprises, Dubai, UAE).
	Solar Pink Pong. Installation. Group exhibition "Constellations – Lines and Pictures", Slusser Gallery, Ann Arbor, MI, USA. Curated by Peter Dykhuis.
	Freedom. Photo documentation. Group exhibition "Written on the City", Lovely, Chicago, IL, USA. Curated by Tori Terizakis.
2013	*Moon Ride*. Interactive installation and documentation. Group exhibition "citydrift/Detroit", Kunsthalle Detroit, Michigan, USA. Curated by Peter Hopkins and Jennifer Junkermeier.
	Freedom Reloaded. Permanent light installation. Basketball court Margaretengürtel, Vienna, Austria. Commissioned by Vienna's 5th municipal district.
	Rolling Shadows. Interactive installation and happening. Group exhibition "INTERCIDADES", Schwanke Contemporary Art Museum, Joinville, Brazil, and Lansing, USA. Juried and curated by Alena Marmo (Brazil), James L. Lawton (USA) and Jefferson Kielwagen (Brazil).
	Rolling Shadows. Video and interactive mixed media assemblage. Group exhibition "2013 North American International Anti Auto Show", The Contemporary Arts Institute of Detroit, MI, USA. Curated by Thomas Bell and Christina de Roos (Spread Art).
	Quantified Self/Reflection. Object and Video. A&D Faculty Show "In Progress", Slusser Gallery, Ann Arbor, MI, USA.

2012	*Moon Ride*. Interactive installation. Group exhibition "Earth, Body, Mind", 2nd Kathmandu International Art Festival, Kathmandu, Nepal. Juried and organized by The Siddhartha Arts Foundation (SAF), Kathmandu, Nepal.
	Solar Pink Pong. Video installation. A&D Faculty Show "First Encounters", Work Gallery Ann Arbor, MI, USA. Curated by Gunalan Nadarajan.
	Rolling Shadows – Energy Plan of the Western Wo/man. Interactive mixed media assemblage. Group exhibition "Quantified Self", Gallery Project, Ann Arbor, MI, USA. Curated by Rocco DePietro and Kyle Kramer.
	Rolling Shadows – A Car Show for Pedestrians. Interactive Installation and happening. "1st Annual Car Cruise at Roosevelt Park", Detroit, Michigan, USA.
	Graf Table. Exhibition organized by Fredericia. Stockholm Furniture Fair, Stockholm, Sweden.
	Pink Prints – Grand Rapids Street Wear. Installation and Video. A&D Faculty Show, Slusser Gallery, Ann Arbor, MI, USA.
2011	*Slim Jim* Table. Exhibition organized by Fredericia. Salone Internazionale del Mobile, Milan, Italy.
	Pink Prints – Grand Rapids Streetwear. Happening, Installation and Objects. Group exhibition "ArtPrize". Venue: Site:Lab + U of M School of Art & Design, Fulton / Division, Grand Rapids, MI, USA. Curated by Elona Van Gent and Paul Amenta.
2010	*Bump – Asia / Europe*. Telematic installation. Group exhibition "Istanbul 2010 – European Capital of Culture". Üsküdar IDO, Istanbul, Turkey / Eminönü IDO, Istanbul, Turkey. Curated by Beral Madra (Visual Arts Director of Istanbul 2010).
	Pink Prints. Object. Group exhibition "Cim Nekül". The Wenzl Collection. Institut Français, Budapest, Hungary.
	Moon Ride. Interactive installation. Group exhibition "Warsaw Under Construction", Plac Defilad, The Museum of Modern Art. Warsaw, Poland. Curated by Kuba Szreder and Zuzanna Fogott.
2007	*Moon Ride*. Interactive installation. Group exhibition "Machine-RAUM Biennale for Video Art and Digital Culture", The Spinning Mills and Vejle Museum of Art, Vejle, Denmark. Curated by Birgit Johnsen and Hanne Nielsen.
	Airlines. Installation. Group exhibition "Agorafolly Inside", Europalia 07. La Centrale Électrique, European Center for Contemporary Art, Brussels, Belgium. Juried exhibition: "Agorafolly Inside gives voice to 27 promising young talents, one from each Member State of the EU".
	Red Carpet. Installation. Group exhibition "Agorafolly artist trail", Europalia 07, Place des Palais/Paleizenplein, Brussels, Belgium. Juried exhibition: "Brussels offers to transform 27 squares in the heart of Brussels by those 27 artists (under 35)".
	Bump – Gijón / Oviedo. Telematic installation. Group exhibition "playware". LABoral Art and Industrial Creation Centre, Gijón, Spain / city center, Oviedo, Spain. Curated by Gerfried Stocker (Artistic Director of the Ars Electronica in Linz, Austria).

2006	*Moon Ride*. Interactive installation. Group exhibition "Simplicity – The Art of Complexity", Ars Electronica Festival, Linz, Austria. Curated by Gerfried Stocker.
	Red Carpet. Installation. Group exhibition "Knock Knock Picnic", Jack The Pelican Presents Gallery. Driggs Av., Williamsburg, Brooklyn, New York City, NY, USA. Curated by Don Carroll.
2005	*A Public Hanging*. Installation and happening. Atlas Meats, Meatpacking District, Manhattan, New York City, NY, USA.
	Freedom. Installation. Basketball court Stadtwildnis Gaudenzdorfer Gürtel, Vienna, Austria.
	Pink Prints – street wear. Happening and urban intervention. Schönbrunner Straße, Vienna, Austria.
2004	*Airlines*. Installation. Group exhibition "Niemandsland". Künstlerhaus, Vienna, Austria. Curated by Jan Tabor, Anna Soucek and Henny Liebhart-Ulm.
	Airline – Paris. Action. Montparnasse, Paris, France.
	Airline – Zurich. Action. Bellevueplatz, Zurich, Switzerland.
	Airline – Warsaw. Action. Pole Mokotowskie, Warsaw, Poland.
2003	*Common Ground – Department of Dance*. Interactive installation. Group exhibition "The Ideal City", The 2nd Valencia Biennal. Convento del Carmen, Valencia, Spain. Curated by Will Alsop and Bruce McLean.
	Airline - Brighton. Action. Beach, Brighton, UK.
	Common Ground. Interactive installation. Group exhibition "Archdiploma, TU-Wien". Kunsthalle Wien-Project Space, Vienna, Austria. Curated by Markus Tomaselli.
2002	*Common Ground – bodenlos*. Interactive installation. Group exhibition "mega – Manifeste der Anmaßung". Künstlerhaus, Vienna, Austria. Curated by Jan Tabor.
	Pink Prints – shoe diploma. Performance and object. Künstlerhaus and Österreichische Nationalbibliothek, Vienna, Austria.
2001	*Bump*. Documentation. Group exhibition „Prix Ars Electronica", OK Center for Contemporary Art, Linz, Austria.
2000	*Bump – Hanover / Vienna*. Telematic installation. CeBIT, Hanover, Germany / Burgtheater, Vienna, Austria. Organized by The Kapsch Group (International Road Telematics, Information Technology and Telecommunications Company).
1999	*Bump – Vösendorf / Linz*. Telematic installation. Group exhibition "Future.com", SCS, Vösendorf / Ars Electronica Center, Linz, Austria. Curated by Gerfried Stocker.
	Bump – Linz / Budapest. Telematic installation. Group exhibition "Life Science", Ars Electronica Festival. Hauptstraße Linz, Austria / Liszt Ferenc tér, Budapest, Hungary. Curated by Gerfried Stocker.
1997	*Windows 97*. Installation. Tram stop Schottentor, Vienna, Austria.

PERMANENT COLLECTIONS

2014 — *Real Estate – Vienna 3/5*. Object. Exhibition, GrazMuseum, Graz, Austria.

2006 — *Real Estate – Vienna 2/5*. Object. Town hall, Gifu, Japan. Acquisition and gift from Meidling, Vienna's 5th municipal district, to Partner city Gifu.

Real Estate – Vienna 1/5. Object. Acquisition, Artothek des Bundes, Vienna, Austria.

FILM SCREENINGS

2016 — *Arising from the Surface*. Film screening. Official selection "Mosaic World Film Festival" Rockford, IL, USA. (with Robert Platt).

Arising from the Surface. Film screening. Official selection "AVIFF - Art Film Festival" Cannes, France. (with Robert Platt)

Arising from the Surface. Film screening. Official selection "4th International Speechless Film Festival", Mankato, Minnesota, USA. (with Robert Platt)

INVITED TALKS AND PRESENTATIONS (selected)

2019 — "What is the Research Telling Us?" panel presentation at the 2019 Annual Conference entitled "2020 Vision: The Future of Online Safety". Hosted by the Family Online Safety Institute, The U.S. Institute of Peace, Washington, DC, USA.

"iGYM: An Interactive Floor Projection System for Inclusive Exergame Environments" paper presentation at the 2019 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '19), Barcelona, Spain.

2018 — "iGYM: an Augmented Reality System for Inclusive Play and Exercise" presentation at the annual Exercise & Sport Science Initiative (ESSI) Symposium, University of Michigan, Ann Arbor, MI, USA.

"Ludic Innovation" presentation at the Universidade Anhembi Morumbi, São Paulo, Brazil. Invited by Rachel Zuanon, coordinator of the PhD/Master Program in Design.

"Assocreation: From the Ground Up" artist talk at The University of Applied Arts Vienna, Austria. Invited by Ruth Schnell, head of the Digital Arts Department.

"Assocreation: From the Ground Up" artist talk at The University of Art and Design Linz, Austria. Invited by Christa Sommerer, head of the Interface Cultures Department.

"PLAY FOR DESIRABLE FUTURES: What emergent technology and early childhood development have, or could have, in common" presentation at the "Speculative Play" Session at CAA's 106th Annual Conference, Los Angeles, USA.

2017 — "Between Sky and Screen" presentation at the AAOSA/OSUM Seminar of the Ann Arbor Section of the Optical Society of America, Ann Arbor, MI, USA. Invited by Cynthia Aku-Leh, OSA president.

"Collective Memories" round table discussion with the Turner Prize winning architect/artist collective Assemble, McLain Clutter, Mark Norman, and Anya Sirota. Popps Packing, Detroit, USA.

	"Synthesize: Art & Technology" artist talk at The University of Michigan Museum of Art (UMMA), Ann Arbor, MI, USA. Invited by Briannon English, Education Program Coordinator, University of Michigan Museum of Art.
2016	"From the Ground Up" public lecture at the Penny Stamps Distinguished Speaker Series, Michigan Theater, Ann Arbor, MI, USA
	"On Game Art and Methodologies of Critique" panel presentation at MACAA 2016: Studio Shift (Mid-America College Art Association Conference), University of Cincinnati, Cincinnati, Ohio, USA.
	"Solar Pink Pong" artist talk at the 19th Japan Media Arts Festival, The National Art Center, Tokyo, Japan.
2015	"Daylight Media Lab and Assocreation" artist talk at the Entrepreneurial Oscars gala at UMMA (University of Michigan Museum of Art), Ann Arbor, MI, USA.
2012	"Art, Technology & Social Change?" presentation at the Symposium "Earth, Body, Mind" as part of the 2nd Kathmandu International Art Festival, Kathmandu, Nepal.
2011	"Technology + Collaboration + Community + Change" Pecha Kucha presentation at the openFrameworks worldwide developers conference, MoCAD (Museum of Contemporary Art Detroit), and The Detroit Digital Justice Coalition. Invited by rootoftwo.
2007	"Assocreation" artist talk at the Machine-RAUM Biennale for Video Art and Digital Culture, The Spinning Mills and Vejle, Museum of Art, Vejle, Denmark.
2001	"Bump" artist talk at the Prix Ars Electronica Gala, ORF studio Linz, Austria.

MEDIA COVERAGE AND INTERVIEWS (selected)

M. Householder (Interviewer): "Researchers level playing field for disabled kids"; Interview with R. Graf, featuring the *iGYM* research project; The Associated Press (USA), 10-12-2019. → story picked up by more than 300 media outlets including The New York Times, The Washington Post, ABC News, Houston Chronicle, and USA Today. **(Advertising Value Equivalency: $4,228,599)**

A. Brede (Interviewer): "'U' researchers develop AR gaming system for children with and without disabilities"; Interview with R. Graf about the *iGYM* research project; The Michigan Daily, Ann Arbor, MI (USA), 08-01-2020.

S. Manning (Interviewer): "Art professor leads creation of interactive, inclusive kids game"; Interview with R. Graf about the development of the *iGYM* research project; The University of Michigan News, Record and Website, Ann Arbor, MI (USA), 10-12-2019.

A. Corrêa (Interviewer): "Can the micro-housing movement help solve the US housing crisis?", R. Graf interviewed in an article on the micro-housing movement; BBC News Brazil, Winston-Salem, NC (USA), 12-08-2018.

"LitKNIT Gateways": featured in a broadcast with Hilary O'Shaughnessy about the Smart Oxford Playable City Commission; BBC Radio, Click (United Kingdom), 30-07-2017.

G. Cornwall (Reviewer): "Giant Bubbles and Urban Periscopes Among Winners of Play Contest"; Group review of the *FitLIGHT* project (i.e., the Brightmoor Runway) in Detroit; The New York Times, New York, NY (USA), 20-09-2016.

“Solar Pink Pong at the 19th Japan Media Arts Festival”; Street video game featured on national television; NTV (Nippon Television Network), NEWS ZERO CULTURE (Japan) 03-02-2016.

D. Hernandez (Interviewer): “Tiny Houses, Big Dreams”; Interview with R. Graf and group review of the Experimental Architecture course; Hour Detroit Magazine, Troy, MI (USA), 04-01-2016.

R. Stanton (Reviewer): “Ann Arbor council member proposes tiny house village across from YMCA”; Group review of the Experimental Architecture course advised by R. Graf and C. Van Dyke; The Ann Arbor News and MLive.com, Ann Arbor, MI, (USA), 02-06-2015.

M. Gillingham (Reviewer): “Students propose public art projects for University course”; Personal review of studio course advised by R. Graf; The Michigan Daily, Ann Arbor, MI (USA), 21-03-2013.

K. Woodhouse (Reviewer): “University of Michigan students to test public art ideas before Ann Arbor panel”; Personal review of studio course advised by R. Graf; The Ann Arbor News, Ann Arbor, MI (USA), 21-03-2013.

K. Dasgupta (Reviewer): “KIAF – Breaking Boundaries with Art”; Group review of Moon Ride and Assocreation; The Kathmandu Post (Nepal), 09-12-2012, p. 8.

K. Dasgupta (Reviewer): “Kathmandu International Art Festival”; Group review of Moon Ride: Frieze Publishing, Blog, 14-12-2012.

“Common theme, different approaches”; Group review of Moon Ride and Assocreation; The Himalayan Times (Nepal), 09-12-2012.

M. Kruvelis (Interviewer): “From the Ground Up: Assocreation takes to the street”; Personal review of R. Graf and Assocreation; The Michigan Daily, Ann Arbor, MI (USA), 29-10-2012.

D. Harrison (Reviewer): “The Year’s best dining tables”; Group review of the Slim Jim Table; Inside Out 2012 Annual Renovating & Decorating Guide (Australia), 2012, p. 154.

V. Schnitzer (Reviewer): “Knitting installation in the heart of campus changes space, mood”; Personal review of studio course advised by R. Graf; The University of Michigan News, Record and Website, Ann Arbor, MI (USA), 09-04-2012.

A. Soucek (Interviewer): “Über den Fortschnitt, Kleine Kulturgeschichte des Haars”; Radio interview with R. Graf about Assocreation´s Fieldwork; Ö1 Radio, Diagonal (Austrian Broadcasting Cooperation), Vienna (Austria), 17-10-2009.

J. Lecher (Reviewer): “Den Meidlinger Markt vorm Abkratzen retten”; Group review of studio course advised by R. Graf; Die Presse, Wien (Austria), 23-06-2008, p. 26.

“Zwischen temporären Interventionen”; TV interview with R. Graf, featuring supervised student projects; ORF – Aviso (Austrian Broadcasting Cooperation), Vienna (Austria), 22-06-2008.

“Because We’re Highly Receptive to Bold, Brilliant, Mildly Lunatic Public Art”; Group review of the Dumpster Swimming Pool and Moon Ride; New York Magazine, NYmag.com (USA), 14-12-2008.

C. Mangold (Interviewer): “Grossvaters Erbe”; Personal review of R. Graf’s work; Magazin – Stuttgart, Bonn, München, Magazin.com (Germany), 2007, pp. 8-11.

A. Feßler (Reviewer): “Moon Ride – Kollektives Strampeln für einen satten Vollmond über dem Linzer Hauptplatz: Das Kollektiv Assocreation will Passanten anzapfen”; Personal review of Assocreation’s Moon Ride installation; Der Standard, Wien (Austria), 08-24-2006, p. A1.

“Pink Prints - Streetware”; TV interview with R. Graf, featuring Assocreation; ORF – Treffpunkt Kultur (Austrian Broadcasting Cooperation), Vienna (Austria), June 2005.

W. Norvell (Interviewer): “A Public Hanging for the Faint of Heart.”; Personal review of Assocreation; NY ARTS, Vol. 10 No. 7/8, New York (USA), 2005, pp. 2, 26.

A. Spiegler (Reviewer): “Interaktives Wellenreiten aufschwebendem Beton”; Personal review of Assocreation; Die Presse, Wien (Austria), 10-04-2002, p. 9.

M. Möseneder (Reviewer): „Ars Electronica auf wackeligen Planken“; Group review of Assocreation; Der Standard, Wien (Austria), 04-09-1999, p. 18.

C. Kühn (Reviewer): “Nur Durchblick, keine Aussicht”; Group review of Assocreation; Die Presse – Spektrum, Wien (Austria), 05-07-1997, p. IX.

“Bump into each other”; various TV interviews featuring Assocreation; ORF (Austria) ARTE (France/Germany), 3sat (Germany/Austria), RTL and MTV (Hungary), September 1999.

EXHIBITION CATALOGS

Assocreation: “bump”; in: “Ars Electronica 2019 – out of the box”, H. Leopoldseder, G. Stocker, C. Schöpf (ed.); published by: Hatje Cantz Verlag GmbH, Berlin, Germany, 2019, ISBN: 978-3-7757-4576-5, pp. 38-39.

Assocreation, Everyday Places: “Red Crossing”; in: “Prague Quadrennial of Performance Design and Space”, Arts and Theatre Institute, Prague, 2019, ISBN 978-80-7008-147-5, p. 75.

Assocreation, Daylight Media Lab: “Solar Pink Pong”; in: “UPDATE_6/NWE TECHNOLOGICAL ART AWARD 2016”, Jan Moens (ed.); Liedts-Meesen Foundation and MER. Paper Kunsthalle, Ghent, Belgium, 2016, ISBN 978-994-9232-147-3, pp. 84-87.

Assocreation, Lab 11: “Internet of Shoes”; in “ISEA 2016 HONG KONG: CULTURAL R>EVOLUTION – 22nd International Symposium on Electronic Art”, H. Kraemer, D. C. Howe, K. Chung (ed.); School of Creative Media, City University of Hong Kong, China, 2016, ISBN: 978-962-442-396-9, pp. 21-23.

Assocreation, Daylight Media Lab: “Solar Pink Pong”; in: “19th Japan Media Arts Festival – Award-winning Works”, Japan Media Arts Festival Secretariat (c/o CG-ARTS) (ed.); Japan Media Arts Festival Executive Committee, Tokyo, 2016, pp. 84-87.

R. Graf: “Detroit Dreamcyclers” and “CTN - Camp Take Notice”; in: “Utopia Toolbox: an incitement to radical creativity”, J. Stiegele, N. Tobier (ed.); published by: Michigan Publishing and TOOLBOOKS Munich, Germany, 2015, ISBN: 978-3-9816731-2-8, pp. 127-129, 155-159.

Assocreation: “Solar Pink Pong”; in: “FILE São Paulo 2015 – Festival Internacional de Linguagem Eletrônica”, Ricardo Barreto and Paula Perissinotto (ed.); SESI-SP editora, Sao Paulo, 2015, ISBN: 978-85-89730-19-8, pp. 19-20.

Assocreation: “Solar Pink Pong – Street Video Game”; in “ISEA2014 LOCATION – The 20th International Symposium on Electronic Art”, J. Bellotto (ed.); Zayed University, Dubai, UAE, 2014, p. 109

Assocreation: “Moon Ride”; in: “KIAF 2012 – Earth, Body, Mind: 2nd Kathmandu International Art Festival”, Sally Acharya and Homraj Acharya (ed.); Siddhartha Art Foundation, Kathmandu, 2012, pp. 26-27.

Assocreation: "Pink Prints – Grand Rapids Streetwear"; in: "SiTE:LAB ART PRIZE 2011", J. C. Stivers (ed.); SiTE:LAB 2 East Fulton Street, Grand Rapids, MI, USA, 2011, pp. 12-15.

Assocreation: "Pink Prints – Streetwear"; in: "Wem gehört die Stadt? Wien – Kunst im öffentlichen Raum seit 1968", T. Edlinger, B. Leidl, A. Lungstraß, V. Ratzenböck (ed.); published by: Verlag für moderne Kunst Nürnberg, Nürnberg, 2009, ISBN: 978-33941185-81-4, p. 238.

Assocreation: "Moon Ride"; in: "Machine-RAUM – a biennale for video art and digital culture", H. Nielsen, B. Johnsen (ed.); The Spinning Mills and Vejle Museum of Art, 2007, pp. 14-15, 48.

Assocreation: "Bump"; in: "Fabrica – The first 10 years", N. Aldred (ed.); Fabrica, Brighton, 2007, ISBN: 0-9543380-2-2, pp. 44-45.

R. Graf: "Feldmark"; in: "DMY Internationale Designausstellung 2007", DMY Berlin, J. Suermann (ed.); Pinguin Druck GmbH, Berlin, 2007, p. 74.

Assocreation: "Red Carped" and "Airlines"; in: "AGORAFOLLY – Outside Inside", S. De Coster, D. Vermaelen (ed.); published by: Europalia International, Brüssel, 2007, ISBN: 978-90-6153-801-1, pp. 14-2.

Assocreation: "Moon Ride"; in "Ars Electronica 2006, Simplicity – the art of complexity", G. Stocker, C. Schöpf (ed.); published by: Springer-Verlag Wien New York, 2006, pp. 164-167.

Assocreation: "Common Ground - Department of Dance"; in: "The 2nd Valencia Biennal - The Ideal City", Luigi Settembrini (ed.); Generalitat Valenciana, Italy, 2003, ISBN: 8881584379, pp. 73-74.

Assocreation: "Bump"; in: "Telematik – NetzModerneNavigatoren", J. Simmen (ed.); published by Buchhandlung Walther König, Köln, 2002, ISBN: 3-88375-547-8, p. 80.

Assocreation: "Bump"; in: "Ars Electronica 99 – Life science", G. Stocker, C. Schöpf (ed.); published by: Springer-Verlag Wien New York, 1999, pp. 412, 419-421.

Assocreation: "Bump"; in: "Cyberarts, International Compendium, Prix Ars Electronica", H. Leopoldseder, C. Schöpf (ed.); published by: Springer-Verlag Wien New York, 1999, ISBN: 3-211-83628-4, pp. 86-89.

TEACHING (since 2013)

***** Graduate Level (selected) *****

MFA Thesis Studio and Directed Studio Practice (F 2011–W 2015, F 2018–W 2020)
Advise Master of Fine Arts (MFA) students with backgrounds in media art, sculpture, and installation. Support their independent studio practice and professional development as their primary advisor and thesis chair.

MDes Thesis Project (Winter 2020)
Lead the MDes in Integrative Design student cohort (class of 2020) in their final thesis semester. Help students synthesize the knowledge and skills learned through the program and apply them in the development of their thesis projects in collaboration with their project partners (i.e., teachers and public schools in the Detroit Metropolitan Area).

Fieldwork Studio Brazil (Summer 2019)
Initiated, organized, and taught an intensive, three weeklong international "service learning" course in Brazil as part of an MDes fieldwork requirement. Students planned and executed an art-based workshop series for 5th and 6th-grade students (involving kite-drone making and flying, filmmaking

and reflection, etc.) in collaboration with teachers at Ateliescola Acaia, an artist-led school providing high quality education and services to a vulnerable and underserved community in São Paulo. Further, students visited public schools, childhood centers, and teacher training centers in Sobral, a small city in Brazil's rural North that got national and international attention due to its innovative city-wide education reform.

MDes Professional Practice Seminar (Fall 2019)
Designed assignments and organized workshops to help graduates of the MDes program clarify and articulate their individual "value propositions" and objectives for the next phase of their career.

Design Studio 3: Co-creation (Fall 2019)
Taught the third design studio, in which MDes students cultivate the co-creation strategies that are necessary to be effective participants in the integrative design process with their project partners.

Design Studio 2: Prototyping (Winter 2019)
Taught the second design studio, in which MDes students test ideas from Design Studio 1 through form-finding, thinking-through-making, and other prototyping methods and approaches.

Design Studio 1: Inquiry (Fall 2018)
Taught the first of a series of three collaborative design studios, in which MDes students are introduced to the general topic of a "wicked problem" and a related project partners that they will work with throughout the program. For the class of 2020 that I led, the main partner was the U-M School of Education and the general topic "Equity and Access in Education", particularly related to the school system in the Detroit metropolitan area.

Augmented Reality, Virtual Reality, and Mixed Reality: **Online Course (Winter 2018)**
Co-developed and co-taught (with Michael Nebeling and Steve Oney) an online course that examines the present and possible futures of AR, MR, and VR through conversations with leading experts and practitioners. The course was launched on Coursera and reached a global audience of 2,423 learners. It was supported by the digital media production team of the U-M Office of Academic Innovation and received an Academic Innovation Award.

Interactive Game Systems (Fall 2015)
Initiated and co-advised (with Edwin Olson and Jason Corso) a special topics graduate engineering course that provided hands-on experience in hardware, software and mechanical systems for the development of non-screen based, interactive outdoor media systems.

***** Undergraduate Level (selected) *****

Second Year Studio (Winter 2015, 2016, 2020)
Work with students in their sophomore year to develop their capacity to work independently and pursue a single project in their area of interest through multiple iterations. The course involves making, writing, research, presentation, critique, and documentation.

Experiments in Architecture, Installation, and Painting (Winter 2017)
Co-developed and co-taught (with Robert Platt) an advanced studio course that explored the expanded fields of painting, architecture and installation in the context of contemporary art practice. The course culminated in the exhibition: "DECONSCIOUSNESS: Three Levels of Consciousness".

Studio: 3D Foundations (Fall 2016, 2017).
Designed the syllabus and taught three-dimensional design and composition through a series of scaffolded assignments using various analog and digital fabrication tools. One of the student group projects, a life-size geodesic dome out of newspaper, was featured in The Michigan Daily.

Integrative Project (2013–2014, 2014–2015)
Taught the yearlong BFA senior thesis project, which is the educational capstone project for Art & Design students and culminates in an exhibition. Supported the synthesis of the student's academic and studio work through the development of their projects and written thesis.

Experimental Architecture (Winter 2014)
Initiated and co-taught (with Graduate Student Instructor Cameron Van Dyke) a design engagement course in which students worked with the local organization MISSION to build a full-scale tiny house as part of a tiny house homeless village initiative in Ann Arbor, Michigan. The project resulted in local media coverage that was used to advocate for zoning changes that are barriers to alternative housing solutions. The design was also featured and awarded in tiny house blogs across the country.

Public Art and Urban Intervention (Winter 2013)
Initiated and taught an introductory course to the field of public art and urban intervention. Students developed a flash mob entitled "Detroit Dreamcyclers", in which they crashed the Detroit Auto Show with imaginary bikes. Further, they interviewed different public art stakeholders (i.e., residents, artists, administrators, etc.) and presented their public art proposals to the Ann Arbor Public Art Commission in the City Council (featured in The Michigan Daily and The Ann Arbor News). Finally, in collaboration with local youth organizations in Flint, students produced videos with High School students, showing 24 everyday life scenes through their eyes (presented at the Flint Free City Festival film screening).

SERVICE TO THE PROFESSION

Social Sciences and Humanities Research Council of Canada, 2020
Invited reviewer for federal Insight Grants application assessment.

ACM Designing Interactive Systems (DIS) Conference, 2019
Invited reviewer for the Design Methods paper track.

UNIVERSITY SERVICE

Promotion/Tenure Review Committee, 2020-Present
Conduct a comprehensive assessment of the candidate's qualifications (including research, teaching, and service) for promotion/tenure. Solicit external review letters. Present findings in a written report and make a recommendation to the Dean and executive committee.

Creative Practice and Research Committee, 2019-Present
Work with the Associate Dean for Research to support the creative work and research of faculty colleagues. Review proposals and funding requests for international and national travel, professional training, and U-M faculty grants. Provide feedback and make funding recommendations to the Dean.

Creative Practice and Research Working Group, 2019-Present
Co-develop a plan with a group of faculty and staff to maintain and develop the skills, competencies and professional development of Stamps' research community. Make recommendations to the Dean and the Associate Dean for Research, Creative Work, and Strategic Initiatives.

Lecturer Review Committee, 2011-13, 2019-Present
Conduct performance evaluation of lecturers for major and interim reviews. Review course materials and conduct classroom observations. Provide written feedback and make recommendations to the Dean and the Executive Committee.

International Engagement Committee, 2018-2019
Supported the development of international study programs for undergraduate and graduate

students. Reviewed study abroad proposals. Explored partnerships with schools in Brazil. Initiated student exchange with the University of Art and Design Linz, Interface Cultures Program.

Search Advisory Committee for 3 Tenure-Track Positions, 2016-2017
Reviewed applications and conducted interviews and reference checks for three Assistant Professor positions in (1) Interaction Design, (2) Information Design & Information Visualization, and (3) 3D Design. Provided a shortlist and recommendations to the Dean that led to three successful hires.

Campus AR/VR Steering Group, 2016-2018
Represented the Stamps School at the launch of a U-M campus-wide effort to collaborate with industry and develop and deploy novel AR/VR applications in instruction and research. Met with the leaderships of IBM, Amazon, Disney, and Lenovo and collaborated on a Microsoft proposal that led to major in-kind hardware gifts to the University.

Studio Instructor Coordination, 2016-2018
Co-coordinated the 2nd year studio and worked as a cohort leader of studio 3D foundation instructors to provide a consistent learning experience across different foundation studio sections. Consolidated learning objectives and course materials in collaboration with instructors.

Bicentennial Anniversary Committee, 2016-2017
Contributed to the discussion and conceptualization of art-based interventions and interdisciplinary research collaborations to celebrate the University of Michigan's bicentennial anniversary.

U-M Office of Research Faculty Grants and Awards, 2015-2018
Reviewed faculty grants and awards proposals to maintain the quality of U-M's intramural research and artistic productions funding program.

Design Salon Committee, 2014-2016
Contributed to the conceptualization and launch of the Stamps School's first two Design Salons that bring together critical thinkers, do-ers, and makers from different fields to create partnerships and research opportunities and to increase the Schools' reputation in the field of design.

Undergraduate Program Committee, 2013-2016
Worked with the Associate Dean for Academic Programs and the Assistant Dean for Undergraduate Programs on a major curriculum overhaul to increase the breadth and depth of students' learning experience within the school and university. Supported the development of the Curriculum Designer app that helps students build individual, research-led, and transdisciplinary learning paths.

MDes in Integrative Design Working Group, 2013-14
Contributed to the conceptualization and launch of the MDes in Integrative Design program to address some of today's most challenging "wicked problems" with a new curriculum that emphasizes cross-disciplinary collaboration and problem-based inquiry.

City Speculations Exhibition, 2013-14
Designed and curated the international part of the City Speculations exhibition at the Work Gallery Detroit, Michigan, USA.

COMMUNITY SERVICE

Play Day Event, 2019
Organized and hosted a Play Day Event for families with children with different abilities to play *iGYM* with their friends in a social setting outside of controlled user studies and playtests.

Makerspace Workshop, 2015-16
Initiated and co-organized a maker space workshop (with Nick Tobier and UMSI PhD students) at the Detroit Community High School in Brightmoor. Students got a crash course in electronics and learned to build wirelessly connected LED shoelaces inspired by my Internet of Shoes project.

Camp Take Notice and M.I.S.S.I.O.N, 2011-2015
Worked with the unofficial tent community Camp Take Notice in Ann Arbor, Michigan (counting over 60 homeless people at its peak in 2011) and the local partner organization M.I.S.S.I.O.N to achieve greater community awareness for their needs. Organized multiple field trips for U-M students. Developed two engagement courses. Initiated an international design engagement program with The University of Art and Design Linz, Austria. Helped with fundraising events and preliminary site plans for the development of a tiny house community on a local 3-acre property. Created preliminary drawings for the remodeling of a house on this property. Participated in planning meetings with city officials.

The r&d 2014 Road Show, 2014
Hosted a three week long urban think tank at the Stamps School parking lot made of two shipping containers converted by faculty and students of the space & design strategies department at the University of Art and Industrial Design Linz, Austria. Organized a program and social mixer events for students, faculty, and staff to promote international and cultural exchange between both institutions.

Flint Public Art Project, 2013-2014
Initiated and co-developed a filmmaking workshop for Flint Northwestern High School Students as part of the Flint Free City Festival. Collaborated with local youth organizations Black Men for Social Change, ReMix, and the college and career readiness advisor to establish connections between the high school in Flint and the University of Michigan in Ann Arbor.

Ann Arbor Public Art Commission, 2012-2014
Contributed ideas and participated in meetings with members of the Ann Arbor Public Art Commission to expand the notion of "public art" in Ann Arbor. Developed a course in which students engaged both the Public Art Commission and residents with alternative public art proposals.

The Prison Creative Arts Project (PCAP), 2013
Visited the Lakeland Correctional Facility in Coldwater, Michigan and met with people in prison to provide feedback and help select their work for the 18th Annual Exhibition of Prison Art.

Monster Drawing Rally Fundraiser, 2013
Contributed to a fundraiser event at the MOCAD (Museum of Contemporary Art Detroit) by curating the live drawing performance "Hoover Floor Polisher".

LANGUAGES
German (native), English (fluent), French (conversant), Portuguese (basic).