

Interfacing the Multiplexer Room

:

Speculative Spatio-Mediated Assemblages
for the Digitally-Interfered Home

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Table of Contents

Abstract	4
Acknowledgements	5
1 Introduction	
1.1 Dear Future Reader	7
1.2 Synopsis	9
2 Background	12
2.1 The Digitally-Interfered Space	13
2.1.1 Mediated Architecture	14
2.1.2 The Virtual is Political	16
2.2 Cognitive Unfolding	18
2.2.1 Embodied Cognition	19
2.2.2 The Extended Mind Model	19
2.2.3 Distributed Knobs and Monitors	21
2.3 Tangible-Experiential Engagement	22
2.3.1 Material Engagement	22
2.3.2 Experience over Interface	22
2.4 The Spatio-Mediated Assemblage	24
2.4.1 Definition	25
2.4.2 The Mediated Tactics	26
2.5 Autobiographical Speculation	31
2.5.1 Design Methodology	31
2.5.2 Assemblage Prototyping	32
2.5.3 Evaluation Method	33
3 Process and Methods	34
Foreword	35
3.1 The 360 Self	36
3.1.1 Sousveiyng the 360 Self	37
3.2 The <i>Multiplexer Room</i>	41

3.2.1 Disrupting signals; streaming attention (<i>Blackout Dongle</i>)	43
3.2.2 I/O Ports, Buses and Addresses	47
3.3 Cardinal Affordances	49
3.3.1 Cardinal Cognition	49
3.3.2 The <i>Cardinal Recorder</i>	52
3.4 The Sonic Dimension	61
3.4.1 The Sonic Landscape	61
3.4.2 <i>Six-Part Galliard</i>	62
3.5 6-DoF Awareness	68
3.5.1 Location-Specific Augmented Domesticity	69
3.5.2 <i>LSD Cognition</i>	70
 4 Evaluation	 78
4.1 Research Claims	81
4.2 Autobiographical Hacks	83
4.3 The <i>Domestic</i> as a Lab	85
4.4 Assemblages and Experiences	88
 5 Contributions and Future Work	 93
 Bibliography	 96
Appendix	101

Abstract

During 2020 and much of 2021, the domestic space became fused with the needs and functions of a remote office. A computational-mediated choreography of different visual, sonic, and tactile operating interfaces has occupied the home disturbing our *beyond-the-brain* bodily experience of reality. Whereas commercial tech products are widely concerned by concepts of *usability* and *efficiency*, this thesis proposes an architectural, materially-informed, and site-specific study of domestic technology through *Spatio-Mediated Assemblages* —a type of environmental-reactive interactive artifact.

Based on this model, three speculative assemblages reflect on a future context-aware computing interface for the *Multiplexer Room* —my own digitally-interfered home. These experiments reveal that non-visual interaction techniques, such as audio spatialization, provide a *seamful* approach to distributing information and actions across various mediums. They also highlight that non-computer-vision-centric tracking systems, such as ultra-wideband location-aware networks, are a barely intrusive alternative for orientation and motion virtualization of domestic interactions.

Finally, this thesis leverages self-driven analysis of one's intimate space and behaviors to design more fine-grained digital interactions. In so doing, it encourages other creative technologists to adopt autobiographical methods when crafting interactive spatial experiences.

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1

Introduction

1.1 Dear Future Reader

In case you find this thesis somewhere in the Internet Archive,¹ I would like to applaud your keenness to have reached this territory to which creative scholars and academicians once referred as *critical making*:

‘an elision of two typically disconnected modes of engagement in the world—“critical thinking,” often considered as abstract, explicit, linguistically based, internal and cognitively individualistic; and “making,” typically understood as material, tacit, embodied, external and community-oriented.’ (Ratto et al., 2009)

It so happens that architects and designers —before the late 20th-century institutional digestion of their respective disciplines— were already using critical design as a way of deconstructing and reconstructing aesthetics and ethics to reach new formal meanings through the fabrication of material and conceptual assemblages —at times called cities, buildings, scenography, or furniture. For the 21st-century architectural technologist, this methodology adjoined the challenge of merging digital frameworks into existing analog processes that embraced the new material and sensorial properties of the physical space.

Following this premise, in May 2021, this thesis served as a proof of concept that I —having previously completed a bachelor’s and master’s in architecture and urban design from the Technical University of Madrid— could officially operate as a *design scholar*. And so, I am liable to advise you why you could see it relevant to read about what did entail to design my own domestic technology during the almost two years that the COVID-19 pandemic lasted. In summary, you will find within this document:

- A literature review on *phenomenology*, *mediated reality*, *embodied cognition*, and *tangible interaction* theories that could frame a better design practice of pervasive technology in the digitally-interfered domestic space.
- A model to characterize and manufacture contemporary spatial interactive artworks and installations that draws inspiration from Surrealist and *site-specific* practices during the 20th-century.

1. Visit: web.archive.org/

- A conceptual and dimensional description of my domestic space to explore new ways of decapitalize digital interfaces from concepts of *efficiency* within the economy of screen-based technology designed for the *productive* society (Han, 2010).
- An *autobiographical narrative* on how I confronted the one-size-fits-all smart home ideology through the design of three behavioral and site-specific assemblages.
- A *graphic speculation* —throughout the various diagrams and drawings present in this document— that reimagines how we can interface our domestic space with spatio-mediated augmented interactions.
- A *technical description* of how to implement orientation and location-aware systems to track our motion and heading under controlled settings and how these can be used to implement a motion-reactive indoor soundscape.
- A *first-person perspective* of how my life unfolded in frenzied directions across the digitally-mediated materiality of my room and how I succeeded in navigating the anxious journey of the self fading amidst a pandemic prototyping my own digital domesticity.

1.2 Synopsis

As Paul B. Preciado points out in *Learning from the Virus*, in 2020 and much of 2021, the domestic space —becoming fused with the needs and functions of a remote office— has turned into an *ultra-connected production and consumption space* (Preciado, 2020). Commuting is now occupied by a computational-mediated choreography of screen-based interactions across productivity tools and smart devices. These technologies’ diverse visual, sonic, and tactile operating interfaces saturate our cognitive system and disturb our *beyond-the-brain* (Wilson & Foglia, 2017) bodily experience of reality in our most intimate habitat. In response, tech solutions relentlessly reimagine ubiquitous and *seamless* (Chalmers et al., 2003) integrated digital systems driven by concepts of *efficiency* and *usability* (Bell et al., 2005). This is probably not the best approach to reconcile our role as intermediate auditors of information processes in the digitally-interfered home.

[...] effective ethical intervention has to be intrinsic to the operation of the system itself. For cognitive assemblages, this means becoming knowledgeable about how the interpenetrations of human and technical cognitions work at specific sites, and how such analyses can be used to identify inflection points, which, rather than preexisting as objective realities, emerge in interaction/intra-action with prior commitments to create new trajectories for the assemblages, providing more open, just, and sustainable futures for humans, nonhuman life —forms, and technical cognizers— which is to say, for the planetary cognitive ecology.’ (Hayles, 2017)

Instead, as N. Katherine Hayles points out, an *intrinsic* methodology to reveal new *affordances* (Gibson, 1979) of this *mediated* space (Mann, 2002) could help us understand better our digital and tangible behaviors in the *reality-virtuality continuum* (Milgram & Kishino, 1994) and overcome the limitations of our rectangular and screen-based interfaced reality.

Placed in the intersection between *where the action is* for James J. Gibson —at the outer layer of the physical matter (Gibson, 1979)— and Paul Dourish —when he explores the future of embodied interaction systems (Dourish, 2001)— the *Background* section (Chapter 2) discusses phenomenology, architecture, and art perspectives on the definition of the *mediated reality*. It also describes our *cognitive unfolding* in spatial interactions to off-load memory processes into our

closeby surrounding, and recalls the need of tangible-experiential engagement in the construction of the *digitally-interfered space*. Then, the chapter introduces an architectural, materially-informed, and *site-specific* (Kaye, 2013) study of domestic technology through the model of the *Spatio-Mediated Assemblage: a type of environmental-reactive speculative artifact that interferes with our spatial cognition where physical and virtual substance adds up to the definition of our surroundings*. This model is characterized by a set of *Mediated Tactics* derived from the analysis of various new media artworks and installations' experiential strategies: *infrastructural disclosure*, *fictional deconstruction*, *formless interfacing*, *material reliability*, and *experiential immersion*. Last, the chapter outlines the autobiographical methodology that I used to speculate on possible alternatives for this new imposed digital domesticity and clarify:

How can I design the non-visual interactive environment of my digitally-interfered home through Spatio-Mediated Assemblages?

The *Process and Methods* (Chapter 3) expands this question by characterizing the site of research of this thesis, the *Multiplexer Room*: a momentary and personal multi-dimensional interfaced space where analog continuous electrical signals, binary instructions, and digital meanings traverse frenetically through mediums and surfaces. Then, I present three speculative *assemblages* developed as a way to expand our vocabulary of context-aware computing and tangible mediated interactions in this space. The first experiment describes the fabrication and use of the *Cardinal Recorder*, a geomagnetic-aware portable recorder that can index voice memos in different cardinal directions and explores the spatial affordances of indoor domestic settings as an audio-mnemonic instrument. The second experiment, *Six-Part Galliard*, iterates on the previous prototype utilizing a head-mounted wireless device's orientation-aware sensing capabilities to synthesize a room-specific six-voice polyphonic soundscape. The last experiment, *LSD Cognition*— or Location-Specific Domestic Cognition — describes the implementation of an ultra-wideband system for accurate indoor localization and virtualization of spatial interactions.

The prototyping process and experiences' are critically discussed in the *Evaluation* section (Chapter 4) through a reflective interview that discloses how my intentions and intuitions have steadily changed during the prototyping process, shaping the design iterations' different stages. The chapter also confirms some of the challenges of engaging with autobiographical methods and how those have shaped late thesis' perspectives on the nature of digital domesticity.

From a technical standpoint, the experiments' results reveal that audio spatialization strategies offer a screenless but *seamful* (Chalmers et al., 2003) approach to distributing information and actions across various mediums. Simultaneously, the orientation-based and location-aware systems tested in this thesis provide a less invasive alternative to computer-vision-centric frameworks for tracking our position and motion in a domestic environment. Beyond the *Multiplexer* perspective, this *Contributions and Future Work* (Chapter 5) discuss how self-driven analysis of one's intimate space and behaviors allows for a more fine-grained digital experience's design and encourages other creative technologists to leverage autobiographical methods when crafting interactive spatial interfaces for domestic spaces.

2

Background

2.1 The Digitally-Interfered Space

Phenomenological studies define the physical space as the three-dimensional container that hosts all the beings and objects of our reality. Its constituent parts are —more or less— *substantial matter*, the surrounding medium (such as the gaseous atmosphere), and surfaces that separate the substances from that medium, also defined as *‘the interface[s] between any two of [the] three states of matter —solid, liquid, and gas’* (Gibson, 1979). We interact and understand this environment through our senses and the perception of the beyond-skin surfaces. Therefore, the surfaces’ textural and material qualities are the ones that shape our mental representation of physical reality. In addition to these qualities, we imbue spatial surfaces with symbolic values that —though not measurable with the same rational metrics that those of our physiological perception— build upon the three-dimensional geometry of reality. Studying our environmental cognition through material means defines how spatial practices have evolved since the adoption of the cave as a shelter, through the construction of stark religious Romanic cathedrals, glorious imperial baroque palaces, to the capitalistic impregnation of postmodernist corporative facades.

‘My body is truly the navel of my world, not in the sense of the viewing point of the central perspective, but as the very locus of reference, memory, imagination, and integration [...] the senses are specializations of skin tissue, and all sensory experiences are modes of touching, and thus related to tactility. Our contact with the world takes place at the boundary line of the self through specialized parts of our enveloping membrane.’ (Pallasmaa, 2012)

As Pallasmaa’s words suggested in 1996, our five senses and their non-universal, heterogeneous calibration define an abstract mental image of our living environment which in a consensual effort for communication is framed inside the logic of language: frequently, those are visual and sonic languages linked with sight and hearing, the *theoretical senses* distanced from practical judgments of the physical world (Hegel, 1835). This subjective map of the sensed matter is what initially was known as *virtual*. But computation challenged that definition forever with complete functional models of our environment built with non-static and non-solid materials.

The *virtual* is eccentric data, displaced information, microscopic and macroscopic fabric, orbiting characterization of the physical. It is the surveyable property of the inhabited spaces

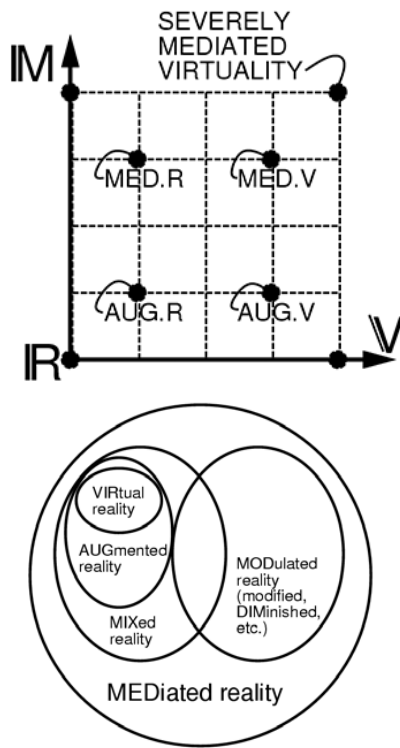
imperceivable without the help of extracorporeal tools. It is the past, the present, and the future status of the physical space: it is its memory. And so, this virtual allows us to accommodate better the temporal dimension of reality. The virtual environment succeeds in representing the dynamic fluctuations of our existence —the time— whereas the physical one connects with our most primitive instincts of discovering our surrounding space.

2.1.1 Mediated Architecture

For the past 100 years, *we have been surrounded by the virtual*. This assertion not only implies a literal technological shift in our domestic and public life but also entails a semantic peculiarity: virtual principles and systems are often defined using spatial terms (Dodge & Kitchin, 2001). On the one hand, *to be surrounded* describes our restricted and pivotal position in that spatial metaphor; on the other, *virtual* applies to those environmental features that fall outside the spectrum of our senses —the unseizable substance of reality.

Before the emergence of sensors and ubiquitous computers, virtual and physical interwove in a stationary process where spatial practices such as architecture played a fundamental role in mastering our surroundings' alteration to accommodate human needs and wills. Architecture bridges the material affordances of our landscape with our cognitive and social representation of it. It constructs the physical environment by rearranging corporeal materials and virtual entities inherent in the geometry and texture of the built surfaces (Gibson, 1979). Architecture is a vessel between physical and virtual environments. Nonetheless, architecture produces statically allocated models of these realities: architectural space is planned to endure and bear changes but not react to human activity. While traditionally, the role of architecture was to build a tangible infrastructure to endorse our survival endeavor, lately, it was also urged to host the genesis of a digital framework that hyper-connects our social and productive ventures *virtually* and *physically* placed *all over the space*.

Pervasive environmental computing could also explain the shift of the discipline towards accepting the externalization of a human-centric constructed image of the *virtual* towards an object-oriented approach that questions where and how the virtual exists. Information impregnates surfaces through intelligent voice assistants, ambient-reactive dimmable lights, 360-degree audio systems, and cloud-based surveillance services. In a reappraisal of architecture's doctrine, designers have realized that the built environment should react to us the same way



Steve Mann. *Mediated Reality Venn Diagram* (2002)

computers were responding to our habits and requests. Rather than stage-setters, architects should work more than ever as interaction designers building our peripheral awareness (McCullough, 2004). For Myron W. Krueger, this shift compromised adding a responsive layer onto the stationary pre-digital environment ‘as the basis for a new aesthetic medium [which would seek to] define arbitrary, abstract, and otherwise impossible relationships between action and result’ (Krueger, 1977). Later, this new spatial proposition would find its place within the virtuality-reality continuum or *mixed reality* space (Milgram & Kishino, 1994), and which ramifications have been thoroughly mapped and classified (Speicher, Hall and Nebeling, 2019) and explored as *cultural and aesthetic practices* rather than *technological research spaces* (Manovich, 2006).

Among all these definitions, Steve Mann’s *mediated reality* framework, a ‘mix of virtual information with visual information from the real world’ (Mann, 2002), is the only one broad enough to accommodate the interactive and experiential installations and buildings designed by Oosterhuis_Lénárd, Torsten Fröhlich, KOL/MAC Studio, or Diller Scofidio+Renfro which in early 2000 were already functioning as media catalysts (Veech, 2005) and are considered the pioneers in the fabrication of digital architecture. The analysis of these eager examples and other *new media* spatial practices reveals new affordances of the digitally-mediated architecture: immersive, interactive, and narrative.



Oosterhuis_Lénárd. *MUSCLE*. Interactive Installation with 72 actuators showcased at the *Non-Standard-Architectures* exhibition. Centre Pompidou Paris (2004)



Mierle Laderman Ukeles. *Washing/Tracks/Maintenance: Outside* (1970)



Trevor Paglen. *Limit Telephotography* (2012)

2.1.2 The Virtual is Political

From Surrealists to 70s site-specific artists, contemporary art practices have consistently explored the virtual as contraposition of the explicit reality as a way to ‘*decode and/or re-code the institutional conventions so as to expose their hidden operations [...] making apparent their relationship to the broader socioeconomic and political processes*’ (Kwon, 2004). This definition of virtuality has a clearly political quality that pushes production and research on the virtual towards a technological and infrastructural disclosure complementary to this space’s sensorial and material study. As Manovich points out, bypassing the appeal of the abstraction of the virtual medium is fundamental to identify:

‘[...] how to represent the personal subjective experience of a person living in a data society [...] the ambiguity, the otherness, the multi-dimensionality of our experience.’ (Manovich, 2002)

NEW YORK APARTMENT

FOR SALE
\$43,869,676,331
 65,764 bedrooms
 55,588 bathrooms
 36,672,535 sq ft

Are you interested? Breathtaking with unique views, this is a once-in-a-lifetime opportunity to own a piece of New York City history. The apartment is located in the heart of the city, just a short walk from Central Park and the Empire State Building. It is a true masterpiece of architecture and design, with every detail carefully crafted to provide the ultimate living experience. The apartment is a true gem, and it is a rare opportunity to own a piece of New York City history. The apartment is a true masterpiece of architecture and design, with every detail carefully crafted to provide the ultimate living experience. The apartment is a true gem, and it is a rare opportunity to own a piece of New York City history.

About the listing

THE APARTMENT IS AVAILABLE

The apartment is available for sale. It is a true masterpiece of architecture and design, with every detail carefully crafted to provide the ultimate living experience. The apartment is a true gem, and it is a rare opportunity to own a piece of New York City history. The apartment is a true masterpiece of architecture and design, with every detail carefully crafted to provide the ultimate living experience. The apartment is a true gem, and it is a rare opportunity to own a piece of New York City history.

Bedrooms

The apartment has 65,764 bedrooms. It is a true masterpiece of architecture and design, with every detail carefully crafted to provide the ultimate living experience. The apartment is a true gem, and it is a rare opportunity to own a piece of New York City history. The apartment is a true masterpiece of architecture and design, with every detail carefully crafted to provide the ultimate living experience. The apartment is a true gem, and it is a rare opportunity to own a piece of New York City history.

Bathrooms

The apartment has 55,588 bathrooms. It is a true masterpiece of architecture and design, with every detail carefully crafted to provide the ultimate living experience. The apartment is a true gem, and it is a rare opportunity to own a piece of New York City history. The apartment is a true masterpiece of architecture and design, with every detail carefully crafted to provide the ultimate living experience. The apartment is a true gem, and it is a rare opportunity to own a piece of New York City history.

Kitchens

The apartment has 36,672,535 sq ft of kitchen space. It is a true masterpiece of architecture and design, with every detail carefully crafted to provide the ultimate living experience. The apartment is a true gem, and it is a rare opportunity to own a piece of New York City history. The apartment is a true masterpiece of architecture and design, with every detail carefully crafted to provide the ultimate living experience. The apartment is a true gem, and it is a rare opportunity to own a piece of New York City history.

Sam Lavigne and Tega Brain. *New York Apartment* (2020)

Perhaps, such a vision could have been the one that encouraged Mierle Laderman Ukeles to reveal the maintenance process of the art gallery in *Washing/Tracks/Maintenance: Outside*² performance; Trevor Paglen to reach the hidden military infrastructure of area 51 in his series *Limit Telephotography*³; or web scraping artists Sam Lavigne and Tega Brain to measure New York’s real state infrastructural size in their *New York Apartment*⁴.

In contrast with artistic practices, the time and resources required for architectural practices to build the politics of reality are considerably longer than

those needed by artists to extract and impose meanings for their study subjects. That is why this thesis will depart from a traditional implementation of architectural typologies as political artifacts, but it will use the discipline as a methodological framework to understand and design the physical-virtual twofold through spatio-mediated interventions, allowing a further reflection on the political meanings of our digitally-interfered space.

2. Mierle Laderman Ukeles' *Washing/Tracks/Maintenance: Outside* at Wadsworth Atheneum Museum of Art: [youtube.com/watch?v=WIhf3UBNTIA](https://www.youtube.com/watch?v=WIhf3UBNTIA)

3. Trevor Paglen's personal website: paglen.com/

4. Sam Lavigne and Tega Brain's *New Apartment* project's website: whitney.org/artport-commissions/new-york-apartment/index.html

2.2 Cognitive Unfolding

Consider a space where all input and output channels of communication were digitally mediated and where each of our actions were to be preceded by an immediate reaction that would clutter our perception of the tangible reality.

'If our attention is a battlefield where the future of our daily submissions and coming rebellions is at stake, then we are at a crossroads. Each of us can learn to "manage" our attentional resources better, so as to become more "efficient" and more "competitive"... Or, we can learn to make ourselves more attentive to one another, and to the relationships from which our communal lives are woven. Depending on the directions in which we turn to look and listen [...] depending on the devices and programs that we plug into our senses we will continue towards a consumerist growth that draws each of us in like moths to a flame. Or we will manage to build together the shared conditions of a life that is more tenable and more desirable, which is more attentive to the quality of what surrounds it than to the quantity of its finances.' (Citton, 2017)

The site that Yves Citton describes here —far from being imaginary— could describe our experience in the current technological realm, where *attention* is the new currency exchanged in each of our electronic interactions with virtual agents that profile our likes, track our motion, and network our social relations. A place overflowed by digital content which economy is based on a *'new scarcity [...] no longer to be situated on the side of material goods to be produced but on the attention necessary to consume them'* (Citton, 2017), and where our ability to manage those attentional resources shorten the path to comprehend concepts, models, and structures about the nature of ourselves, others and our environment.

Traditional cognitive science has tried to encapsulate the process of living in this site into one single mental unit abstracted from other bodily mechanisms of sensory processing and motor control (Wilson & Foglia, 2017). In contrast, new theories have extended cognition beyond our bodies into our environment. Not only do these models seem to explain better our interactions with the world but they have proved to be useful navigation charts in an infinite sea of intangible notifications, reminders, LED blinks, DMs, friend requests, pop-up windows, and unsolicited nudes that collapse our biological schedule and surrounding habitat.

2.2.1 Embodied Cognition

The model of extended cognition seems to be certain in how we understand and behave in the digitally-mediated medium. That is why the *embodiment thesis* gathered by Robert A. Wilson and Lucia Foglia in *The Stanford Encyclopedia of Philosophy* could also prove to be useful in such space:

‘Many features of cognition are embodied in that they are deeply dependent upon characteristics of the physical body of an agent, such that the agent’s beyond-the-brain body plays a significant causal role, or a physically constitutive role, in that agent’s cognitive processing’ (Wilson & Foglia, 2017)

This allows the authors to further articulate three functions or roles of the body in the embodied cognition framework:

‘Body as Constraint: an agent’s body functions to significantly constrain the nature and content of the representations processed by that agent’s cognitive system [...]

Body as Distributor: an agent’s body functions to distribute the computational and representational load between neural and non-neural structures [...]

Body as Regulator: an agent’s body functions to regulate cognitive activity over space and time, ensuring that cognition and action are tightly coordinated.’ (Wilson & Foglia, 2017)

These definitions expand the limits of our mind-body affordances further into the surrounding environment and position our body intersectionally between our mind and the beyond-skin cognition instruments which will be disclosed as part of the extended mind model.

2.2.2 The Extended Mind Model

The *extended mind* theory presented in 1998 by Andy Clark and David Chalmers builds upon the idea of embodied cognition, stating that *‘an agent’s mind and associative cognitive processing are neither skull-bound nor even body-bound, but extend into the agent’s world’* (Wilson & Foglia, 2017).

To exemplify this idea, Clark and Chalmers explain that the user's rotation action of a falling piece in the Tetris game does not merely exist in the user's mind. Still, it is distributed across the agent and the computer-based system. This action is what they described as *epistemic actions*, those that we execute 'to alter the world so as to aid and augment cognitive processes such as recognition and search' (Clark & Chalmers, 1998). If this action is shown to be essential in the cognitive task, then the human organism and the external tool defined an inseparably coupled system in its own right. The lack of one of those two entities will result in the failure of the cognitive system: the removal of the external component will drop the system's behavioral competence.

If we were to agree on this theory, the evolution of our environments —as computational ecosystems that sense and react to our physical and mental presence in the space— have allowed our minds to expand and parasitize our livable spaces, reducing our 'memory load, and even transforming the nature of the computational problems themselves' (Clark & Chambers, 1998).



Janet Cardiff. *The Forty-Part Motet*. Showcased at BALTIC, Gateshead, England (2012)

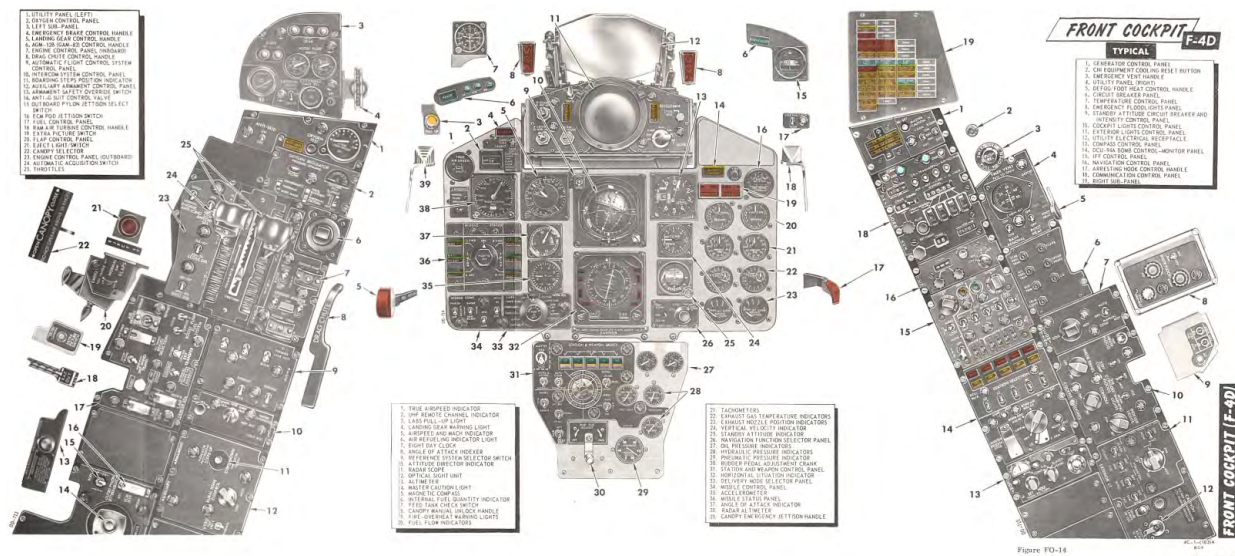
Cardiff's Cognitive Space

As an evocative application of this theory, I propose analyzing the audio installation *The Forty Part Motet* created by Janet Cardiff in 2001.⁵ The artist spatialized the sixteenth-century motet *Spem in Alium Nunquam Habui* by recording each choir member individually for then, piping each voice into its own speaker inside the exhibition room. The installation encourages the user's spatial exploration and navigation to acquire different polyphonic interpretations of the piece by isolating or combining different voices. Cardiff's work allows unfolding a cognitive process that, on conventional means, would have required the expertise of a trained ear to selectively coupled voices to identify the melodic structure. Instead, the listening experience here is distributed between mind and space.

5. Janet Cardiff's *Forty Part Motet* at Tate Modern UK (2017): [youtube.com/watch?v=38ORiaia9r8](https://www.youtube.com/watch?v=38ORiaia9r8)

2.2.3 Distributed Knobs and Monitors

The model of *distributed cognition* takes advantage of the *extended mind* claim and adventures multi-channel spatial settings that continuously send, process, and receive signals in all directions to enable the resolution of cognitively complex tasks. According to Edwin Hutchins experiments navigating in a US navy vessel, the individual and the context are so closely entwined that they cannot be separated into ‘*information processor and information to be processed*,’ (Hutchins, 1995) therefore defining a cognitive model distributed across time and space, individuals, experiences, and objects. Pervasive and ubiquitous technology have used this model to off-load information-based systems into the environmental-embedded control and display devices since this idea allows to decompose the information-based system in terms of its inputs and outputs displaced into a problem space (Perry, 1998). Cockpits are a good example of a cognitive process unraveled as a spatio-tactile interface: instruments, indicators, and displays are distributed across all surfaces in the cabin so the pilots can decompose their flight procedures into small single operations.



F-4D Phantom Front Cockpit Panel. Source: aviation.watergeek.eu/f4c-panel.html

The site explored in this thesis —my room— is essentially a multifold space where actions and experiences intertwine and are already distributed through a tangible system of knobs and monitors that interface the virtual and the real. Thus, prototyping in such a space would require perceiving how the mind unfolds through the body into the matter and, inversely, how the environment reverberates in our spatial awareness, exploiting the theory of distributed cognition reconsidering our skin as part of this mediated space.

2.3 Tangible-Experiential Engagement

2.3.1 Material Engagement

Once the challenge of navigating the physical-virtual twofold becomes a spatial problem, attention can be placed on the design and material interface that defines the paths and boundaries of our cognitive protocols, or what Lambros Malafouris defines as:

‘Material engagement [...] the optimum point to perceive what for many years remained blurred or invisible, i.e. the image of a mind not limited by the skin.’ (Malafouris, 2004)

The metaphor of a mind deployed over a tangible-experiential setting has been a constant in the work of interaction designers and researchers such as the Tangible Media Group at MIT, whose prototypes augmenting surfaces, interfacing virtual environments with graspable controllers, and overlapping ambient media in room surfaces brought new qualities and affordances to the perception and manipulation of virtuality (Ishii & Ullmer, 1997). Although we can argue that the scope of these interactive and augmented surfaces is purely interfacing physical matter with digital means, in such interactions, the cognitive unfolding still lies in between the self and the instrument, and so, the experience design prevails over the interface.

2.3.2 Experience over Interface

Designing experience frameworks for specific cognitive processes —instead of manufacturing fixed interfaces for specific actions— warrants that even when the digital system becomes obsolete, the cognition mechanism remains valid. The vision of Mark Weiser of integral *ubiquitous computing* devices —exemplified later as *tabs* ideated by Xerox PARC during the 90s (Weiser, 1999)— responds to an experiential design process that translates the portability of paper into the digital office. Despite the technological evolution from the prototyped pad to GUI windows, smartphones, or iPads, the vision of an extended bodily interaction placed in a spatio-material system as an experiential optimization solution prevails.

Myron W. Krueger’s position in respect to the value of the experience design is even more radical since *‘it may be desirable that the output does not qualify as beautiful in any sense,*

for that would distract from the central theme: the relationship between the observer and the environment' (Krueger, 1977) which would be later supported by Paul Dourish's HCI central handbook —*Where the Action Is*—:

'Embodied interaction is not a technology or a set of rules. It is a perspective on the relationship between people and systems. The questions of how it should be developed, explored and instantiated remain open research problems.' (Dourish, 2001)

These notes have encouraged this thesis to adopt a critical standpoint against the *seamless*⁶ UI and UX aesthetics of screen-based commercial tech products that do neither contest the untidy reality of our livable environments nor address the complexity of human spatial behavior. A *seamful* embodied approach to design interactive systems would shape more unambiguous experiences across tangible and screenless digital mediums. Grounded on this perspectives, this thesis proposes a series of assemblages and systems that work collaboratively with our surrounding space, with the textural and geometrical qualities of our close material environment, with the transmission and atmospheric properties of our aerial medium, and the immaterial nature of the social matrix that surrounds my identity and presence in my room.

6. In his invited talks, Mark Weiser suggested that *seamless* designs would amount to make everything the same, reducing everything to their lowest common denominator. Instead, he proposes a *seamful* approach that could oppose this homogenization by advocating for systems with beautiful seams that show the richness of each of their well-contrasted parts (Chalmers et al., 2003).

2.4 The *Spatio-Mediated Assemblage*

Outlining the mediated space defined in between what our mind defines as virtual and what we can empirically prove as physical will not be the purpose of this thesis, since literature reveals that such space is open to numerous interpretations that contravene each other. Instead, I propose to research those artifacts that exist indivisible within this double medium and cannot be studied divorced from either the object itself or their virtual construction. An object-image couplet where both physical and virtual substance add up to the cognitive construction of their existence (Garcia & Ettlinger, 2014) similar to the one observed in Pablo Garcia's *Memento Mori*: a series of clamp-ons attached to Ljubljana's public bike racks that create through their reflection a memento mori skull on the shiny metallic surface⁷.



Kurt Schwitters. *Merzbau*. Hannover (1933)

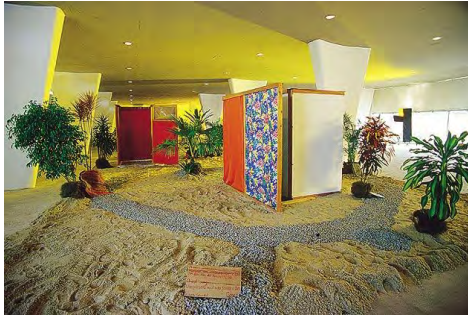


Pablo Garcia. *Memento Mori (Catoptric)*. Ljubljana (2014)



These artifacts are contingent and manufactured for a specific space and its cultural context. They have to be experienced on-site and their reproduction and preservation —inevitably divorced from a live showcase— modify their situated nature. A nature that is more than an aesthetic experience towards sensible materiality but a philosophy towards the artifact itself.

7. Pablo Garcia's personal website:
pablogarcia.org/



Hélio Oiticica. *Tropicália-Penetráveis PN2 e PN3*. Installation for the XXIV Bienal Internacional de São Paulo (1998)

For Kurt Schwitters, this wholesome was circumscribed with the term *Merz* —a nonsense word used by the Dada artist to trademark his work. His *Merzbau* —a room-sized living sculptural construction composed of grottoes, columns, and found objects arranged all over his studio— showcased the ever-shifting and ever-expanding nature of a dated artwork unfeasible to trace beyond its living time. The ‘*Merzbau was not just a static painting or a sculpture, but a whole environment, and one that was in constant flux*’ (Thomas, 2012) and therefore was not an autonomous artifact. Instead, it reacted along with their inanimate and lively vicinity following the same guidelines that later, Helio Oiticica’s letters would define as the *new environmental art* materialized in his *Tropicália* installation.

‘o eternamente móvel, transformável, que se estrutura pelo ato do espectador, e o estático, que é também transformável a seu modo, dependendo do ambiente em que esteja participando como estrutura [...]’ (Oiticica, 1986).

The artifact does no longer engages in a directional relationship with the viewer but a multifold spatial experience. It environmentally senses and reacts to one or several ambient features and distributes new meanings and relationships among the components of their surrounding landscape through analog and —for the past 30 years— digital means.

Inspired by these definitions, I will refer to this type of artifact hereinafter as:

2.4.1 Definition

Spatio-Mediated Assemblage, a type of environmental-reactive speculative artifact that interferes with our spatial cognition where physical and virtual substance add up to the definition of our surroundings.

2.4.2 The Mediated Tactics

The lively and wide-ranging nature of the spatio-mediated assemblage makes debatable its classification within a generational movement, aesthetic style, or material typology. Instead, each assemblage should respond at least to more than one of the following tactics used as a way to interface the mediated space with new media qualities onto the material surfaces and the fluid medium.

Infrastructural Disclosure (ID)

Our analog and digital space today is surrounded by an excess of embedded information and media content overlaid on top of the physical surfaces of our environment. As Byun Chul Han bespeaks, this *faux* transparency derives from a political effort to disassemble mass surveillance ideas to a demanding society. However:

‘Anesthetic hypercommunication reduces complexity in order to accelerate itself. It is significantly faster than sensory communication. The senses are slow. They impede the accelerated circulation of information and communication. Thus, transparency comes with an absence of sense. The mass of information and communication derives from a horror vacui.’ (Han, 2015)

What Han sees as an *absence of sense* —the loss of awareness to seize the magnitude of what is contingent to our *self*— spatio-mediated assemblages have understood it as conceptual grounds to reclaim our attention on the environmental crisis (Fig. 1), expose the surveillance methods of AI systems (Fig. 2), reveal our kinship with ubiquitous technologies (Fig. 4)

See figures in page 30

- 1 Diller Scofidio + Renfro. *Exit* (2008)
- 2 Ai Weiwei, Herzog & de Meuron. *Hansel & Gretel* (2017)
- 3 Richard Vijgen. *Hertzian Landscapes* (2019)
- 4 Simon Weckert. *Google Map Hacks* (2020)
- 5 Jonathan Chomko. *grindruberairbnb.exposed* (2020)

and abstract interfaces (Fig. 5), or purely disclose the infrastructural size of the *Hertzian* landscape (Fig. 3).

Fictional Deconstruction (FD)

Spatio-mediated assemblages intersect the 3-dimensional space —either physical or virtual— interfering with our understanding of the environment before our brain completes this process with additional signifiers. As creators of these assemblages, we can adjoin meanings across the space constructing new fictional narratives on top of the plain perceptual message. This is shown in Janet Cardiff's audio walks (Fig. 8), where the interactive process of navigation through a prerecorded audio narrative reveals the space that was once experienced. The architecture does not happen anymore as a unique mental representation of Kassel-Wilhelmshöhe station, but a cross-effect of waves and sequential images interfaced through a mobile app. Regardless of the materiality of this interference —video projections (Fig. 6, 7), patent sketches (Fig. 9), or virtual performances (Fig. 10)—, the experience and decoding of spatio-mediated assemblages provide a fictional deconstruction of the mediated site.

Formless Interfacing (FI)

In the last ten years, designers of every field have slowly transitioned towards UI and UX roles requested by a tech industry that encourages every single company and capitalistic venture to invest in screen-based products. While the true cause of this deal is to acquire free user data to model marketing and strategic consumer needs, this comes with an unrequested transition to a one-directional interactive

See figures in page 30

- 6 Michael Naimark. *Displacements* (1980)
- 7 Shimon Attie. *The Writing on the Wall* (1991)
- 8 Janet Cardiff & George Bures Miller. *Alter Bahnhof Video Walk* (2012)
- 9 Jeremy Bailey. *Patents Pending* (2016)
- 10 Lauren McCarthy. *LAUREN* (2019)

space between our 2-dimensional smartphones and our thumbs. Spatio-mediated assemblages withdraw from these conventions and distribute interactive features — such as time-based interactions (Fig. 11), spatial audio (Fig. 13, 15), lighting (Fig. 12), or motion tracking (Fig. 14)— across space, providing a formless interface and encouraging multidirectional user interactions.

Tangible Reliability (TR)

The idea of an aerial controlled, interactive, multidimensional, and multisensorial space —peaking in 2002 Spielberg’s *Minority Report*— has been widely entertained by mass media and pop culture during the great part of the 20th and 21st centuries. Lately, the current sanitization protocols that cities have implemented due to the COVID-19 expansion have also motivated a rebirth of material-less and touch-less interactions with our digital environment to avoid contact with possibly infected surfaces. This has driven UI and UX practitioners towards a *swipe* gesture supremacy over other human-computer interaction standards, perhaps, more connatural to the ways we are used to interacting with our tangible reality. However, this temporary transition obviates the importance of materiality as a vehicle of meaning and the importance of graspable and tactile interfaces that emulate congenital behaviors. In contrast, spatio-mediated assemblages rely on familiar objects (Fig. 13, 20), tactile (Fig. 17), and haptic (Fig. 16) feedback or action-reaction tangible systems (Fig. 18) to provide extracorporeal meanings to the interactive space they define.

See figures in page 30

- 11 Dan Graham. *Time Delay Room* (1974)
- 12 Rafael Lozano-Hemmer. *The Trace* (1995)
- 13 Theodore Watson. *Audio Space* (2005)
- 14 Madeline Gannon. *Manus* (2018)
- 15 Yutaka Makino. *V* (2019)

- 16 Thought Collider. *WiFi Dowsing Rod* (2007)
- 17 Everyware. *Cloud Pink* (2011)
- 18 Random Studios. *Sun* (2017)
- 19 Chris Salter. *Haptic Field* (2017)
- 20 Urs Fischer. *PLAY* (2018)

Experiential Immersion (XI)

The spatio-mediated assemblage most fundamental tactic to interface our reality is to behave as an experiential artifact that circles our senses into an all-surrounding embodied experience of the medium. George Bures Miller defines this strategy in their joint sound experiments produced along with Janet Cardiff:

‘We create a scenario where we try to suspend your disbelief, so that you’re within the reality of our piece, and then somehow we will pull the rug out from under you by saying something or having a sound that destroys that reality’ (Blegvad, 2014)

During the late 20th century, this was signaled by the substitution of the white exhibition room with the *black box* (Manovich, 2006) that seemed to neutralize our perception of the space, for later, re-establish a set of experiential environmental conditions. While this inspired the spatio-mediated strategy of numerous 360 screen-based experiences (Fig. 21, 22, 25), some of these assemblages leverage an abstract interpretation of this idea using vast amounts of data —sometimes numeric (Fig. 23), others meteorological (Fig. 24)— to qualify the mediated space as an experiential immersion.

See figures in page 30

21 Luc Courchesne. *Landscape One* (1997)

22 Ryoji Ikeda. *data.tron* (2009)

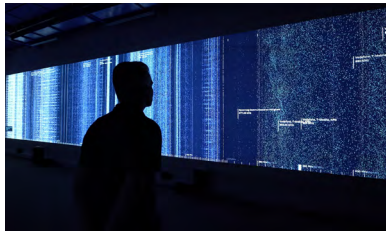
23 James Bulley & Daniel Jones. *Variable 4* (2010)

24 Monocolor. *Latent Space* (2019)

25 Olafur Eliasson. *Symbiotic Seeing* (2020)



Fig. 1



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3



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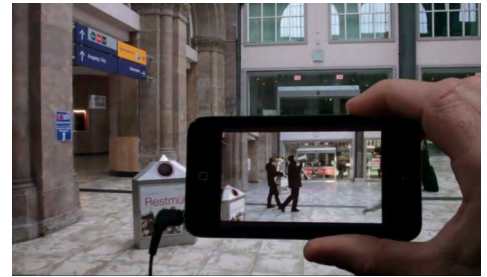
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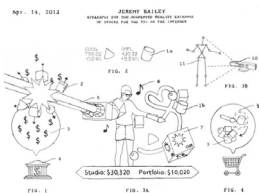
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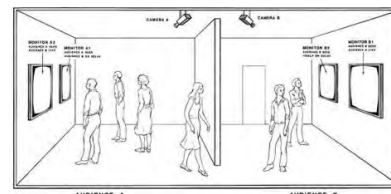
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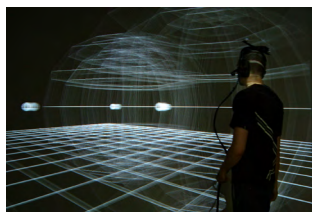
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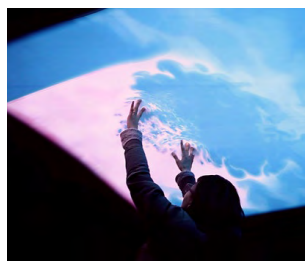
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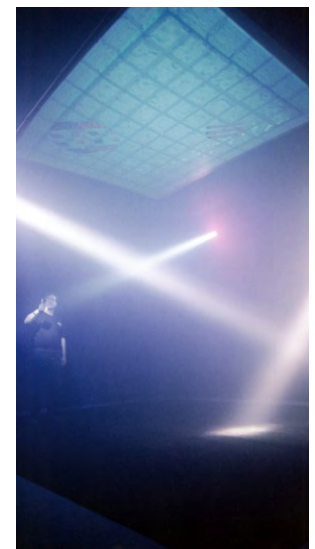
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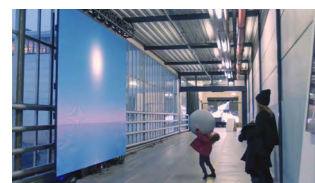
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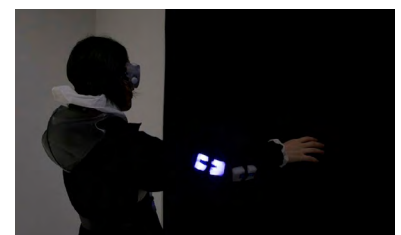
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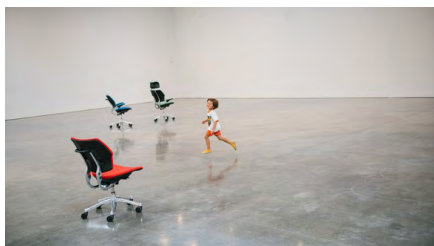
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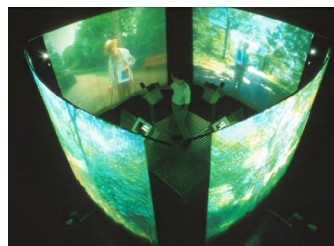
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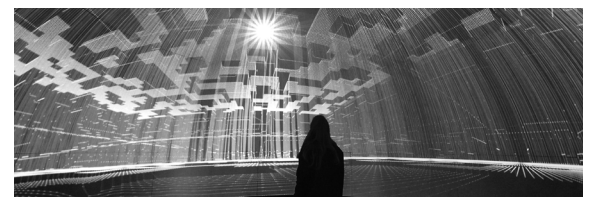
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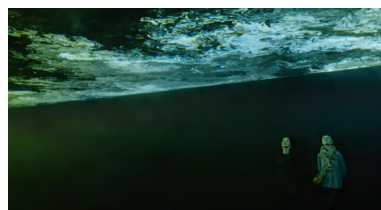
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See captions in pages 26-29

2.5 Autobiographical Speculation

2.5.1 Design Methodology



Tracey Emin. *My Bed*. Tate Britain, UK (1998)

This thesis articulates a narrative around a general but mostly personal use of the screen-based interfaces surrounding me. Scrolling across infinite feeds of personalized digital content is an adaptation to the existing widespread screen medium that serves a capitalistic economy, not a natural or ambitious design choice that expands our cognition of others and the world surrounding us. As a daily user of screens, I knew that new ways of interaction could only come from radical methods that avoid the comfort of continuing the current experience design trends and conflict with the ideas that I had in regards to what is naturally *comfortable* or what has been externally acquired through mindless repetition. And precisely because of this, the site of research had to be denaturalized to discern automated perceptions of what seems natural and unquestionable (Bell et al., 2005) —like that crude Tracey Emin’s self-portrait depicted as a bed covered in stained sheets, condoms, and empty bottles displayed in the middle of a polished white gallery.

‘Making domestic life and technologies strange provides technology designers with the opportunity to actively reflect on, rather than passively propagate, the existing politics and culture of home life.’

(Bell et al., 2005)

Due to the inability to engage with a broad spectrum of study subjects —a result of COVID-19 gathering restrictions— a first-person exploratory process was demanded as the vehicle of this research. This method granted a granular understanding

of the research site, shortening times between ideation and execution stages and producing faster iterations over design motivations and intuitions. However, designing for oneself raised continuous concerns on how to engage with scholarly research practice. For that, I decided to iterate on Neustaedter and Sengers' tenets for autobiographical research (Neustaedter & Sengers, 2012) since this methodology '*offers a different set of epistemological commitments that allows researchers to investigate the lived experience from within, generating deep, evocative, and rich insights*' (Desjardins & Ball, 2018). Broadly, this method emphasizes:

- creating and developing fully functional systems;
- engaging with long-term interactions with the assemblages;

acknowledging the difficulty of identifying the cause of each design choice from personal preferences —exposed in the designer-user dualism (Desjardins & Ball, 2018)— when:

- fast-tinkering;
- recording and documenting each design stage;

and finally, reframing some of those guidelines towards a self-defined methodology that:

- explore speculative avenues of research and accept contradictory motivations over genuine needs.

This last precept comes along reflecting on less optimistic and more problematic design briefs (Bell et al., 2005), acknowledging these contradictions in the prototyping process, and thus, aligning with speculative HCI research methods focused on articulating research spaces with situated artifacts and speculative materialities (Wakkary et al., 2015). In this scheme, landmarks are not product realizations but placeholders that articulate a wider exploration of interactive technologies in everyday life (Gaver & Martin, 2000).

2.5.2 Assemblage Prototyping

Following this methodology, this research frames prototypes as *assemblages*. With this figure of speech, these systems try to connect with those early 20th-century unsettling and surprising sculptures created out of mundane materials and found objects from dada and surrealist artists. A concept that in the late 50s and 60s would also become a synonym of an '*an apparently anti-aesthetic approach to making art*' disrupting '*the values of the commercialized contemporary gallery system*'.⁸ In this thesis, the prototypes are a reflection of these mixed techniques but using digital

8. Assemblage definition from TATE Gallery UK: [tate.org.uk/art/art-terms/a/assemblageterms/r/readymade](https://www.tate.org.uk/art/art-terms/a/assemblageterms/r/readymade)

frameworks and software environments, generative audiovisual systems, CNC fabrication methods, virtual simulations, and site-specific performances. These assemblages —inspired digital *readymades*—⁹ are instructed by a set of detailed descriptions and plans that allow a future reconstruction of the system. Similar to that *Door, 11 rue Larrey* that Duchamp commissioned to an unknown craftsman in 1927,¹⁰ the real contribution of the thesis is not to praise the material reproduction of these assemblages but to *contextually* and *critically* discuss related interactive design research practices, explore new ways of decapitalizing digital interfaces, and sabotage ideas of convenience culture and attention economy in the digitally-mediated productive society.



Marcel Duchamp. *Door, 11 rue Larrey*. New York (1927)

2.5.3 Evaluation Method

Due to the lack of in-person assessment and public showcasing, the work has strongly relied on virtual conferencing tools, chat rooms, and email communication to get feedback from the advisory team and other peers during the design process. That has enforced experiments to be self-evaluated through reflective comparison against the initial motivations and recommendations described in previous phases. In parallel to an autobiographical assessment of the work, the public presentation of this thesis will function as a final exhibition of the work granting a last collective interpretation of the constructed digital assemblages.

9. The term *readymade*, initially defined by Marcel Duchamp in 1917, refers to artworks purposefully made from manufactured products where the choice of those products functioned itself as a creative act. Along with that interest, readymades are also characterized by canceling the *useful* function of the assembled objects and using the piece's title as a creative vehicle to provide new meaning to the original objects. Source: tate.org.uk/art/art-terms/r/readymade

10. The *Door, 11 rue Larrey* is a wooden door commissioned by Marcel Duchamp to a local craftsman that questions the notion of authorship in the produced artwork. With this readymade, Duchamp points out that the artist does not need to execute the art piece physically but only need to craft the idea, commissioned the piece, and foster a later discourse: no longer is the artist a craftsman but a curator of ideas. Source: toutfait.com/unmaking_the_museum/Door.11%20rue%20Larrey.html

Process & Methods

Foreword

At the beginning of March 2020, unaware of how the rest of the year would unfold due to the COVID-19 pandemic, this thesis suddenly turned towards an already existing —although not utterly exploited yet— site of production of the West: the domestic space. Allegheny County's stay-at-home order enforced the retreat of all its residents to their houses to avoid the virus's spread across the communities. Carnegie Mellon University also restricted in-person access to its labs, classrooms, libraries, and common areas, reducing all educational experience to a distressing choreography of video calls and online lecture materials. The institutions of well-being, the entertainment industry, the production and consumption ventures, all communication services, and other platforms for social interaction moved from governmental and private buildings to a dispersed ecosystem of smart devices in our homes. What used to happen outside of my walls, short, was happening virtually all over the place, and the apartment now circumscribed a temporal nation in itself.

3.1 The 360 Self

Returning home indefinitely produces an unsettling sentiment of oddness. For some, this felt identical to the surprise of that man in Chantal Akerman's *Le déménagement*¹¹ that stands bewildered by the asymmetry of his apartment. For others, a perpetual suite of small happenings across the different scenes of their home similar to the piano pieces that the composer Henri Cowell titled—in gerund form—*Nine Ings* in the early 20th century:

floating, frisking, fleeting, scooting, wafting, seething, whisking, sneaking, swaying.

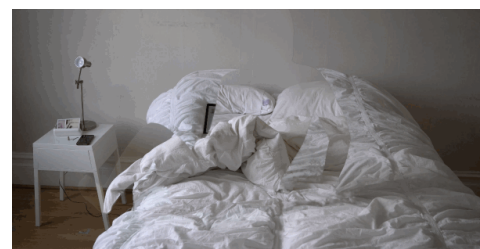
More recently, Ivan Haidar's—an Argentinian artist who develops new performative languages using his house as a scenic lab—*Composiciones*¹² portrayed the strangeness of the self fading in one room through video collages of rotoscoped memories and imaginary affections. Joyce Wang—an artist and creative technologist who I met during the Experimental Capture course taught by Golan Levin and Nica Ross at The *Frank-Ratchye STUDIO for Creative Inquiry* at CMU—depicted in *A Momentary Stay*¹³ her transient and cloistered presence in a friend's apartment surrounded by unfamiliar belongings during the lockdown. These distinct lectures of the nature of the interactions and interchanges between the self and the space that they occupy have motivated the choice of site in this thesis. The spatial and material qualities of this space and the variety of digital and analog interfaces distributed in this environment are also elements for a close examination and prototyping tools for the alteration of the self's performance in the home as a site of research.



Chantal Akerman. *Le déménagement* (1992)



Ivan Haidar. *Composiciones*. Buenos Aires, Argentina (2020)



Joyce Wang. *A Momentary Stay*. Pittsburgh (2020)

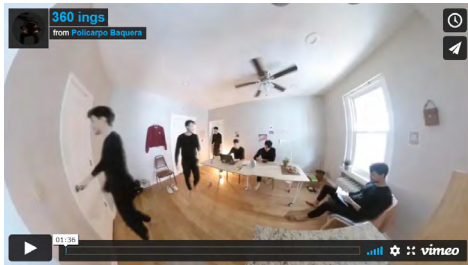
11. Teaser video of Chantal Akerman's *Le déménagement*. VFSTA (1992): vimeo.com/141691899

12. Ivan Haidar's. *Composiciones* (2020): youtube.com/watch?v=vMITIGqqVmY&t=656s

13. Joyce Wang's performance series: joycewang.me/person_in_time/

3.1.1 Sousveiyng the 360 Self

By March 2020, I was lucky to own a big table that occupied my apartment's central position. I initially fabricated it as a multipurpose object out of a 4 x 8ft. plywood board and 5 legs on wheels and used it as a dining table, working desktop, and display stand for found objects. During the stay-at-home order, I became strongly aware of my effects and actions around that table, and other scenes distributed around the apartment. Action by action and location by location, my daily movements became thick, almost solid, foreseeable.



360 Ings (2020). Awarded the Frank-Ratchye STUDIO for Creative Inquiry's Residency-In-Your-Room Fellowship 2020.

Video:

vimeo.com/413440325

Interactive 360 Video:

youtube.com/watch?v=B5Gx1PocVds

14. Jeremy Bentham's *panopticon* is an architectural typology of a concentric institutional building. Its shape allows a guard located in a central tower to control the surrounding cell units in the perimeter, diverting cells' inmates from detecting their continuous surveillance. In Foucault's *Discipline And Punish* (Foucault, 1975), social and private life is said to be regulated and observed following this model, which is no different from how governments and private companies surveil social media platforms and smart digital devices in current societies. In contrast with this vision, Mann's *sousveillance* (Mann et al., 2003) proposes a bi-directional system where those observed in the panopticon can also observe those surveilling our daily actions. *360 Ings* entertains the idea of using 360 recorded images as the sousveillance currency of an autonomous domestic economy.

To materialize the strangeness of this prolonged encounter between myself and the apartment, I decided to perform a small video piece in one single act: *360 Ings*. Although the apartment's dimensions needed to be captured from multiple camera angles, the performance had to reflect an analytical —almost scientific— ground-truth. That could only be achieved by filming all the sequences in a one-shot scene which could only be achieved with a spherical perspective recorded from a central position. The capturing was done using a Xiaomi Mi Sphere 360 Camera with a video resolution of 3.5K. The video output was an equirectangular projection of the spherical dual fish-eye input image easily readable by any video editing software. The recording files were also considerably big due to the sensor's resolution. For that reason, I had to reduce the performance time under 5 min —approximately 4500 frames at 15 frames per second— hence, spatial and time planning became essential. A few seconds were enough to enact each domestic action and collect small gestures and their variations in 360-degrees, almost like a *panopticon sousveillance* scheme¹⁴ as a form of *reflectionism* to neutralize the surveillance of those in power through the collection of one's own personal data (Mann et al., 2003).



Spherical video frames from 360 Ings.

The 360 video footage —initially meant to be seen sequentially— had to be processed so as to achieve a condensed single shot where all actions and movements happened at once, overlapping past and present actions in the same space. For that, I chose a machine-learning enhanced computer vision method to segment each of the singular positions of the human body and render a continuous path across the medium. Due to the lack of a commercial solution for 360 video processing, this was solved with a twofold process: an auto capturing and rotoscoping¹⁵ framework that recorded and processed an output mask of the video footage, and a manual editing pipeline to compose the final cut. Each frame of the raw footage was isolated, cropped, and processed using an ML enhanced rotoscoping method that subtracted each image's background and produced an alpha matte channel with crisp but smooth edges contouring human figures. *Mask R-CNN for Object Detection and Segmentation*¹⁶ and *Detectron 2*¹⁷ provided convincing results for undistorted human shapes. However, these methods were unsuccessful when processing remapped 360-degree video footage with warped human figures.¹⁸ *Deep Labelling for Semantic Image Segmentation* (DeepLabV3)¹⁹ was able to segment human bodies rightly, but the mask was not sharp enough for rotoscoping the video sequence.

A second algorithm was needed to succeed in this task. *Background Matting*²⁰ is an ML method developed by a group of researchers at the UW Reality Lab at the University of Washington that uses a deep network with adversarial loss to predict a high-quality alpha matte channel by judging the quality of the composite with a new background —here, that background was my empty living room. The images are processed frame by frame using the GPU running Pytorch and Tensorflow with CUDA 10.0.



Original Footage, Segmentation Mask, Alpha Matte, and Final Composite of the ML-enhanced rotoscoping pipeline

15. Rotoscoping is an animation technique that consists of segmenting a live-action object or shape in a video footage frame by frame, which later will be used as a graphic asset for compositing the final sequence. Recent advances in ML recognition techniques applied to digital processing pipelines have automatized the process, shortening editing times.

16. Source code: github.com/matterport/Mask_RCNN

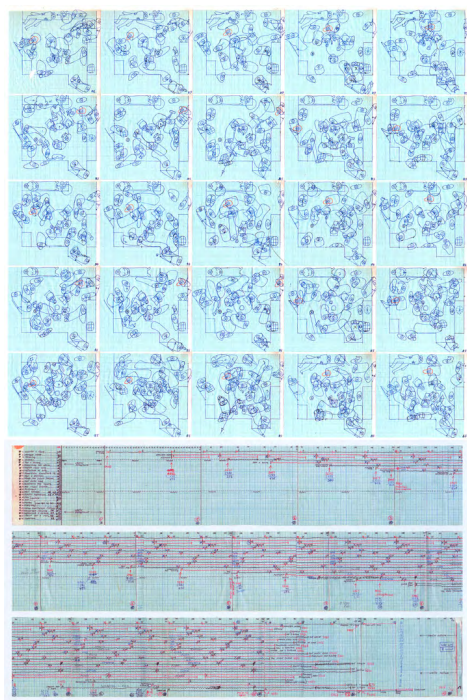
17. Source code: github.com/facebookresearch/detectron2

18. In March 2020, RunwayML —a creative ML image and video editing tool— did not provide any successful rotoscoping method to process the equirectangular 360-video footage. Source: runwayml.com/

19. Source code: github.com/tensorflow/models/tree/master/research/deeplab

20. Source code and paper: grail.cs.washington.edu/projects/background-matting/

‘Thirty-six characters from different stages of life —representations of different times— interact in one room, moving in loops, observed by a static camera. I had to draw and paint about 16000 cell-mattes and make several hundred thousand exposures on an optical printer. It took a full seven months, sixteen hours per day, to make the piece. The miracle is that the negative got through the process with only minor damage, and I made less than one hundred mathematical mistakes out of several hundred thousand possibilities. In the final result, there are plenty of flaws black lines visible around humans, jitters caused by the instability of film material resulting from film perforation and elasticity of celluloid, changes of colour caused by the fluctuation in colour temperature of the projector bulb, and inevitably, dirt, grain, and scratches.’ (Rybczyński, 1997)



Video frames, floor action planning and timeline of Zbigniew Rybczyński's animated short film *Tango* (1980)

Once the video layers were processed, I manually composed them as a batch in Adobe Premiere. This process draws inspiration from the 1980 Oscar-winning animated short film *Tango*,²¹ produced by the experimental polish filmmaker Zbigniew Rybczyński. In the 8-minute film, thirty-six characters engage in thirty-six everyday action shots overlapped in time and space in a singular room. A frantic choreography of anxious patterns that took several months to develop and composite from the original film negative.

Thanks to the power of current editing commercial software such as Adobe Premiere, months became hours in 360 Ings but still, the compositing pipeline reminds to that Rybczyński diagram showing the choreographic efforts to interweave actor's entries and exits to and from the set. Finally, the final cut — output from Premiere as an equirectangular video— was processed in Insta360 Studio,²² a software program for spherical video editing in which camera transitions were added to create a flat version of the film.

21. Zbigniew Rybczyński, *Tango* (1980): vimeo.com/90339479

22. Insta360 Studio 2020 Software Website: insta360.com/

3.1 The *Multiplexer Room*

In August 2020, I moved to a new apartment in Pittsburgh —the same from where I am writing these lines. All my belongings acquired in my one-year stay in the United States were now displayed in a single 215 sq. feet room. Though initially unfamiliar with its dimensions and spatial properties, after a few weeks, I finally could behave in this new environment more intimately: the room became *domestic* again. But now, the *domestic* featured also the needs of the in-home office: fast internet connection for online classes, free desktop area for a secondary monitor, various tools and electronics organizers for DIY tinkering, and a decent homogeneous front-lighting setting for Zoom video-conferencing calls. YouTube’s obsession in building the ultimate dream desk setup for computer gaming sessions became more relevant than ever, and digital creators and gamers enjoyed a momentary elation seeing how we all could benefit from their lifelong experience producing content from futuristic home workspaces. Soon, I could not resist the urge to acquire my own Smart WiFi LED Strip Lights to increase my productivity beyond daylight hours.

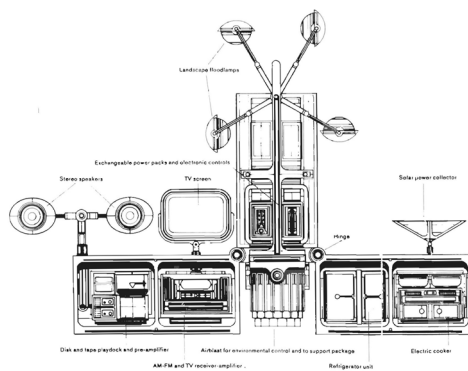
For many individuals and families who had the privilege to transfer their offices back home and continue their productive ventures without getting exposed to the virus—in contrast to all essential workers that risked their health and life during the COVID-19 pandemic—their houses experienced a temporal process of industrialization similar to the one that the kitchen suffered in the early 20th century. The urgency for cheap social housing projects in Germany after World War I motivated space-saving design solutions that especially impacted the kitchen’s typology. The *Haus am Horn*’s kitchen by Benita Koch-Otte or the *Frankfurt Kitchen* by Margarete Schütte-Lihotzky showed how rationalization and industrialization were perpendicular to all social classes. From an American perspective, Genevieve Bell’s *Kitchen Manifesto* justifies this shift as a late effect of *Taylorism*’s influence over all the public and private life institutions. Ideas of efficiency as a ‘*relevant metric in getting things done*’



US Department of Agriculture, Office of Public Affairs. *A Step Saving Kitchen* (1949). Source: youtube.com/watch?v=2N9RCQjPqh4&t=175s

were widely spread from the factory to the home environment, and soon *'kitchens became one of the key sites of innovation'* (Bell et al., 2002). Women were at this time the target of the capitalistic economy and were narrowed by the US Department of Agriculture as a homebound necessary key part for the functioning of the productive society. The domestic evolution also reflects Banham's concerns exposed in his *Environmental Bubble* design: a utopic house that tried to signify the mid-century American standards of cleanliness, car dependence, individualism, and consumerism morals (Banham, 1965). As a consequence of these ideas, technology acquired a central role in the definition of the *home*, which was no longer a synonym of an environmental refugee but a sophisticated energy-dependent machine. Even more:

'The power of the Internet carries forward Taylor's primes of efficiency to a new century, with talk of zero-friction business models and optimal pricing algorithms' (Bell et al., 2002)



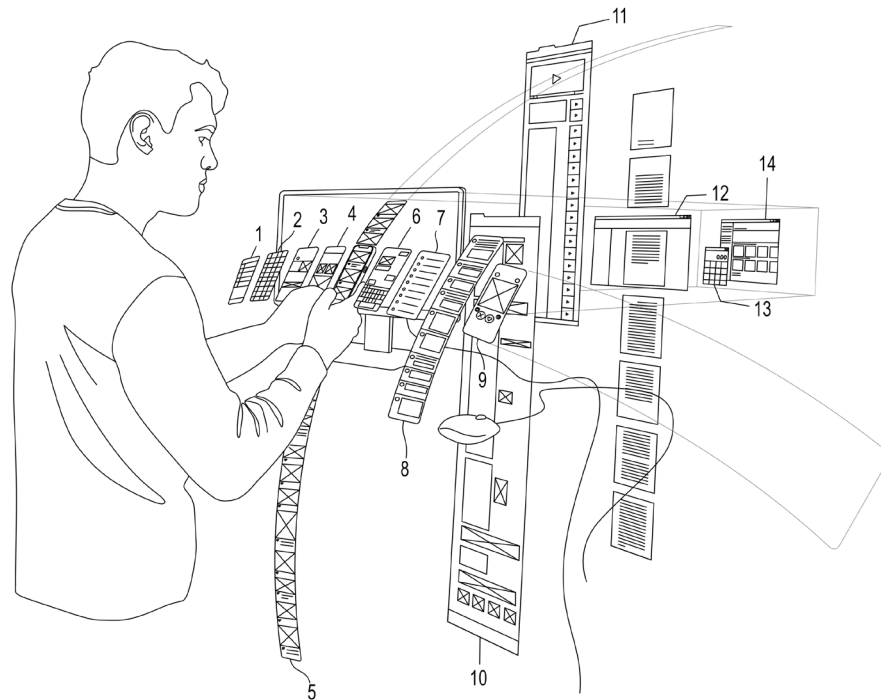
Reyner Banham. *Transportable Standard-of-Living Package* (1965)

The widespread inclusion of IoT devices and broadband wireless connection in the domestic space—now branded as the *smart home*—has contributed to its transformation as a place of production. This domestic turn also implies a political shift or what Paul B. Preciado in their article *Learning from the Virus*—published along with the reflection of other thinkers and philosophers—rightly depicted when they described Hefner's Playboy Mansion:

'One might say that the Playboy Mansion and Hefner's rotating bed, transformed into objects of pop consumption, functioned during the Cold War as spaces of transition where the new prosthetic, the ultraconnected subject, and also the new forms of pharmacopornographic production and consumption that would come to characterize contemporary society were invented. That mutation has become widespread and has amplified with the management of the Covid-19 crisis: Our portable telecommunication machines are our new jailers and our own domestic interiors have become the soft and ultraconnected prisons of the future.'

(Preciado, 2020)

Unwittingly, my home became the control room for the production, consumption, and biopolitics of my life and the heart of virtual consumption and telecommuting processes. I myself became an intermediate auditor of information processes in this digitally-mediated space.



The screen-based interactive space of my room

3.2.1 Disrupting signals; streaming attention

Learning from home requires an extraordinary effort to maintain a clean stream of attention towards the communication devices we use for that purpose —computers, external monitors, smartphones, iPads— as well as an unimpaired dexterity with peripheral electronics —mouse, keyboard, external drives— and traditional tools —for me, a mechanical pen, a notebook, and tons of Post-its. The complex choreography across technologies has an additional challenge: each of those devices and tools is interfaced with our brain in different ways. The different operating systems, visual and sonic interfaces, tactile experiences, and cognitive mechanisms involved in mastering and transferring knowledge from one to another system saturates our capacity to focus our attention on this task's main goal: to acquire knowledge and develop our understanding of the *beyond-the-brain* body.

'Today, there's a new kind of chore. A new set of numerous, mindless errands embedded into our already overwhelming busy lives.'

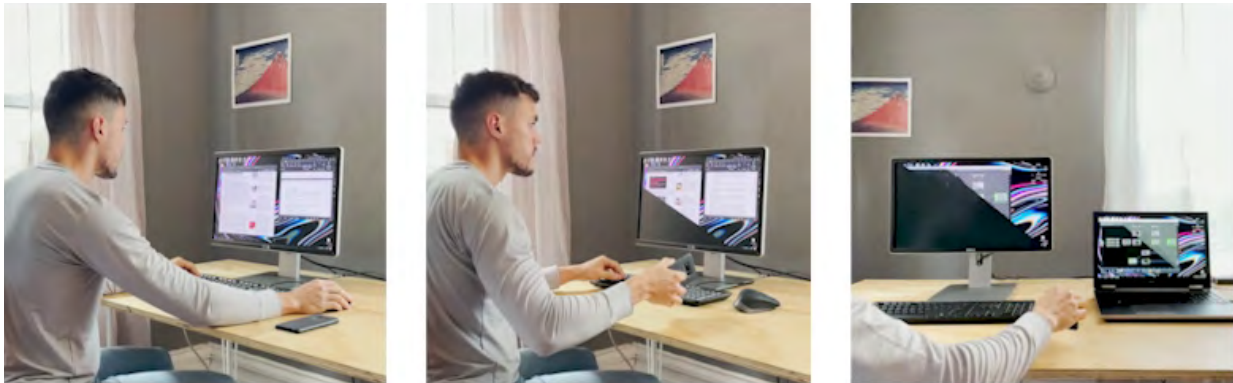
(Krishna, 2015)

Far from Xerox Park ideals of working and living in a seamless universe of computers that could help me achieve my educational goal during the in-home university, I spent my hours clicking icons, chasing hyperlinks, scrolling up and down, swiping left to right, typing user and password forms, and delighting my vision with carefully crafted UI/UX designs and *lazy rectangles* (Krishna, 2015).

Though sometimes I have taken advantage of multiscreen settings for accomplishing complex processes that require auxiliary tasks—such as searching for words in my phone or uploading snapshots from my camera to the cloud—, the presence of my smartphone in a learning environment is counterproductive to complete such processes fully and most of the times is a distracting tool. As many studies suggest, *‘the mere presence of one’s own smartphone may occupy limited-capacity cognitive resources, thereby leaving fewer resources available for other tasks and undercutting cognitive performance.’* (Ward et al., 2017).

Blackout Dongle

This scenario encouraged the prototyping of a multidevice interactive filter driven by a fictional AV dongle: *Blackout Dongle*, the first prototype that inspired the research space of this thesis. This add-on filter disrupts the video signal of a computer workflow when the user’s attention shifts to their smartphone device.



Real interaction of the prototype. Video: vimeo.com/473164780

Praising concepts of efficiency in the workspace and optimization of multidevice screen-based behaviors, this portable video dongle connects between the HDMI connector of a standard monitor and the HDMI cable from the user’s workstation interfering with the video signal when the phone is in use. The system allows the user to better stream their attention to one digital platform at a time: as soon as the user flips the phone, the *Blackout Dongle* interfaces the video signal with a *blackout* effect that covers the angular area proportional to the phone’s orientation.

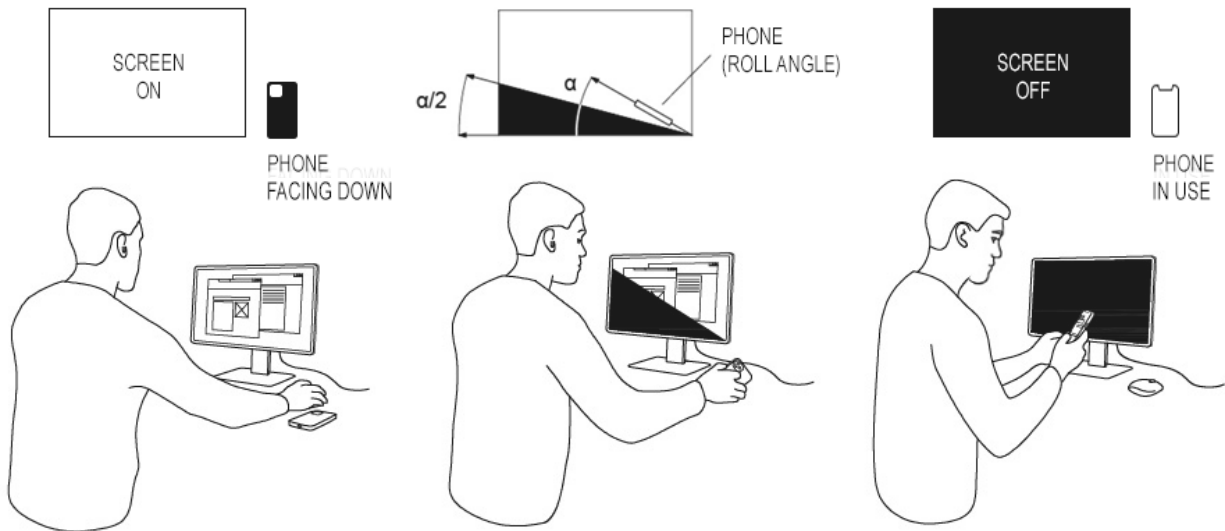
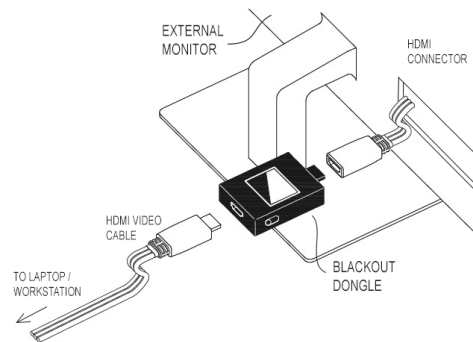


Diagram of the filter animation: screen activity, phone awareness, phone activity.

Designed in the context of online learning and remote working, this autobiographical artifact aims to solve my current inability to maintain longer interactions with one single platform while integrating new computational workflows into my existing computer setting. Despite the fact that the prototype only exists formally as a virtual 3D model, its conceptualization as an add-on dongle aspires to materialize a digital interference into the physical realm. The interaction has been prototyped using TouchDesigner²³ as the main interfacing framework and TouchOSC²⁴ to stream the accelerometer data from an Android phone.

First, I run a TouchDesigner file in the background to stream the screen of my laptop on an external monitor and apply the reactive blackout animation over this image. In this configuration, the phone sends in real-time the x-axis, y-axis, and z-axis accelerometer readings using OSC²⁵ protocol which then are assigned in TouchDesigner's *oscIn* component as 3 different variables. The data is smoothed using a low-pass filter (average) and it is used to compute the roll angle —arctangent of the z and x readings— of



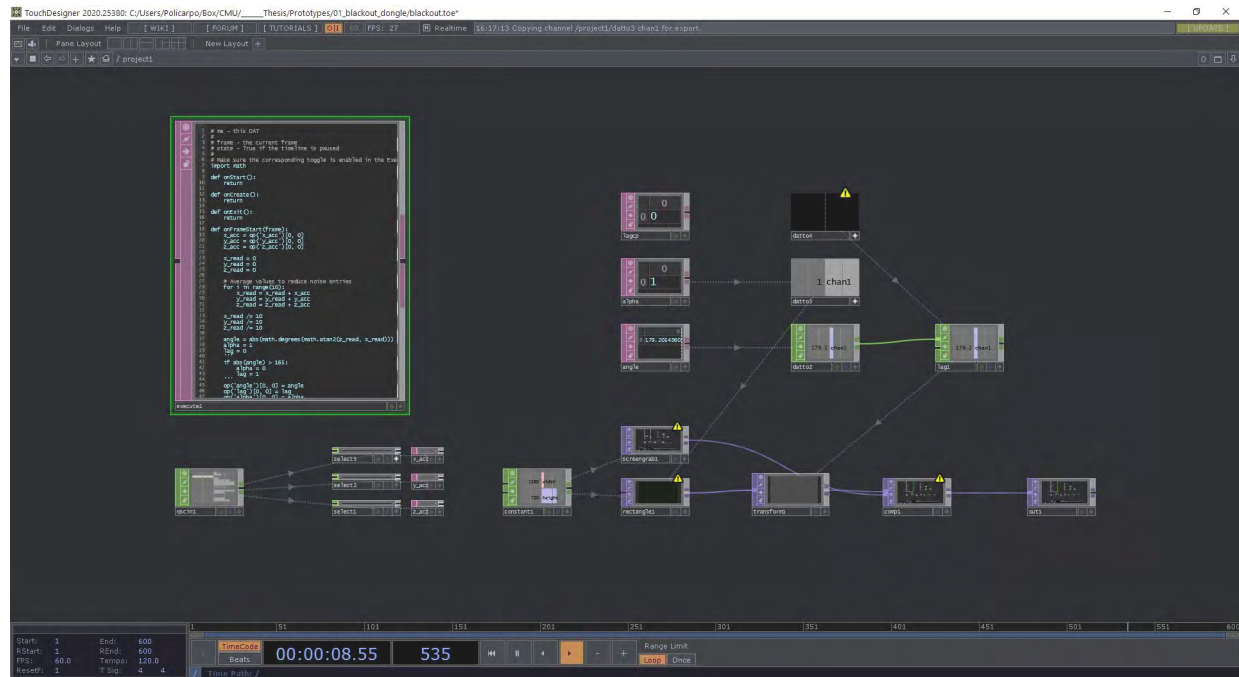
Connection schematic

23. TouchDesigner is a node-based visual creative software for real-time media streaming and interaction design developed by Derivative in Canada. It is especially useful for streaming video and audio content to external monitors, screens, and projectors allowing a wide range of input and output channels and communication protocols. It can run Python programming language in the background for more extended functionality: derivative.ca/

24. TouchOSC is a modular OSC and MIDI control surface app for iOS and Android systems. It allows real-time communication of the terminal's sensor data (orientation of the phone, touch screen input, etc): apps.apple.com/us/app/touchosc/id288120394

25. Open Sound Control (OSC) is a communication protocol for networked sound synthesizers, computers, and other multimedia devices released in 2002. It is used mainly in audiovisual industries for media processing among different programming languages and hardware devices. OSC messages consist of an address pattern, a type tag string, arguments, and an optional time tag. Its data type resolution makes it more preferable than MIDI messaging when available. TouchDesigner allows OSC protocol for input/output communication: opensoundcontrol.org/

the phone. The roll angle controls the rotation angle of a black rectangular shape that sweeps my laptop screen's image from the corner of the monitor. A lagging factor has been added to decelerate the animation when it gets closer to the end of the sequence. Finally, the processed image is streamed to the external monitor creating the effect of the user interacting with this device, yet having used the laptop at all times.



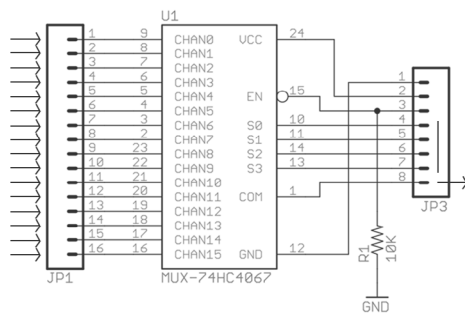
TouchDesigner interaction framework

After testing the prototype for some hours and determine which role could that play in the digitally-interfered space of my room, I noticed that my approach to understand and perform that space was purely functional and reductionist: the dongle only reorganizes and condenses the screen-based infrastructure of my room ignoring those tools and devices that do not count with a visual communication protocol. It appraises only a few cubic feet of my room in between myself and my working desk, and for that, I decided to expand the limits of my research to the entirety of the room.

3.2.2 I/O Ports, Buses and Addresses

Besides being a multi-dimensional interfaced space, analog continuous electrical signals, binary instructions, and digital means traverse frenetically through the walls of my room. To truly understand a volumetric —almost millimetric— 360 behavior in my room, I had to identify first the parts and functions performed in what now was no longer my room, but a spatial circuit board extended from my subconscious.

Similarly, to the conceptualization of the room as an electrical component, *multiplexer boards* control and divert input signals to their output ports. This electronic component functions as a combinational logic switch that allows some signals to flow and pass through to the output port while maintaining others on hold until the selector channel —an addressable set of inputs— indicates otherwise. The multiplexer board also can work as a *demultiplexer*, by diverting one input signal to the addressed channel²⁶. At this point, my room was already working as a multiplexer, filtering Hertzian-transferred meanings in the domestic electrosphere (Dunne,



Analog-digital multiplexer/demultiplexer board schematic

2008). This motivated the digitalization of the room into a virtual model addressing furniture, devices, and spatial features as input and output ports of a multiplexer board, connected via *buses*²⁷ to other ports, and encouraging a multi-layered understanding of the room as a digital-mediated assemblage. Following these guidelines, I modeled my room in Rhinoceros 6²⁸ in a manual fashion, highlighting the elements that seem to construct the twofold experience of living and working in the same space: those that trigger dynamic processes of cognition beyond my body and —in its extension— throughout the walls.

The room's final model has been updated on various occasions to accurately reflect specific spatial features for the following prototypes described in this thesis. This model has also been the angular file of this research: it provides the matrix to coordinate both virtual and physical copies of reality and the anxieties that span along with those two mediums.

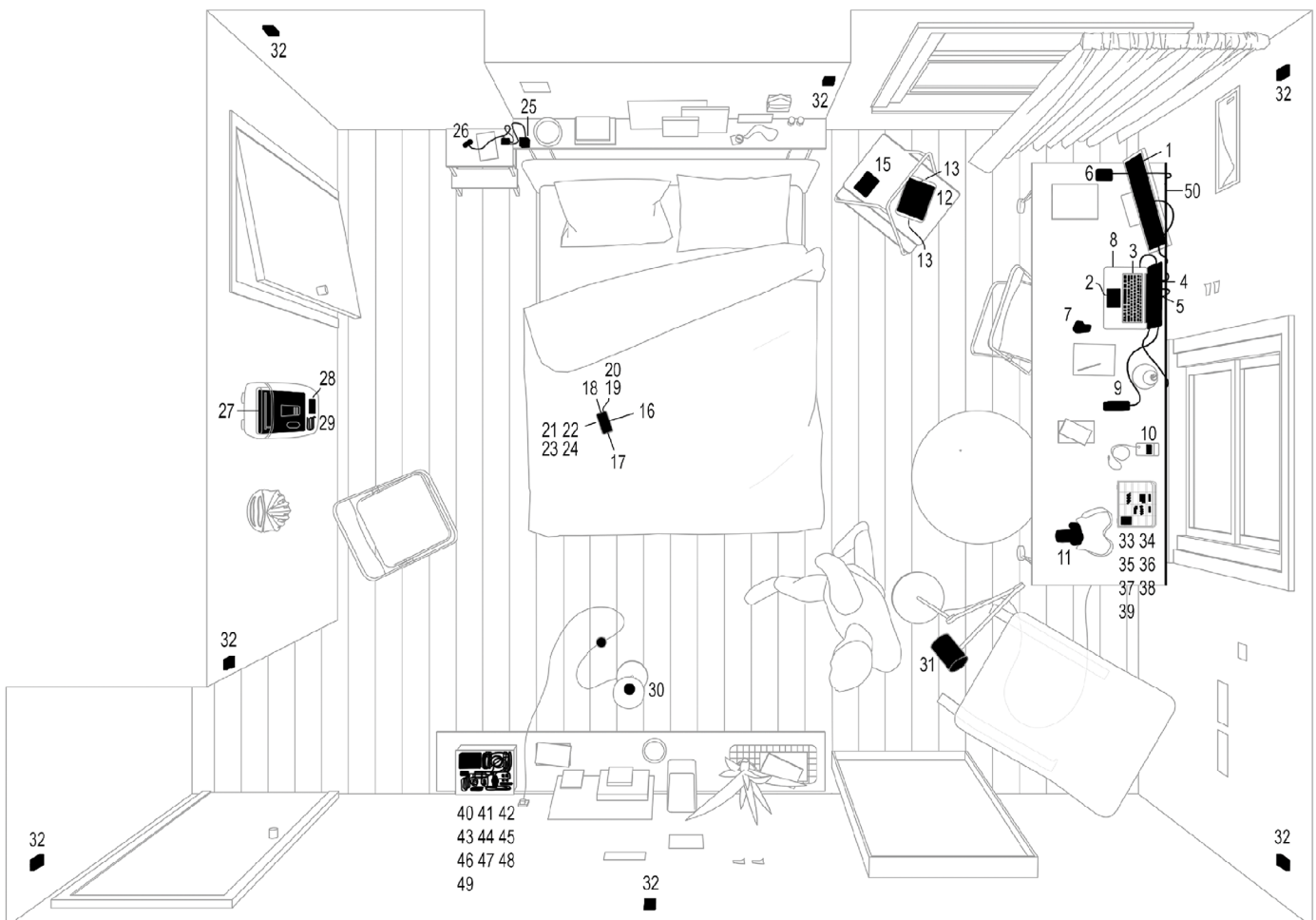
26. Source: [geeksforgeeks.org/multiplexers-in-digital-logic/](https://www.geeksforgeeks.org/multiplexers-in-digital-logic/)

27. A *bus* or *data highway* is a communication system that transfers data between components inside a computer or between computers. Source: [en.wikipedia.org/wiki/Bus_\(computing\)](https://en.wikipedia.org/wiki/Bus_(computing))

28. Rhinoceros is a commercial computer-aided design (CAD) software program developed by Robert McNeel & Associates widely used in product design, engineering, and architecture projects. Website: rhino3d.com/

- | | | | |
|--------|-------------------------------------|--------|------------------------------------|
| 01 O | 23-Inch HD LED Monitor | 26 I/O | Bluetooth Earphones / Built-in Mic |
| 02 I | 3-Inch Trackpad | 27 O | 16-Inch LED Monitor |
| 03 I | 104-Key Mechanical Keyboard | 28 I/O | 5.5-Inch Touch Screen |
| 04 O | 15.5-Inch LED Monitor | 29 T | 1m Lightning to USB-A Cable |
| 05 I | Mic / 2MP Built-in Camera | 30 I/O | 8W WiFi LED Lightbulb |
| 06 I/O | 1TB External Hard Drive HDD USB 3.0 | 31 I/O | 8W WiFi RGB LED Lightbulb |
| 07 I | 1000 dpi Bluetooth Mouse | 32 I/O | UWB Bluetooth Transceiver Module |
| 08 I/O | Built-in Stereo Speakers | 33 I/O | Arduino Nano ATmega328 |
| 09 I/O | Mic / 215W Bluetooth Stereo Speaker | 34 I/O | Raspberry Pi Zero W |
| 10 I/O | AC / DC Multimeter | 35 O | TFT Backlit LCD Screen |
| 11 I/O | 24.2MP APS-CMOS Digital Camera | 36 I | BNO080 IMU 9-Axis Sensor |
| 12 I/O | 10.9-Inch Touch Screen | 37 I | GY-61 3-Axis Accelerometer |
| 13 I/O | Mic / Built-in Stereo Speakers | 38 I/O | ESP32 WROOM Module |
| 14 I/O | 8MP Built-in Camera | 39 O | PiXie 4 MkII Control Board |
| 15 I/O | 6-Inch Touch Screen | 40 T | 1m USB-A to USB-C Cable |
| 16 I/O | 6-Inch Touch Screen | 41 T | 1m USB-A to USB Micro B Cable |
| 17 I | Microphone | 42 T | 1m USB-C to Lightning Cable |
| 18 O | Built-in Stereo Speakers | 43 T | 1m USB-C to USB-C Cable |
| 19 I | Infrared Camera / 12MP Camera | 44 T | 1m USB-A to USB-B Cable |
| 20 O | Infrared Light Projector | 45 T | 3m HDMI to HDMI Cable |
| 21 I | 12MP Camera | 46 T | 1m HDMI to HDMI Mini Cable |
| 22 I | 12MP Camera | 47 T | Display to HDMI Converter |
| 23 I | 12MP Camera | 48 O | 600 lumens HD Projector |
| 24 I/O | LIDAR 3-D Laser Scanner | 49 T | 2m Ethernet Cable |
| 25 I | 2MP Infrared Camera | 50 O | 16.4ft WiFi LED Strip Lights |

I Input Port
 O Output Port
 I/O Input and Output Device
 T Transmission Device



Input and Output ports of the *Multiplexer Room* (2020)

3.3 Cardinal Affordances

The space outlined under the *multiplexer* room perspective —host of 360-degree behaviors and obsessions— was starting to reveal more than a collection of 2-dimensional screens and strategic input and output devices placed to optimize my remote working experience. The shape of the room, its dimensions, proportion, placing in respect to the rest of the house, but also, its geographic location and cardinal orientation could be acknowledged as suitable *affordances* (Gibson, 1979) to interface the digital processes and tasks performed during a day. As William Gaver points out, affordances appear distributed along with space as sensory cues helping our cognitive system to allow a better exploration of the environment. While some of these are visually perceived —those mainly explored by Gibson’s ecological approach—, others are hidden from our eye thus have to be inferred from other evidence (Gaver, 1991). This search for new spatial features that can leverage the *extended mind* model made me think of the orientation of an object in regards to the earth’s geomagnetic fields to interface my room and achieve a more embodied use of technology independent from sight and touch screen interactions.

3.3.1 Cardinal cognition

During my high school years, I actively enrolled in my hometown’s *orienteering* club in Leon —a northern city in the Iberic peninsula. *Orienteering* is a sport practice in which the participant —known as *orienteer*— has to run across rough country areas —sometimes urban settings— finding various control points in a planned order with the aid of a compass and a map containing geographical features of the area —such as the form of vegetation or grade of the ground. The runner who scores the lowest elapsed time wins the race. Physical endurance is essential to achieve a good time. Still, a good sense of spatial orientation in the landscape —with no GPS tracking smartphone built-in app allowed in the competition— and strategic planning —to efficiently approach each checkpoint in the designated order— were equally important to score over other orienteers. In the race, inferring connections between the spatial features of the surroundings and the cardinal directions of the compass rose —the qualitative directions of our globe: north, south, east, west, and the intermediate ones, northeast, northwest, southeast, and southwest— was key to success. The use of the compass as a sensory augmentation device—along with the map— encouraged an extended spatial cognition of the environment.



Orienteering map, compass, and contactless digital control card (on the finger)

At the end of each race, I always was surprised by something unexpected: the memory of the race was subjected to the cardinal direction I was heading. Different landscape features, obstacles, and moods were associated with my orientation at that precise moment: I could retrieve information from the race as if each memory was cardinal-indexed in my brain. Thinking about east sometimes felt optimistic as the race was unfolding in that direction; the north reminded of how I ascend a stony slope with the midday sun in my back —Leon’s mountains show all their south side to the region—; south-thinking brought back a relieved and cheering message of reaching the finish line. The compass’s use during a time-extensive and spatio-discursive experience constructed a mnemonic device for recalling context-dependent details and mental imagery from a previous event: a species of memory palace²⁹ where the compass rose replaced the loci.

‘Context-dependent memory refers to improved recall of specific episodes of information when contextual cues relating to the environment are the same during encoding and retrieval.’

(Godden & Baddeley, 1980)

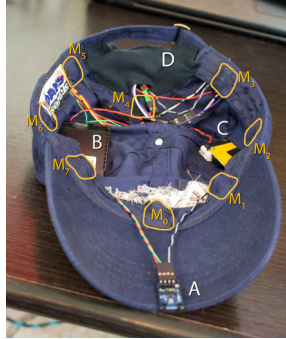
The use of cardinal sensory augmentation devices is not new to any society in the world: geographical charts, sea navigation, military assistance, urban planning, architectural design, or geomancy arts have made broad use of the cardinal affordances of space throughout history. More recently, haptic-enhanced direction sensing embedded in a wearable belt³⁰,

29. The *Method of loci* or *memory palace* is a strategy of memory enhancement that uses visualizations of familiar spatial environments to enhance the recall of information. As John O’Keefe and Lynn Nadel describe, ‘In this technique, the subject memorizes the layout of some building, or the arrangement of shops on a street, or any geographical entity which is composed of a number of discrete loci. When desiring to remember a set of items, the subject “walks” through these loci in their imagination and commits an item to each one by forming an image between the item and any feature of that locus. Retrieval of items is achieved by walking through the loci, allowing the latter to activate the desired items.’ (O’Keefe et al., 1978).

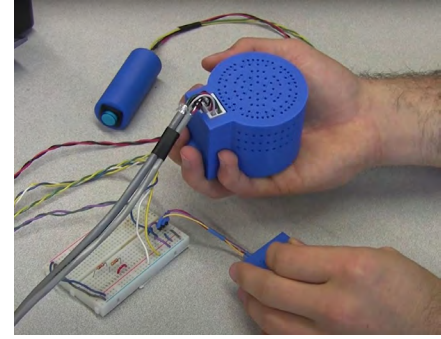
a motorized cap,³¹ or a redesigned compass³² show a steady interest from speculative design communities in bestowing sixth senses to our inborn bodies (Bains, 2007).



Caleb Kraft. *The Haptic Compass Belt* (2009)



Paul Ganssle. *The HaptiCapMag* (2015)



Lynette A. Jones. *A Haptic Compass for Navigation* (2017)

Cognitive science studies also show that this type of cardinal augmentation could provide rapid and long-lasting effects on human perception and orientation within the physical environment. The hearSpace app developed in the Laboratoire Psychologie de la Perception at Université Paris Descartes is a novel iOS-based application that measures head orientation to North via headphone integrated sensors (compass, gyro, and accelerometer) and transforms their output into a spatial sound situated in the direction of magnetic North (Schumann et al., 2017). The results of their experiment with a group of 23 participants showed a truly perceptual impact on how this wearable sensory augmentation artifact improved their vestibular calibration³³ for spatial orientation.

30. Caleb Kraft. *The Haptic Compass Belt* (2009): gradman.com/projects/haptic_compass/

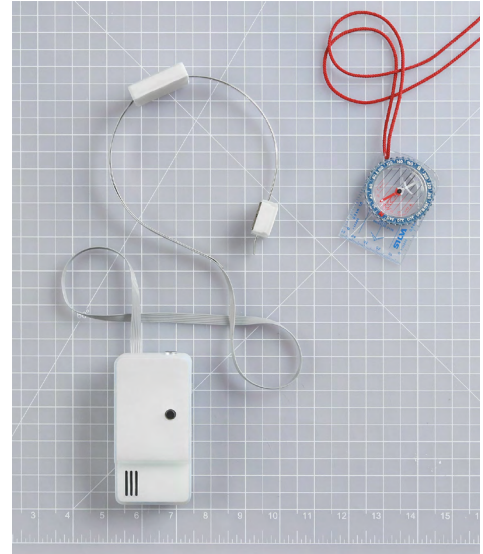
31. Paul Ganssle. *The HaptiCapMag* (2015): pganssle.github.io/HaptiCap/

32. Lynette A. Jones. *A Haptic Compass for Navigation* (2017): computer.org/csdl/magazine/co/2017/06/mco2017060006/13rRUxBrGbg

33. The vestibular system is a sensory system —mostly found in the inner ear— that is responsible for providing our brain with information about motion, head position, and spatial orientation; it also is involved with motor functions that allow us to keep our balance, stabilize our head and body during movement, and maintain posture. (Khan et al., 2013). Vestibular calibration is the process by which the vestibular organs help our cognitive system to orient ourselves within a spatial setting.

3.3.2 The *Cardinal Recorder*

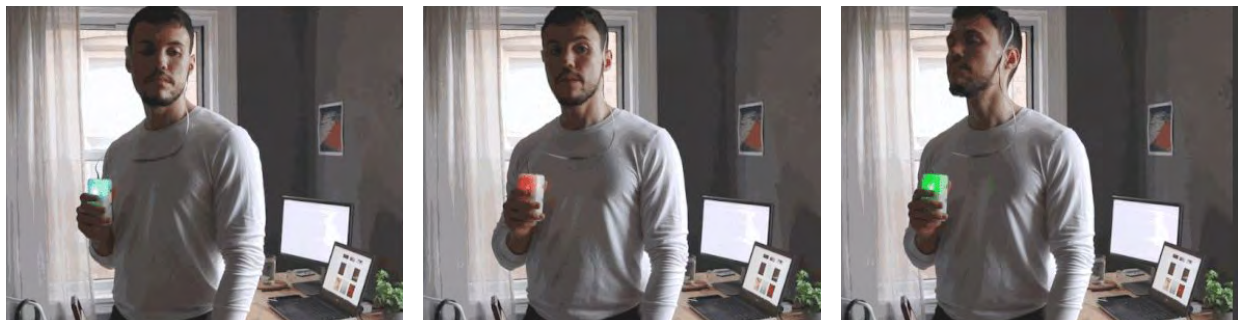
Beguiled by the speculative use of cardinal orientation as a mnemonic device, persuaded by its potential to formlessly interface the multiplexer room, and intrigued by plausible new immersive and experiential values of this spatial affordance, I decided to prototype a sensory augmentation device that could interface the cardinal space of my room with an audio-memory archive: *Cardinal Recorder* is a geomagnetic-aware Arduino-based portable recorder that can index voice memos into one of the four cardinal directions and their intermediate ones: N, NW, W, SW, S, SE, E, and NE.



Cardinal Recorder prototype

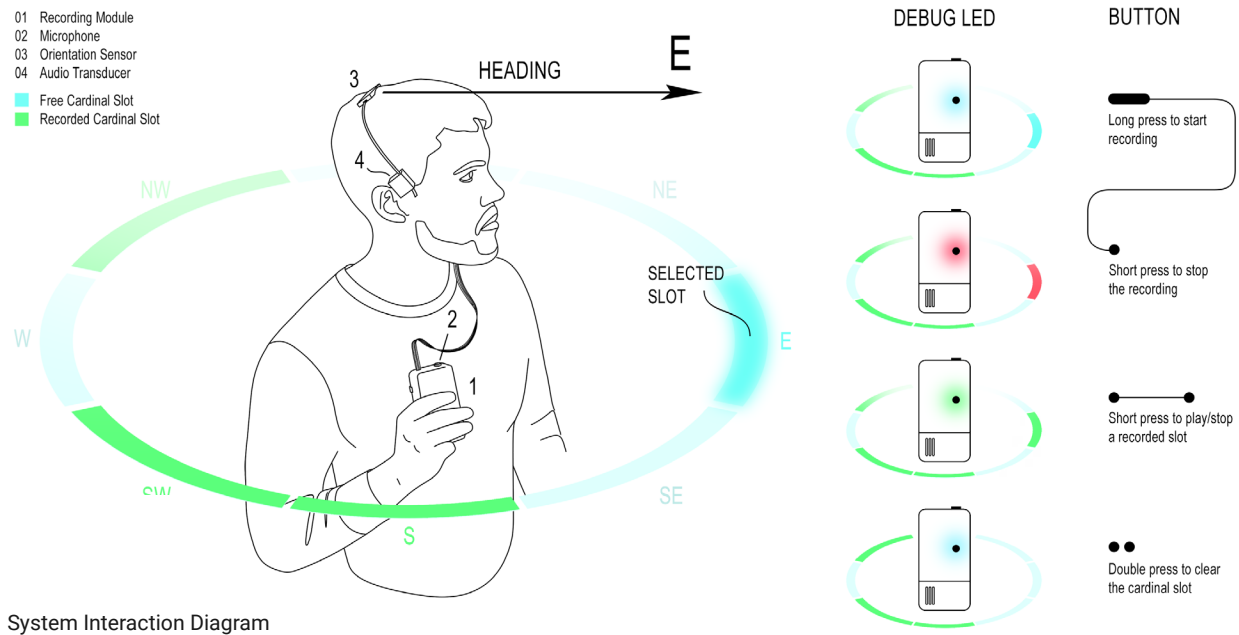
System Design

The *Cardinal Recorder* is a wearable sensing device comprised of two parts: a main recording module with audio-processing power and a built-in microphone; and a wired headband with a magnetometer sensor and a bone conductor audio transducer for ear-free playback. Once the wearer mounts the headband and turns on the device, the system enters the *searching mode*. The orientation sensor perpetually detects and streams the cardinal orientation of the user's heading to the main module. For every cardinal direction, there is one *cardinal slot* that can store one single recording of up to 1-minute duration. A debug LED mounted in the handheld module indicates the state of the cardinal slot: if the light is blue-white, the slot is free, and the user can store a voice memo; if the slot is green, the slot already contains a voice memo, and the user can decide to play it back, overwrite it, or erase it.



System modes (from left to right): *Searching mode*, *Recording mode*, and *Playback mode*

A long press of the button when heading to a free cardinal slot initiates the recording mode in their heading; a short press at any time stops the recording. After that, a short press when heading to a recorded cardinal slot starts the *playback mode* of the voice memo stored in that direction; a second short press stops the playback. To overwrite a recorded slot, the user only needs to enter in recording mode with a long press. If they only want to clear it out, a double press erases the recording and restores the cardinal slot.



A long press of the button located in the main module when heading to a free cardinal slot initiates the *recording mode* in their heading; a short press at any time stops the recording. After that, a short press when heading to a recorded cardinal slot starts the *playback mode* of the voice memo stored in that direction; a second short press stops the playback. To overwrite a recorded slot, the user only needs to enter in recording mode with a long press. If they only want to clear it out, a double press erases the recording and restores the cardinal slot.

The first iteration of the prototype only allowed to store voice notes in the four main cardinal directions. After a short evaluation, I realized that it was easy enough to identify the intermediate ones in my room's space, so I allowed the system to store up to 8 voice memos. The length of these voice notes changed during the design process. At first, the user could decide to stop the recording at any given time. That was not only troubled for implementation purposes —the Arduino core cannot handle such long computing processes— but also went against the main interest of this speculative design research: linking simple thoughts through voice memos to different spatial settings. In the next iteration, I limited the recording duration to one minute.

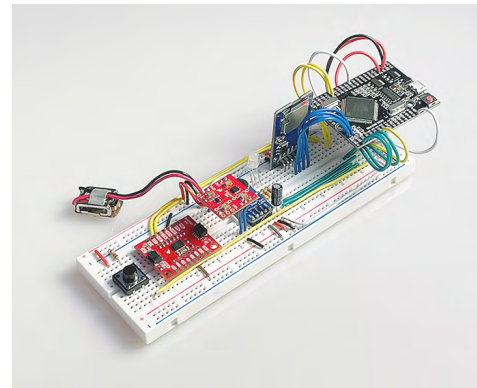
Implementation

The recorder uses an Arduino MEGA 2560 PRO Embed board as the system's main computing module. This board is based on the ATmega2560 microcontroller and the USB-UART adapter CH340 in a compact 38x55 mm factor. Their functions are identical to other Arduino Mega 2560 boards, but its size was preferred to develop a compact device³⁴.

The cardinal orientation sensing is performed by the Bosch-manufactured BNO080 IMU (Inertial Measurement Unit), a triple-axis accelerometer, gyroscope, and magnetometer with a 32-bit ARM Cortex M0+ that processes the absolute Euler angle and geomagnetic orientation on-board saving the Arduino board processing time and ensuring a faster communication rate of 400 kHz. The sensor is connected to the MEGA board using the I2C protocol³⁵ through a Qwiic cable—a 4-pin JST connector to quickly interface development boards with sensors developed by SparkFun.

The audio is recorded using a microphone amplifier MAX9814 with built-in automatic gain control that quiets nearby loud sounds—so they do not clip the audio file—and amplifies far-away quiet sounds. The audio output is then pass through a SparkFun mono preamp board based on the Texas Instruments TPA2005D1 chip. This amplifies the sample up to 1.4 Watts before it is sent to the audio transducer module in the headband. The bone conductor audio transducer that lies against the skull bone vibrates, transmitting the voice memo directly to the internal cochlea skipping the eardrum, allowing ambient sounds to be heard even when playing one cardinal recorded memo.

The recording framework is completed with a microSD card adapter connected to the board using the SPI protocol³⁶ for writing and reading each of the audio files. A push-button and an RGB LED light have been added to switch and identify the different program modes.

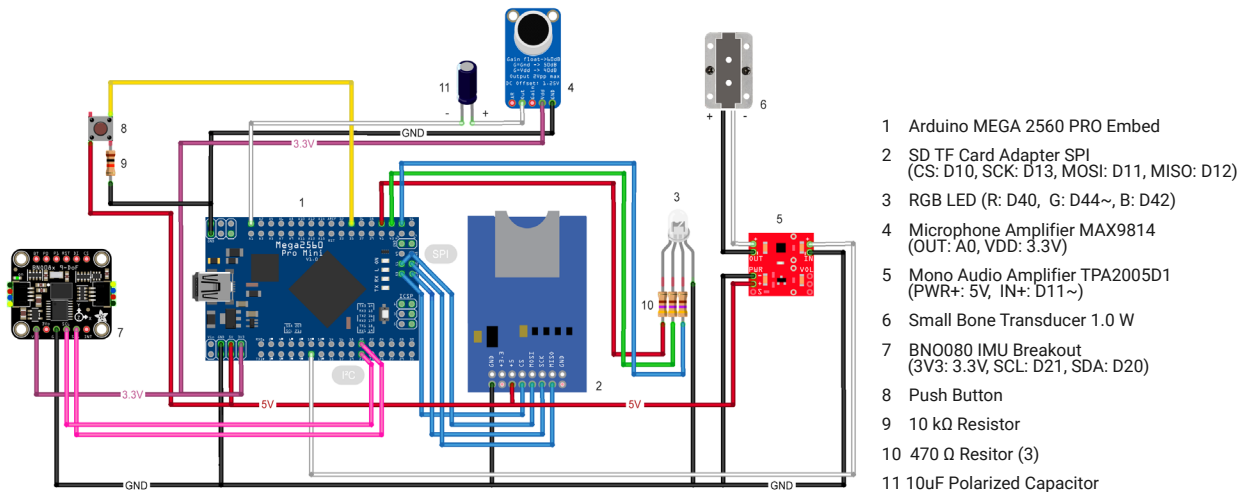


First working prototype developed as part of the HCI course 05-833 *Gadgets and Sensors for Activity Recognition* taught by Scott Hudson

34. During the development phase, I tried to use an Arduino NANO board with the ATmega328, but it lacked enough SRAM (2 KB) to store all code dependencies and the main program. Since I was using off-the-shelf libraries built for the Arduino family, I withdrew using more powerful chips—such as Espressif ESP32—and the Arduino MEGA 2560 with 8 KB of SRAM was the only choice available.

35. I2C (Inter-Integrated Circuit) is a synchronous, multi-master, multi-slave, packet-switched, single-ended, serial communication bus used as a communication protocol between sensors, processors, and microcontrollers in short-distance. It works breaking a data message in different data frames led by an address frame. The I2C protocol uses two communication lines: SDA or Serial data—sends and receives data—and SCL or Serial Clock—carries the clock signal. Source: [en.wikipedia.org/wiki/I²C](https://en.wikipedia.org/wiki/I%C2%B2C)

36. SPI (Serial Peripheral Interface) is a synchronous serial communication interface specification used for short-distance communication in embedded systems. The SPI protocol uses a four-line serial bus for communication: SCLK or Serial Clock (output from master), MOSI or Master Out Slave In (data output from master), MISO or Master In Slave Out (data output from slave), and SS or Slave Select (output from master). Source: en.wikipedia.org/wiki/Serial_Peripheral_Interface

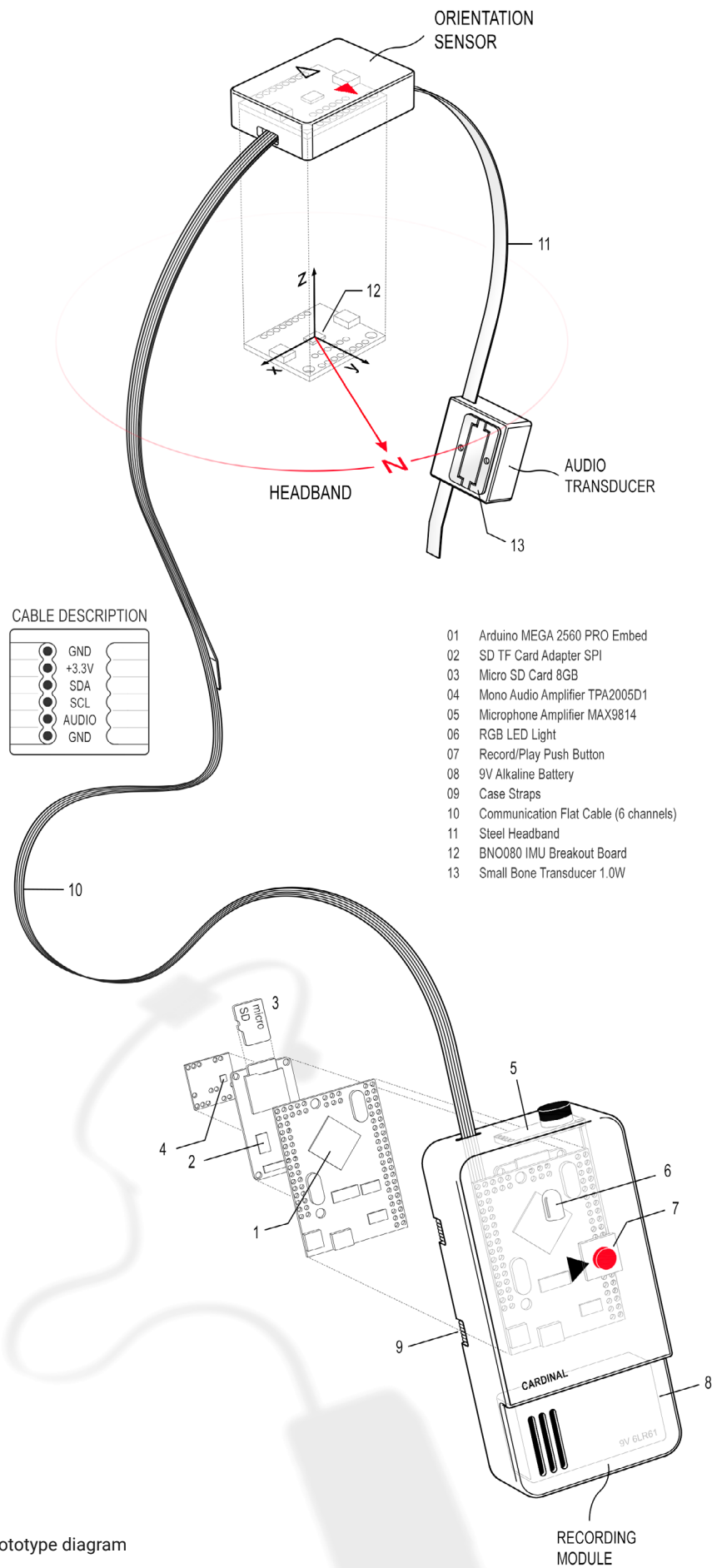


Schematic diagram of the *Cardinal Recorder*

Fabrication

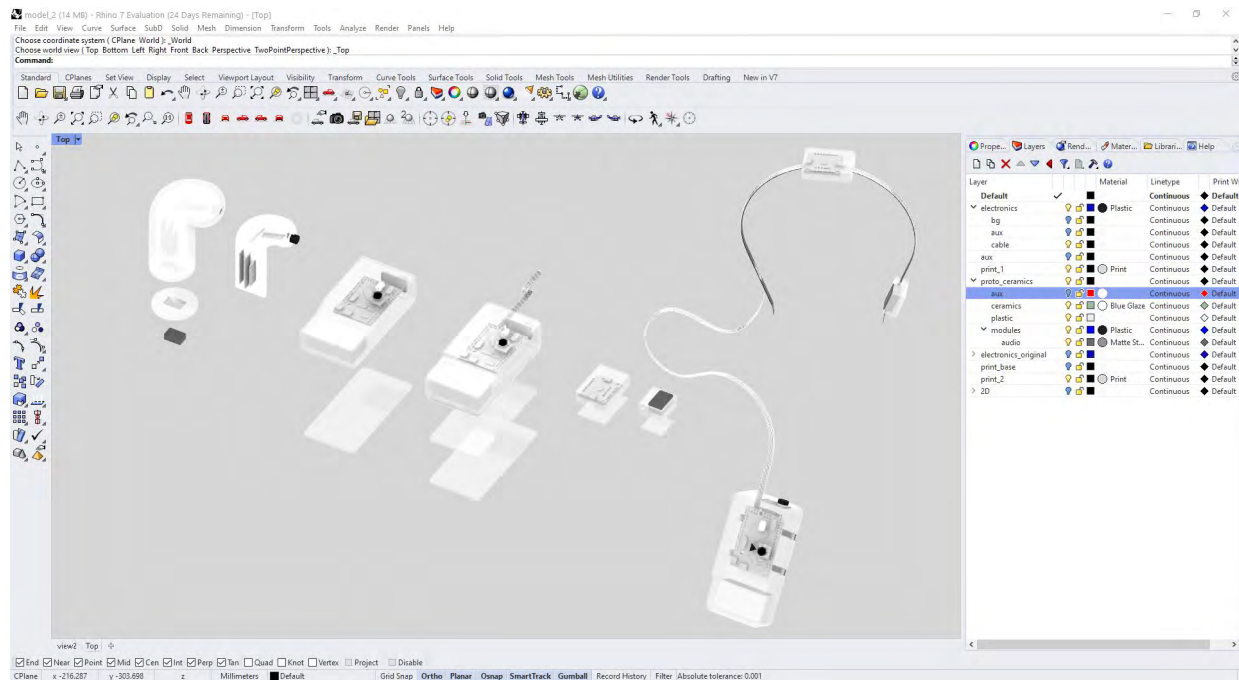
The first design iteration of the *Cardinal Recorder* encapsulated all components in a single volume that could be single-handed-used following traditional audio recorders' form factor. The audio transducer component was also present from the beginning of the design to offer a more intimate and close playback experience of the cardinal-indexed voice memos. This feature encouraged a two-sided case that could incorporate a microphone in one end and the bone conductor in the other. In this design, the device was planned to be used in a traditional fashion for recording memos but should be held tight against the forehead—or any bony area next to the ear—so the soundwaves could travel to the cochlea.

There was an initial desire for creating an object that could provoke the expectation and intrigue of future users: a kind of secretive artifact able to store memories in an unmaterial dimension of our space. Thus, the design acquired an unfamiliar and unexpected form factor—from what one could understand as a traditional recorder—and I decided to smooth the case's edges towards a more organic and ergonomic shape. In the midst of this process, I noticed that encasing all components in one single module could place too much relevance in material features of the object itself while the true intentions of the project were in the speculative character of creating a spatio-mediated assemblage. Though some tactility grade was essential, I opted for divorcing the main parts of the device into two modules: a sensing wearable headband and a hand-held recording module connected through a flat 6-channels communication cable. This also seconded a more embodied perception of the cardinal-indexed memories just with my head's movement since both playback and orientation sensing features were built in the headband.



Cardinal Recorder prototype diagram

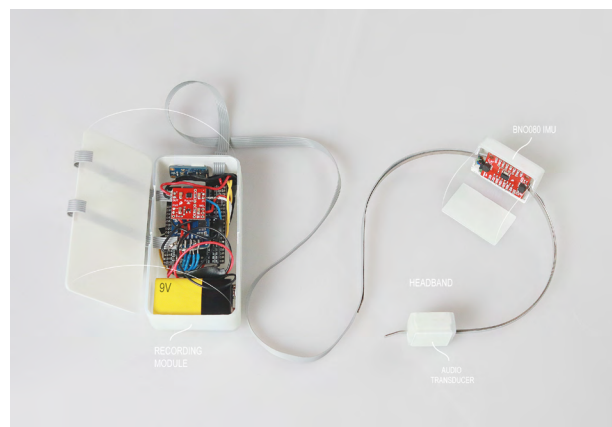
The final prototype —inspired by Dieter Rams’ industrial curves and functionalists surfaces—³⁷ was printed in clear resin using a FormLabs Form 2 —an SLA (laser stereolithography) printer that uses UV light to solidify the liquid resin layer by layer. After curating and sanding, I coated the inner side of the case with a thin layer of white primer spray paint, so it looked translucent enough to perceive the light of the inner debug LED, yet opaque in brighter settings.



Cardinal Recorder design iteration



Clear resin 3d printed prototype



Electrical components of the recorder

37. Dieter Rams (1932-) is a german industrial designer notably responsible for Braun's 60s to 90s designs, founder of the furniture design company VITSOE, and theorist of the ten principles of *Good Design* —*Good design* is innovative, aesthetic, makes a product useful, understandable, is unobtrusive, honest, long-lasting, thorough down to the last detail, environmentally friendly, and it is as *little design* as possible. Source: vitsoe.com/us/about/dieter-rams

Code

One of the project's main challenges was to build an audio recording device on a board from the Arduino family. Their processor —yet powerful for simple computations— is not really prepared to handle input and output audio signals. However, I was lucky to find the library `TMRpcm Audio`³⁸ developed by the Github user `TMRh20` that contains several functions for asynchronous playback and recording of PCM/WAV 8-bit files direct from/to SD card, making use of the internal timers of the processor. The library's Github community was also kind enough to solve some of my questions before its final implementation in my program. For communication purposes with the rest of the components of the device, I installed the Arduino official libraries `SD`, `SPI`, and `Wire`, as well as the off-the-shelf library for the `BNO080 IMU sensor`,³⁹ which retrieved the absolute roll, yaw, and pitch angles of the sensor to obtain the absolute magnetic cardinal orientation.

In addition, the main program used the library `RBD Light`⁴⁰ for light fading and blinking effects of a PWM-connected LED light, and `ButtonFever`,⁴¹ a button manager library that handled the single, double, and long-press events of the button of my recorder.

The code is structured in the following way:

1. Assignment of pin values and allocation of constants and arrays for file names and program variables.
2. Setup of all the components —RGB LED, serial communication, audio speaker and microphone, SD card, and IMU sensor— with intermediate LED indications and serial print messages for debugging purposes.
3. Initialization of four modes and their functions: *magnetoMode* (searching), *recordMode* (recording), *playMode* (playing), and *eraseMode* (erasing).
 - `searching()`: reads the cardinal direction of the sensor and triggers a green or white light depending on the state of the cardinal slot in that direction: white is empty; green is full.
 - `recording()`: triggers a red LED light confirmation at the beginning of the sequence, initiates the recording, and waits for a button event to stop it.
 - `playing()`: plays the audio file in the selected cardinal slot.
 - `erasing()`: removes the file from the SD card in the selected cardinal slot.

38. Github repository of the `TMRpcm Audio` library: github.com/TMRh20/TMRpcm

39. Github repository of the SparkFun `BNO080 IMU` library: github.com/sparkfun/SparkFun_BNO080_Arduino_Library

40. Github repository of the `RBD Light` library: robotsbigdata.com/docs-arduino-light.html

41. Github repository of the `ButtonFever` library: github.com/mickey9801/ButtonFever

4. Auxiliar functions.

- `readOrientation()`: requests the sensor's yaw angle and performs a series of operations to obtain the horizontal projection angle of the heading vector. The function classifies this angle in one of the 8 cardinal slots and assigns this value to the global variable *orientation*.
- `lightW()`: RGB LED calibration for white light.
- `lightBlink()`: RGB LED debugger blinking.

Testing and limitations

During the testing of the recorder in my room, I scoped a series of problems of the cardinal recording spatio-mediated system:

- In the final prototype, the recording module had to be continuously hand-held to interact with the voice memos, which prevented a full-body exploration of the multiplexer space.
- The light interface of the prototype forced me to look to the recording module to identify the state of the cardinal slot towards I was heading. This felt unnatural and diverted my attention to the visualization of the directional-visual setting unfolded in front of me.
- The button interface felt outdated to more sophisticated tactile interfaces existing in the present—pressure detection, grasp sensing, etc.— and did not respond quickly enough to the pace of my interactions.
- The system functioned in an always-on fashion with no on/off switch since it was designed to be always ready to use in my room. This set a fast battery draining.

Some of these problems highlight issues normally confronted in a prototyping stage — undeveloped UI transitions, inadequate form factor, unconsidered interaction behaviors, etc. A more careful and extensive testing phase with more users involved would be essential to improve the design and reveal the spatio-cardinal affordances of a domestic environment. However, here I outline some of the limitations and propose some recommendations for future design iterations:

- To upgrade the audio processing features of the system —better audio quality and transition effects—improve the unit's efficiency, allow a more seamless UI, and program the system in a broader selection of libraries, it is recommended to prototype the *Cardinal Recorder* using a Raspberry Pi board.
- A custom PCB —integrating all electrical components wirelessly— would optimize the device's form factor and facilitate the design of a more embodied wearable recorder.
- A hands-free system with all components encased in a headband would encourage a deeper

immersion into the multiplexer room's memory landscape. This also will alleviate the problems confronted with the button and light interface and open a new research area: design and implement a head-motion-aware device. This new design could leverage the IMU sensor's use, e.g., to detect a head-nodding to record over an empty cardinal slot or play an existing voice memo. An embedded vibration motor could easily substitute the light indicator as a non-visual non-audible cue for identifying which cardinal slots are empty and which of them are full.

3.4 The Sonic Dimension

3.4.1 The Sonic Landscape

A soundscape is the humanly-perceived acoustic environment formed by a combination of natural and artificial immersive sounds that unfold in any inhabited space. Though their study as an ecological science has been more recently characterized by Canadian composer and environmentalist R. Murray Schafer during the 70s and 80s, soundscapes have been coetaneous to all societies along with history across the different scales of untamed and manufactured nature and architecture spaces. However, Schafer points out an important contemporary phenomenon for the acknowledgment of the sonic environment as a site of research and study: *‘Since the invention of electroacoustical equipment for transmission and storage of sound [...] We have split the sound from the maker of the sound. Sounds have been torn from their natural sockets and given an amplified and independent existence’* (Schafer, 1993). Or what he defines as *schizophonia*:

‘Schizophonia refers to the split between an original sound and its electroacoustic transmission or reproduction.’ (Schafer, 1993)

While this phenomenon is responsible for the current anarchism of sonic waves traversing our urban and natural landscape —entailing numerous of our disorders and anxieties we suffer in the digitally-mediated environment— it also yields *‘an opportunity for space to unfold’* since *‘listening to unseen sound and disregard its source [...] creates a relatable and yet unreal situation’* (Pinheiros et al., 2019). Sound —the same as wood, plasterboard, or paint— is a cognitive material, and by layering customized sound samples and effects that do not necessarily derive from the physical properties of their hosting space, we can modify the perception of such space, thus revealing new spatial affordances and building a new interaction vocabulary in that medium.

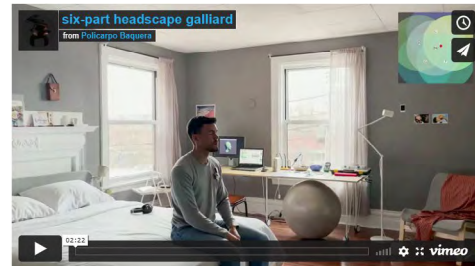
The spatio-mediated augmentation of the *Cardinal Recorder* prototype focused on filling the space with singular words through different directional interactions. This system composed a heterogeneous landscape where I could add and retrieve as much as one audio *figure*⁴² per cardinal direction. If we understand sound as an architectural material, this experiential construction would be ungrounded, unfounded, and those individual audio notes would be floating meanings in the *multiplexer*. The audio architecture of the room was fragmented. As Juhani Pallasmaa points out in his *Architecture of the Senses*, architecture effectively constructs and intersects our senses

42. Schafer's soundscape is defined following the visual principles of Gestalt theory. Accordingly, he defines a soundscape *background* as the ambient noises that compose the ground of a scene; the *figures* of this soundscape are all sound signals and significant frequencies that are detached from the background ambient sounds (Schafer, 1993).

as a surrounding experiential machine where ‘*atmospheric characteristics of spaces, places, and settings are grasped before any conscious observation of details is made*’ (Pallasmaa, 1996). This set my goal for the next prototype of this research: thicken these sound slots into ground surfaces that able to the multiplexer’s sonic dimension ahead of its visual cognition.

3.4.2 Six-Part Galliard

Following the auditory principles introduced by Cardiff’s *Forty Part Motet* —see section 2.2 of this thesis— this experiment examines one’s cognitive and emotional response to navigating across an orientation-aware interactive soundscape relocated from an open and public exhibition space to an enclosed domestic setting. *Six-Part Galliard* is a spatio-mediated audio installation that leverages a head-mounted wireless device’s orientation sensing capabilities to synthesize a room-specific six-voice polyphonic soundscape in my room.



Six-Part Galliard (2020).
Video: vimeo.com/488829515

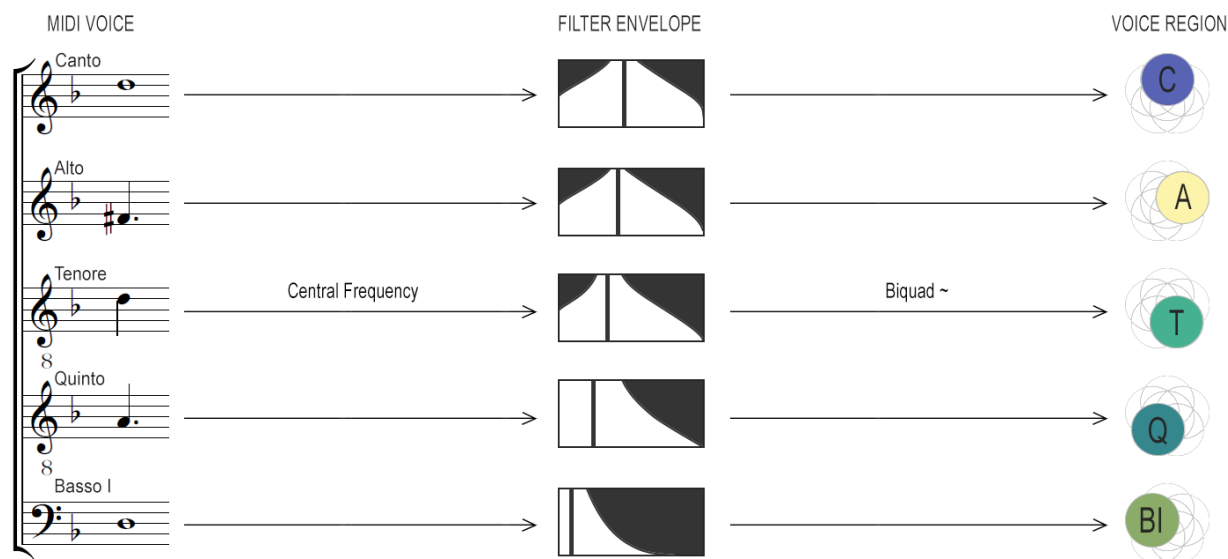
Soundscape Composition

The Earl of Essex Galliard is a late 16th-century renaissance dance composed by John Dowland, originally written as a soloist and lute song under the title of *Can She Excuse My Wrongs*. Following renaissance fashion, Dowland later adapted the piece in a five-voice polyphonic style arranged by a *canto*, *alto*, *tenore*, *quinto*, and *basso* interweaving melodic lines. In *Six-Part Galliard*, I used MaxMSP⁴³ to parse the melodic structure of each of these five voices plus a sixth one called basso II —duplicated from the basso I voice and transposed an octave below the original— as a MIDI sequence⁴⁴ of pitch and velocity triggers to synthesize six new voice regions.

See *The Earl of Essex Galliard* interpreted by The Royal Wind Music recorder ensemble. Lingen, Germany (2011): youtube.com/watch?v=WXkRgUvY6PM

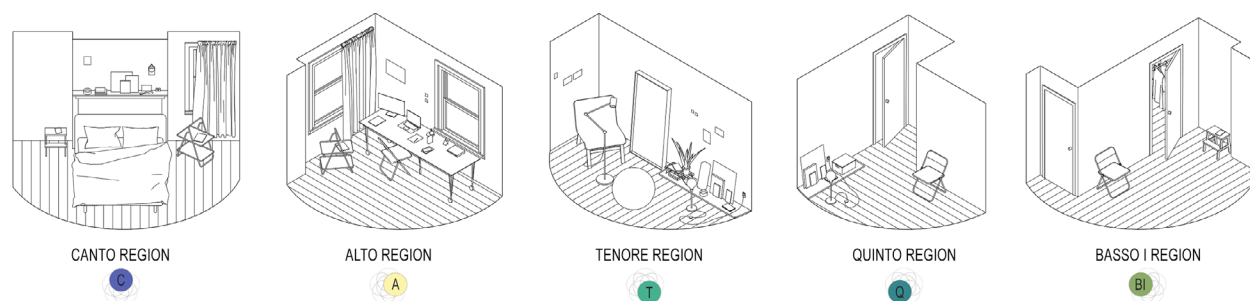
43. Max —also known as Max MSP Jitter— is a commercial creative software language for music and multimedia creation currently developed and maintained by Cycling '74. Max is an evolution of the graphical interface *The Patcher* created by Miller Puckette in 1985 for real-time synthesis of computer-generated music scores. Source: cycling74.com/products/max

44. MIDI —an acronym for Musical Instrument Digital Interface Sequence— is a standard protocol for communication among electrical devices and digital software widely used to interface musical instruments with computers. It allows real-time reading, transmission, and playing of music scores via data messages composed of synchronous notation, pitch, velocity, vibrato, panning, and tempo values for various voices. Source: en.wikipedia.org/wiki/MIDI



Voice filtering and distribution in each of the voice regions

The frequency of each melodic line controls the biquadratic filter⁴⁵ envelope's central frequency applied to a random noise generator for each of the six voices. The noise base files have been compiled from different prerecorded libraries of outdoor scenes and industrial sounds (such as an engine room, a railway station, the sound of track sleepers, an overnight train cabin ambient sound) to add a natural texture and unpredictability to the output mix. The six resultant noise regions are self-crossfaded and looped infinitely to generate a continuous soundscape. The interactive system described in the next section controls the final gain of each of these channels and determines the experienced output audio mix.



The five voice regions of my room

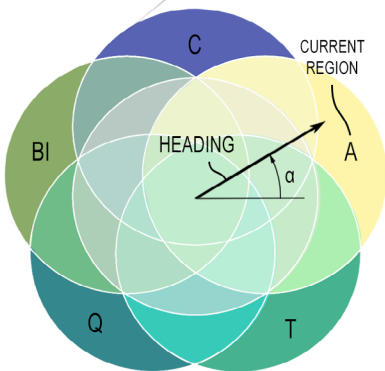
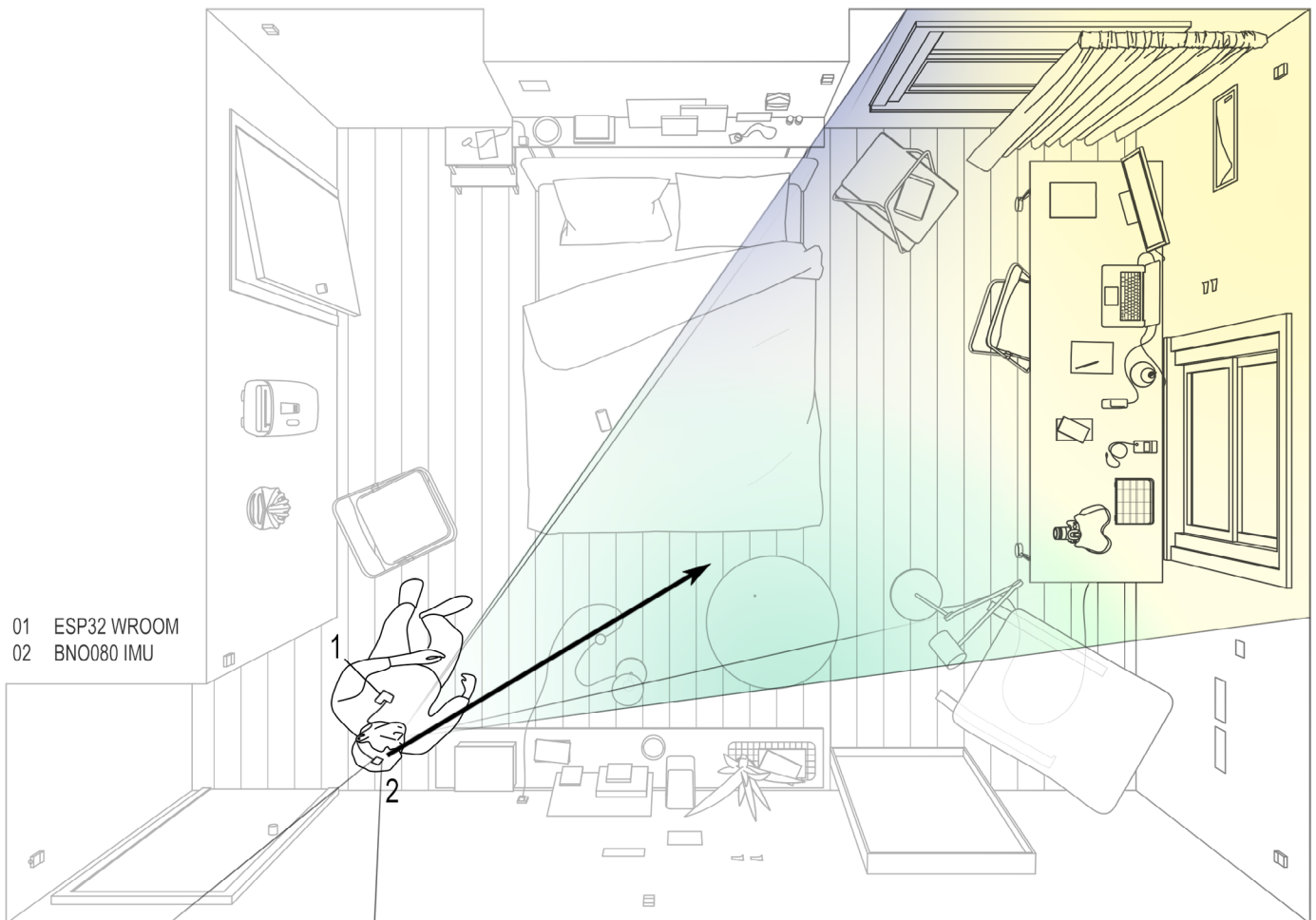
System Design

The six noise regions of the new *galliard* are placed in a 2-dimensional polar soundscape overlaid to the 3-dimensional space of the *multiplexer* room. The five leading voices are oriented towards the most significant scenes/furniture configurations in the room —the bed and the

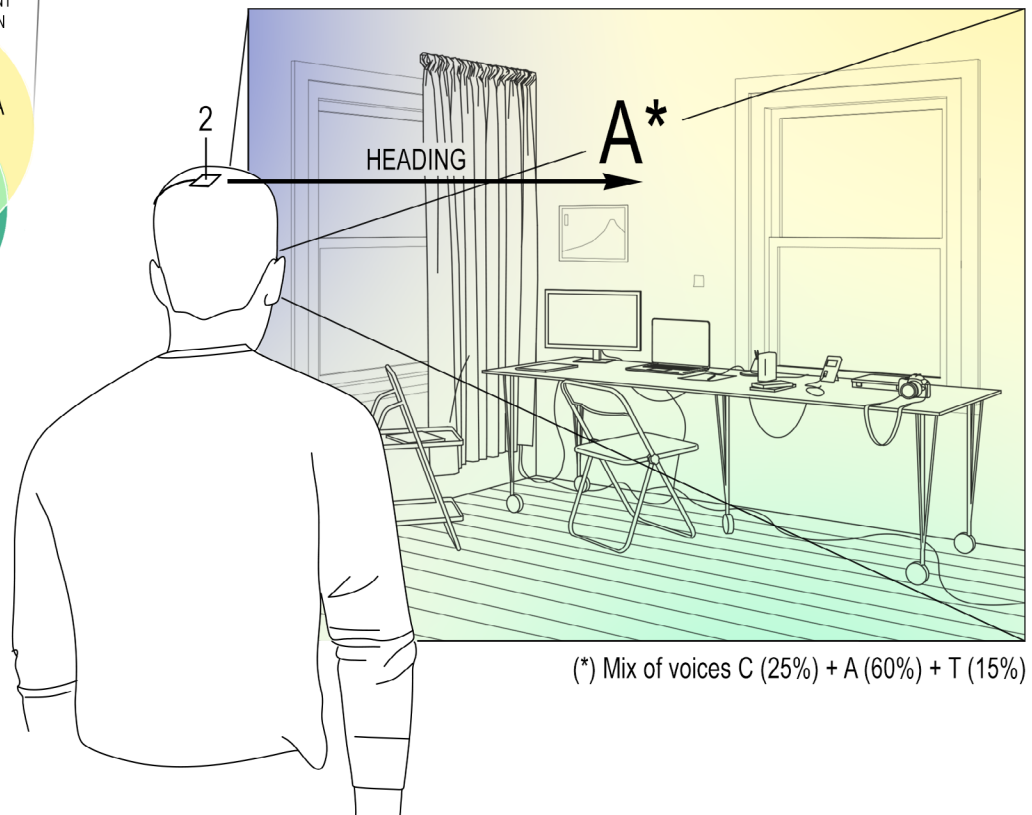
45. A biquadratic filter is a second-order IIR filter with two poles and two zeros that can take the shape of other more common filters. In Six-Part Galliard, their equation coefficients are set so the filter operates as a resonant or a bandpass (lowpass and highpass) filter depending on the voice region they act upon.

Source: music.arts.uci.edu/dobrian/maxcookbook/biquad-filter

ROOM PLAN



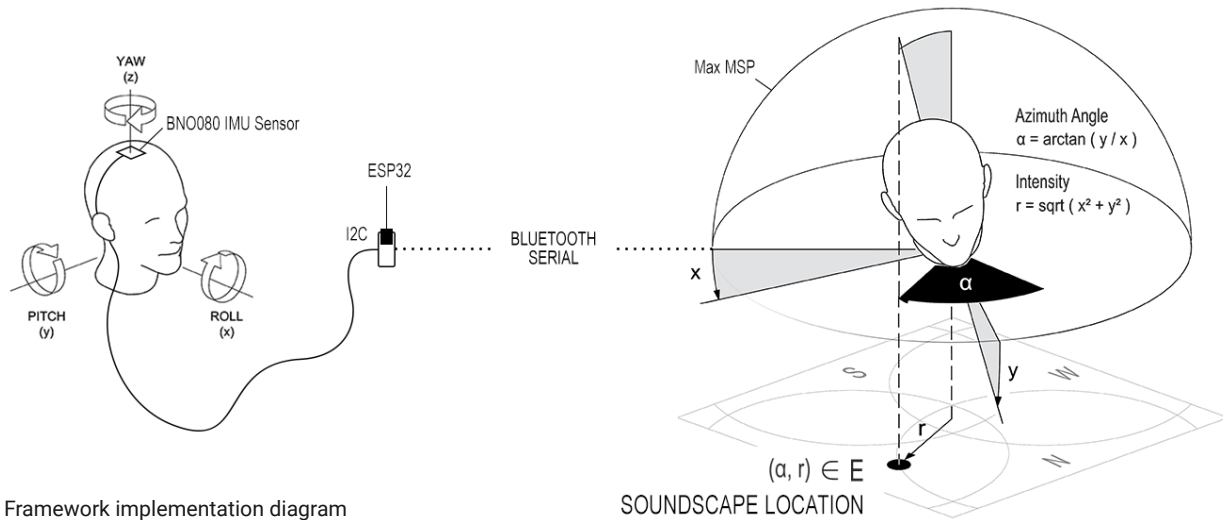
CURRENT VOICE REGION



Soundscape system diagram

fireplace mantel; the desk at the window; the lounge chair where I read; the entrance; and the corner of the closet— creating five cardinal voice regions. The *basso II* voice region is placed centrally reinforcing the bass frequencies in the output mix and emphasizing the sense of a sound centrum located in the real center of the room for a better audio location perception.

The listener wears a head-mounted orientation and motion-aware sensor to detect their absolute heading angle in the room. This value determines the listener's location in the soundscape in real-time, therefore perceiving an immediate audio experience linked to their motion and navigation across space. If the user heads towards the *alto* region (A) —visually connected to the desk and window area— they will listen to a proportional mix of voices to their heading —in this case, the adjacent voice regions *canto* (C) and *tenore* (T).



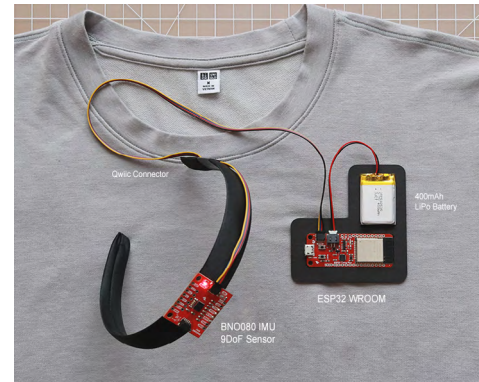
Framework implementation diagram

Implementation

The soundscape framework is implemented using a Max patcher that computes the listener's virtual location from their heading orientation. For that, the program uses the absolute yaw, pitch, and roll angles received from an IMU sensor. The soundscape location is represented as a 2-dimensional coordinate vector that points towards one of the existing voice regions with a certain intensity:

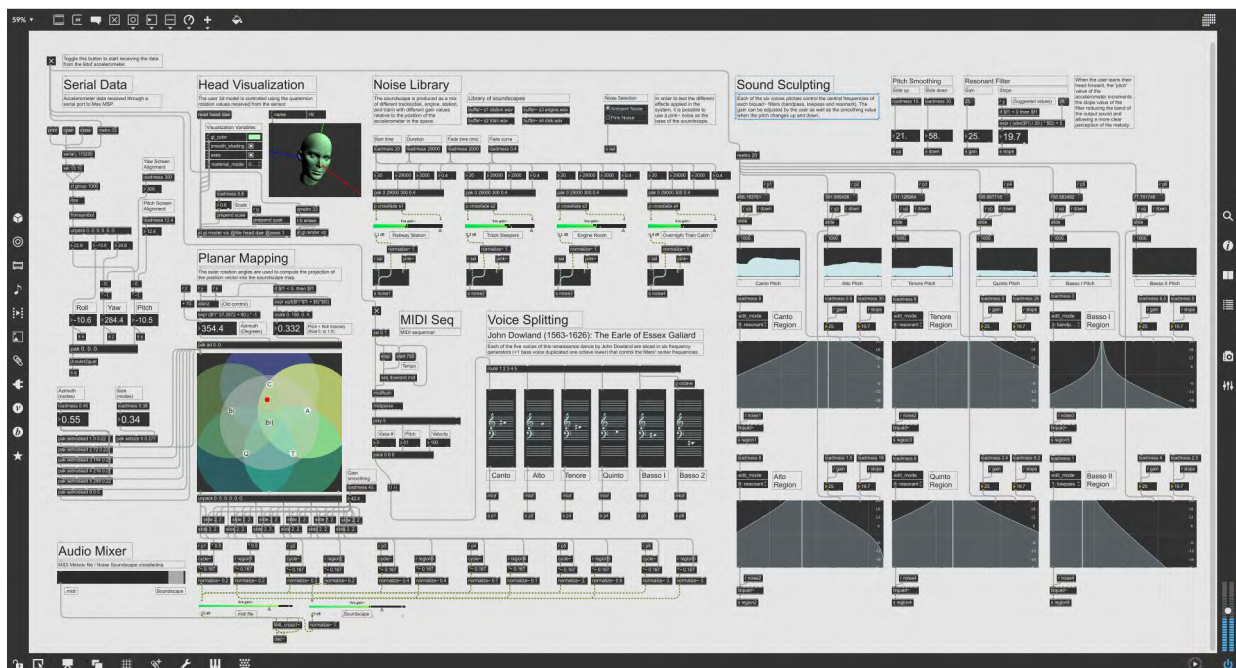
- The first coordinate is the *azimuth* angle (α) computed from the yaw angle after a preliminary calibration to correlate the physical room with its copy. This provides the directional angle of the listener's heading. In the first prototype, the azimuth was computed as the arctangent of the pitch and roll angles since that test only intended to collect a stationary listener's heading forced to head towards the computer screen (see figures).
- The second coordinate is the *intensity* (r) of the interaction with the voice region. This value

is commonly known as *elevation* and represented as an angle from the horizontal plane. Here, I have chosen to use its horizontal projection in the soundscape plane computed as the hypotenuse's pitch and roll angles. This calculation is also clamped and rescaled to avoid negative values and keep the final output intensity within the soundscape regions' limits.



Sensing headband and chest computing module

This vector is used as an input to the Max object *nodes* that visualizes a dot at the end of the direction vector and outputs a message with the percentual proportion of all encountered voice regions in the current listener's heading. In the final prototype, my heading's absolute orientation in the room is sensed and computed by the BNO080 IMU sensor used in the previous prototype. This board is connected using the I2C protocol and a Qwiic cable⁴⁶ to an Espressif's ESP32 WROOM module with WiFi and Bluetooth antennas that provide wireless communication with a computer through the serial port. The IMU sensor is mounted to a headband while the ESP32 —powered by a rechargeable 400mAh LiPo battery— is assembled in a chest-mounted gear.



Six-Part Galliard soundscape Max patcher

46. The Qwiic cable is a connection system commercialized by SparkFun that allows I2C connection among sensors and boards with this standard. It consists of a 4-pin JST polarized connector with a 5V, ground, and SDA and SCL channels that guarantees that these wires are always connected in the right order. Most Qwiic-friendly boards have two connectors for Qwiic wires leveraging I2C protocol's interconnectivity to daisy-chain multiple devices. Source: sparkfun.com/qwiic#overview

The orientation data is encapsulated in a serial message and sent every 50ms to the computer's serial port. Max then reads and unpacks this message in different float variables. The yaw, pitch, and roll angles are used to animate a 3d simulation of the listener's head position in the computer screen for debugging purposes and facilitate the demo of this experiment.

Testing and limitations

During the testing phase of this experiment, I noted some aspects of the interaction that conditioned the quality of the interaction and revisited the weight of the initial assumptions:

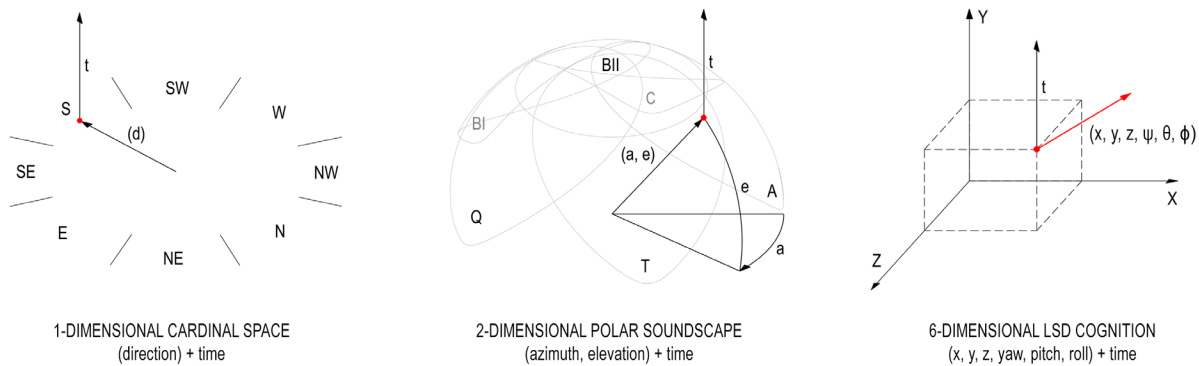
- When I was getting closer to the center of a cardinal voice region, Dowland's galliard was more easily recognizable as a whistle obtained from the very same ambient noise that I was listening to an instant before. Similarly, if I wanted to retrieve a neutral state after exploring one specific voice, I was prone to position my head straight to obtain an equally balanced mix of the six voices. Consequently, I incremented the gain slope of the filters' action obtaining more demarcated audio regions for both cases.
- The soundscape mix was output during the testing phase via a stereo Bluetooth speaker located in the room's center. In a final prototype, the audio was supposed to be played simulating a binaural 3d spatial configuration through a wireless headphone set. Per contra, I did not implement this feature, and what was initially considered a preliminary circumstance ended up supporting one of the project's initial claims: to create the background of a bifold sonic landscape. The ability to overlay my speak voice over the ambient soundscape revealed a transient quality to the system that could run for as long as the battery power the sensor without feeling deprived of the hearing sense of listening to one-self.

In addition, I detected some limitations concerning the scalability of the system:

- My room's furniture's eccentric configuration—which matches how small single domestic units are ordinarily furnished—allows couple directional audio regions to cardinal-oriented room scenes. This backs the mental identification of voice regions to visual scenes and assists the listener in the soundscape's spatio-cognitive navigation. An upscaled version of the system executed in a different indoor environment will demand maintaining a non-occluded peripheral distribution of the significant scenes throughout the room. However, an outdoor extrapolation will require a location-aware framework that can also sense the listener's 3-dimensional position in the space—a similar approach is explored in this thesis's final experiment.

3.5 6-DoF Awareness

While I was writing these late lines in this research, I noticed how all spatio-mediated assemblages —studied and manufactured— shared the *dimensional* nature of space. Beyond their 3-dimensional materiality, spatio-mediated assemblages propose dimensional interactions in the intersection of physical and virtual worlds: our interactions within them can be measurable and specified with a minimum number of coordinates. Sound—as revealed in the previous prototypes— is also transversal to these worlds. It is defined in terms of time —expressed as frequency and period— and intensity. Since intensity is correlated to a spatially measurable magnitude —the distance to the sonorous object—, time is the only dimension that escapes from the cognition of the visual and tangible medium and, therefore, intersects with the spatial perception of our environment.



Dimensional spaces of each of the spatio-mediated assemblages prototyped

If actions could be represented in their entirety—including all different sensory perceived parameters, but also those that are hidden from our senses and depend on how we cognitively experience reality—, two identical interactions will produce the same results. The elusiveness of this exercise has encouraged a simplified evaluation of the previous prototypes which can be represented with algebraic coordinate systems. The interactive space of the *Cardinal Recorder* arranged an 8-slot indexed audio framework. This can also be expressed as a 1-dimensional coordinate system—with an additional time dimension. *Six-part Galliard* expanded this space with an extra dimension constructing an audio surface or *polar soundscape*: the listener's heading direction and pitch controlled their aural experience in the room. The next iteration in the dimensional evaluation of the interaction space of my room builds upon these two previous prototypes and applies a cartesian coordinate system to represent the position of the self in the

multiplexer. This conceptualization provides a 6 degrees-of-freedom vector decomposed in 3 position values—with respect to the origin of the coordinate system—and 3 orientation angles—yaw, pitch, and roll—for every instant of a time-based experience.

3.5.1 Location-Specific Augmented Domesticity

In recent years—even more during the pandemic—sociological, cultural, artistic, and capitalistic practices have converged in the domestic space to study and analyze how our behavior unfolds in each square foot of our home. Pervasive technology designers—often associated with IoT-connected smart objects—have also been largely interested in introducing location-aware features to digital devices in order to interface our home’s materiality with its virtual alter in a more granular way. A software-based approach to this question is augmented reality implementations enhanced by computer vision algorithms that identify the humanly-altered material surroundings through real-time image analysis. This method provides enough sensing power to classify oneself’s activity over time. It is also an inexpensive way of interfacing our home since it only requires digital video cameras—which are nowadays produced in affordable formats—and the processing power of computers that no longer need to run complex algorithms on-site but can transfer those processes to external servers.

This is the case of Robert Twomey *Machine for Living In* (2018), where he rediscovers Le Corbusier’s architectural machine and reveals his intimate and personal interactive space through a domestic computational-based sensing installation. Using several video and audio nodes placed in different locations of his house, Twomey’s machine ‘*produces a complex portrait of the home: as a space of language, intimacy, bodily practice, and quotidian narrative [...] in contrasts with utopian illusions of beautiful, frictionless utility [...] into the messy, material realities of the everyday*’ (Twomey, 2018).



Robert Twomey. *A Machine For Living In* (2018): roberttwomey.com/machine-for-living-in/

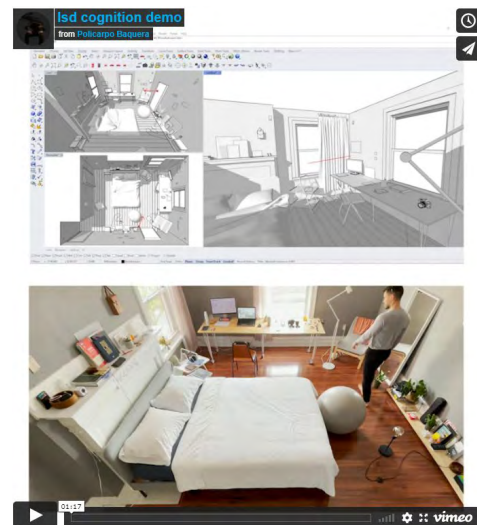
Opposed to the richness and beauty of everyday life depicted through the detection and classification of our presence in the intimate sphere, the effects caused by using real footage as evidence to deconstruct our affections in the domestic space are somehow unsettling from a privacy perspective. Hardware alternatives such as Ultra-wideband (UWB), Bluetooth Low Energy (BLE), Wi-Fi, and ZigBee triangulation, Radio Frequency Identification (RFID), or Ultrasound imaging and object detection (Dahlman, 2019) evade those problems by utilizing the non-visual electromagnetic spectrum to retrieve our position in indoor settings. Former MSCD student Richard Kang researched the potential of using UWB triangulation, gesture, and voice recognition systems to demonstrate how simple spatial interactions —such as pointing at objects— can be accurately tracked in ordinary indoor environments (Kang et al., 2019). His results also show this technology’s potential to integrate and coordinate an analog and digital network of smart —and unsmart— domestic objects.

Encouraged by these research precedents, the next prototype will leverage the location-specific affordances of non-visual location-aware systems to interface the *Multiplexer Room*.

3.5.2 LSD Cognition

LSD Cognition —or Location-Specific Domestic Cognition— is a computer-vision-centric digital framework for real-time virtualization of physical interactions in the domestic space. This experiment is only a technical implementation of the sensing system that tracks a user’s location and heading in an indoor environment to control a virtual camera that navigates a 3-dimensional replica of the *Multiplexer Room*.

The framework is designed as a dual system with both physical and virtual dependencies. The physical spatial tracking is implemented through an Ultra-wideband Real-time Location Network able to locate one of their tag modules in the room. A wearable device has been designed to interface this location tag with an IMU sensor to retrieve the absolute orientation of the



LSD Cognition Demo (2021).
Video: vimeo.com/541460386

user's heading back to a computer serial port. In this experiment, both position and orientation are used to control the parameters of a virtual camera in a 3d modeling software in real-time. In the next sections, the implementation is described as a proof of concept of the technology encouraging future designers to easily set up this framework in spatial interactive settings.

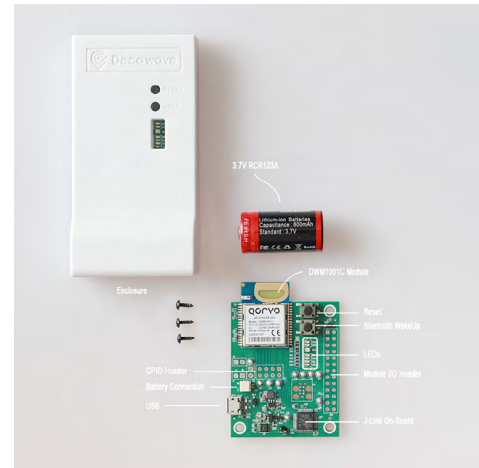
RTLS Implementation

Decawave DWM1001 Description

The Decawave DWM1001 is an Ultra-wideband and Bluetooth transceiver module based on Decawave's DW1000 IC and Nordic Semiconductor nRF52832 SoC. The module contains proprietary firmware for the accurate deployment of an UWB-based Real-Time Location System (RTLS) with data encrypted network connectivity. Each module can be configured as:

- *Anchor*: detect UWB pulses emitted by UWB tags and forward them to the location server for calculating tag positions.
- *Tag*: attach to objects that need to be tracked and send out blinks to the *anchors* to calculate its own position.
- *Gateway*: access the location and configuration of other modules through an MQTT⁴⁷ broker and enable the deployment of a Personal Area Network (PAN) via IP addressing.

The company also manufactures the ready-to-use DWM1001-DEV Development Board, which mounts a DWM1001 module soldered in place, a J-Link On-Board Debugger Microcontroller, GPIO headers (compatible with Raspberry PI), LEDs, buttons (for reset and Bluetooth Wake Up functions), as well as a USB and battery connections. For this project, I acquired the MDEK1001 Kit with 12 of these development boards



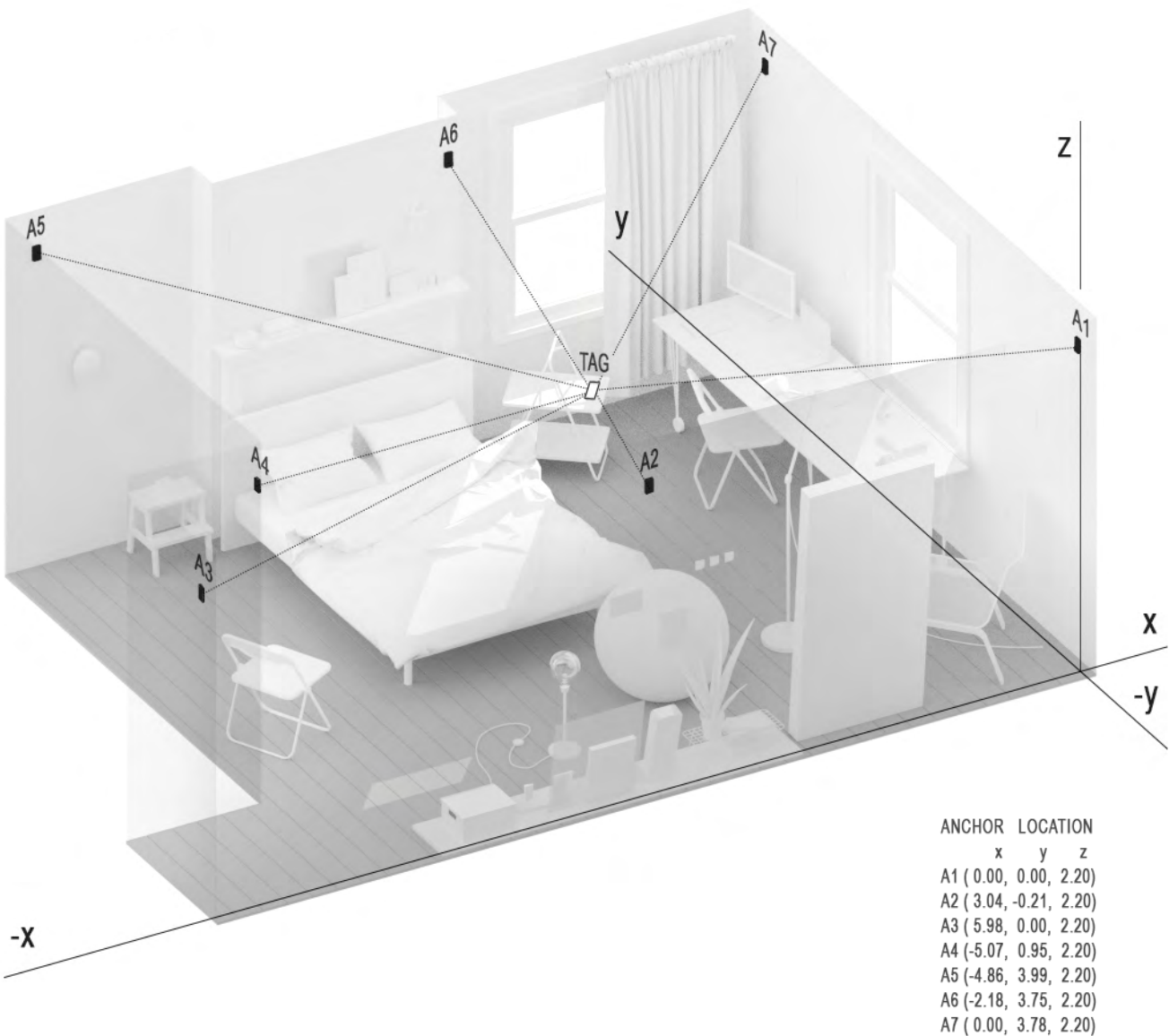
DWM1001-DEV Development Board, rechargeable battery and case

47. MQTT is an OASIS standard messaging protocol for the Internet of Things (IoT). It is designed as an extremely lightweight publish/subscribe messaging transport that is ideal for connecting remote devices with a small code footprint and minimal network bandwidth. Source: mqtt.org/

plus different accessories to easily set an indoor RTLS network. Complimentary to this kit, I purchased 3.7V RCR123a rechargeable batteries to powered the boards.

Setup and calibration

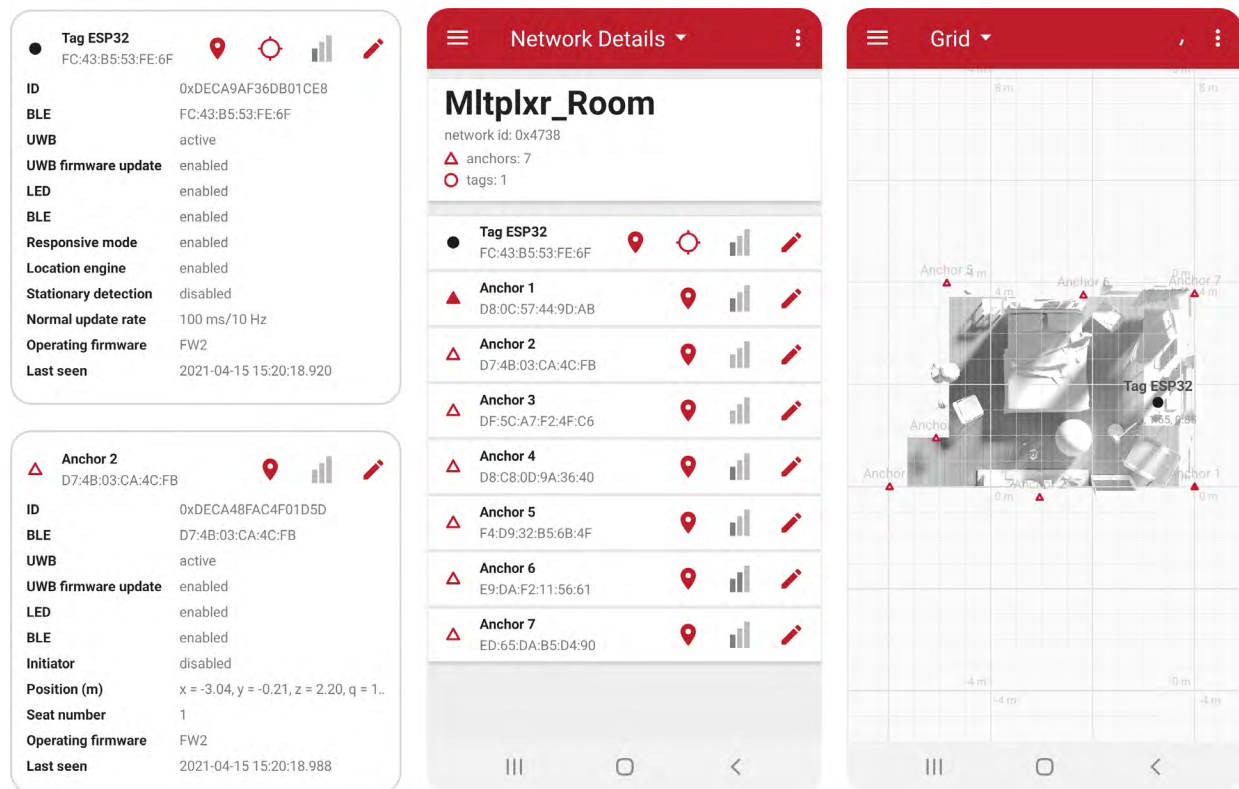
For this project, I set up an 8-module RTLS network. The minimum number of modules designated as anchors to create such a network is 3 (Decawave recommends 4 for better accuracy) though 7 were required to cover every corner of the room’s area and provide a more reliable positioning; the 8th module of the RTLS was used as a tag. The anchor units were hung in the wall at an identical height of 2200mm above the floor level, allowing a clear coverage of all points in the room.



RTLS Anchor Modules Location Map (meters)

After anchoring the units across the room, I used the app *DRTLS* developed by Decawave to configure a Bluetooth network interfaced with an Android smartphone or tablet. This app provides a graphical interface to configure each unit as an anchor or tag, set their different unit parameters —such as update rate or physical position—, update their firmware via Bluetooth, and visualize in real-time the tag's position in a 2-dimensional map —easily customizable with a background image. In the first test I:

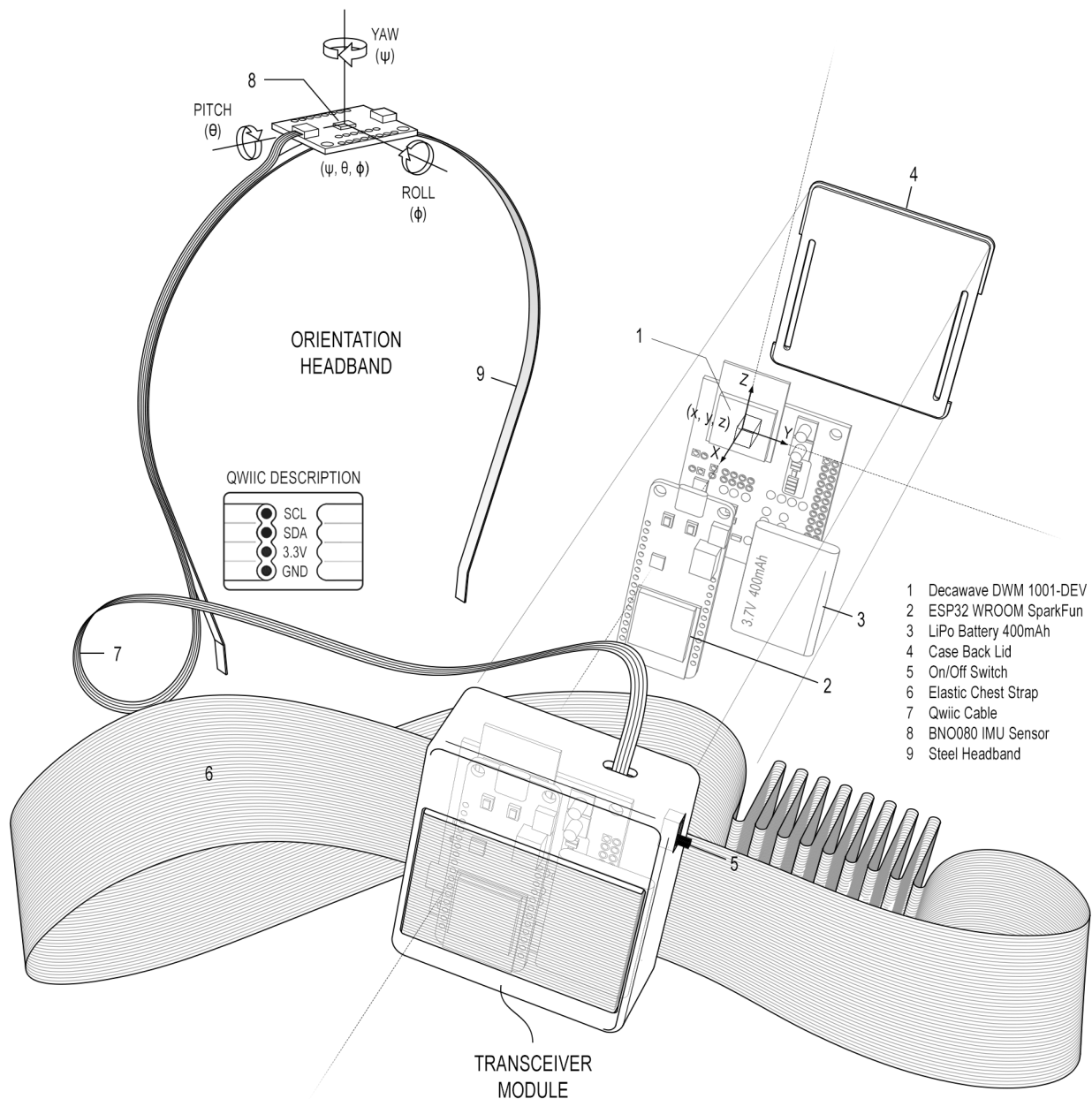
1. Labeled each anchor with a number for identification purposes.
2. Set at least one of the anchors as initiator of the network (anchor no.1).
3. Forced all units to work at their maximum update rate of 10Hz or 100ms.
4. Input each anchor's physical position manually relying on the multiplexer room 3d-model since the auto-positioning feature built in the Android app did not provide enough real accuracy.
5. Disabled the stationary detection of the tag unit which was later implemented in software.
6. Used an extra 9th module as a *listener* connected to my computer through the serial port to log the tag's position in the PC terminal.



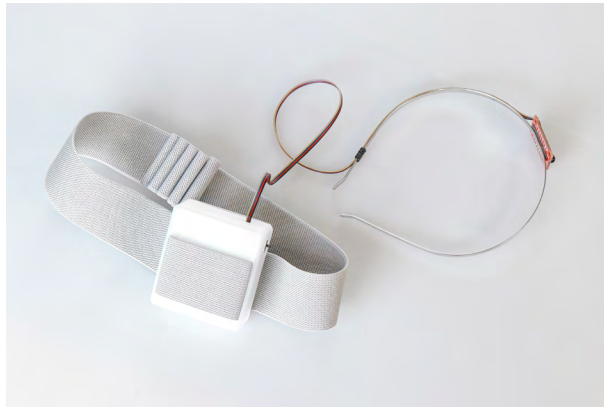
Tag/anchor setup parameters, *Network details* and *Map* view. Decawave's DRTLS Android app

6DoF Sensing

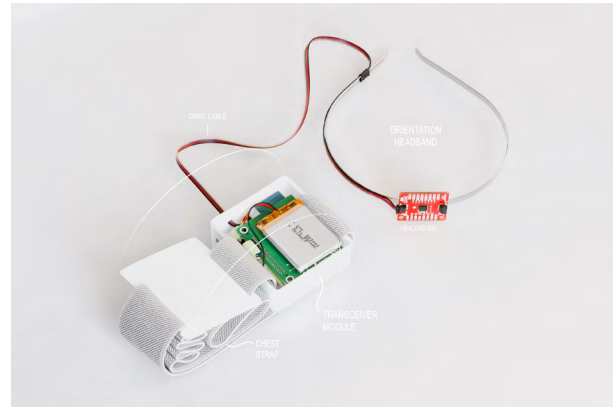
A 6 degrees-of-freedom sensing in the room required—in addition to the tag-configured Ultra-wideband unit—an IMU orientation sensing unit to retrieve the user's heading. Both components had to be interfaced throughout a computing module with Bluetooth capabilities to send a combined message to a computer serial port. These extra features lead to the fabrication of a wearable device that could host both the UWB unit and the computing module while providing head-mounted support for the orientation unit.



LSD Cognition sensing wearable module diagram



Clear resin 3d printed prototype



Electrical components of the modules

Fabrication

The wearable sensing unit is divided into a chest module containing the transceiver unit, an ESP32 WROOM unit, and a 400mAh LiPo Battery with a switch button, and an orientation headband with the IMU unit connected to the latter module through a 4-channels Qwiic cable. The chest module was designed with a cross-sectional opened slot to slip a double-sided twill woven elastic band that secures the back lid to the front of the case and is long enough to be wrapped around the body. The prototype was printed in clear resin and innerly coated with a thin layer of white primer spray paint.



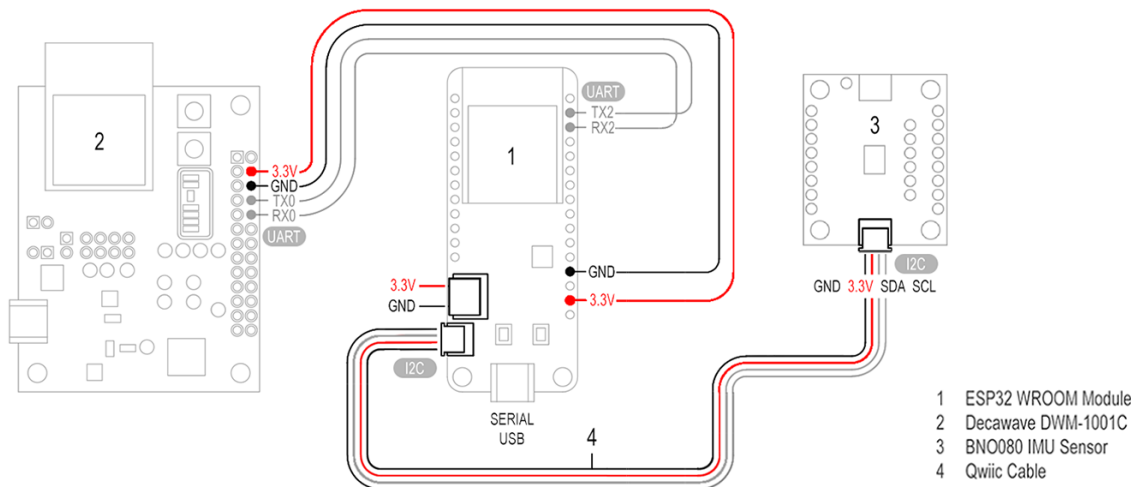
Transceiver module



Transceiver module and orientation headband

ESP32-WROOM Implementation

Following Decawave DWM1001 module⁴⁸ support documentation, I removed one of the units from its off-the-shelf case and connect its UART-dedicated pins⁴⁹ to the UART-dedicated pins in my ESP32 WROOM unit. Since the UART0 and UART1 of the computing unit were already in use — automatically assigned for primary communication and Bluetooth connection—, I chose the UART2 protocol of the board to communicate with the transceiver unit. The code —see appendix— contains a series of `Serial2.write()` messages in the setup function that send the word `lep` to the Decawave module to start the retrieval of the coordinates `x`, `y`, `z`— from the tag as indicated in the support documentation. This message is combined with the orientation angles —roll, pitch, and yaw in degrees— received by the BNO080 IMU sensor composing the final message: `POS, x, y, z, quality factor, roll, pitch, yaw`.⁵⁰



Schematic diagram of the LSD Cognition sensing wearable portable unit

Virtual Simulation and Testing

The 6-DoF message —sent via the serial port to the computer— was later processed in Grasshopper using the library Firefly.⁵¹ The values were individually calibrated to match the physical room and its virtual model built in Rhino. These controlled the parameters of a virtual

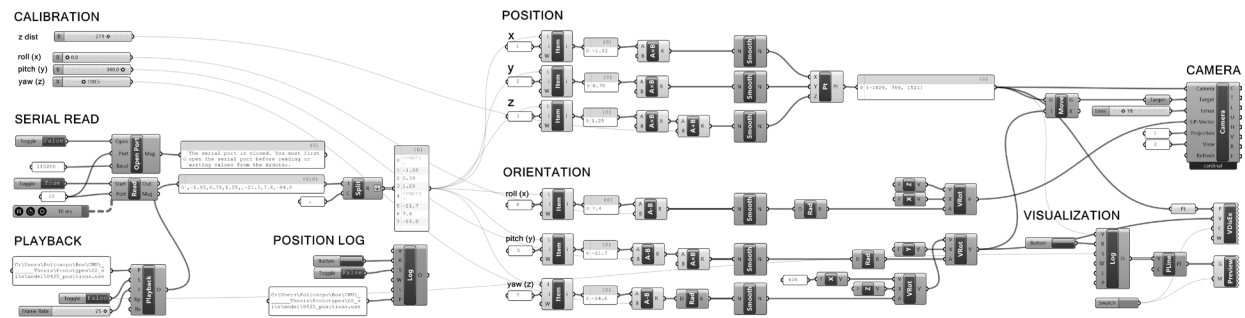
48. Decawave DWM1001 Documentation: decawave.com/product/dwm1001-module/

49. Universal Asynchronous Receiver-Transmitter or UART protocol is a computer-hardware asynchronous serial communication protocol in which the data format and transmission speeds are configurable. It sends data bits one by one, from the least significant to the most significant, framed by *start* and *stop* bits so that the communication channel handles precise timing. Only two wires are needed to transmit data between two UARTs devices: a Tx pin to transmit the message and an Rx pin to receive it. Source: circuitbasics.com/basics-uart-communication/

50. Note that the *quality factor* —disregarded in this experiment— is a measure of confidence of the accuracy of the location estimate based on the ranges received.

51. Firefly offers a set of software tools dedicated to bridging the gap between Grasshopper and micro-controllers. It allows near real-time data flow between the modeling software Rhino and physical prototypes: fireflyexperiments.com/

camera that replicated my real motion and heading in the 3d software with a 10ms refresh rate, These values were logged in parallel in a CSV file to maintain a historical record of my *LSD Cognit-ive* interactions within the *Multiplexer Room*.



Firefly/Grasshopper framework definition

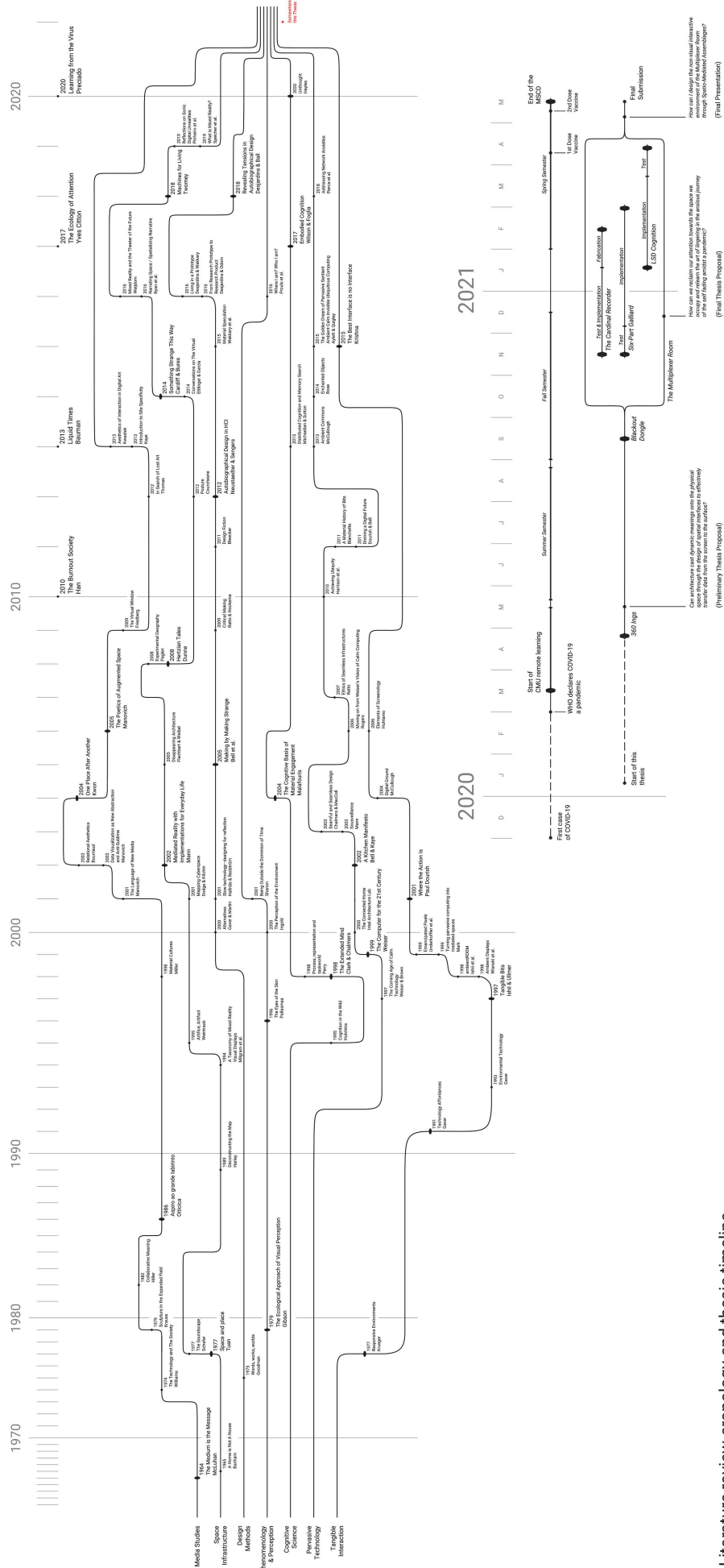
Testing and limitations

The framework previously described has been only a technical implementation of an existing technology in a domestic environment and—in contrast to the *Cardinal Recorder* and *Six-Part Galliard*—has not been tested from an experiential perspective. However, here are some considerations that its testing phase has revealed:

- The communication rate of the transceiver module was fast enough to use the location message as an input parameter in spatio-mediated installations. An averaging filter applied to the input stream of data is recommended to avoid noise and to allow smooth transitions between position values.
- The wearable communication was down a few times, stopping the serial port from reading the location and orientation values. This was partially due to the signal interference in the wearable module since both the transceiver and the computing unit Bluetooth antennas were operating very close to each other—a previous prototype of the system mounted on a traditional breadboard did not confront such challenges. It is recommended to build a customized PCB—instead of clustering together off-the-shelf modules—with surface-mounted integrated components and avoid as much as possible any physical occlusion between the room anchors and the tracked tag unit.

The conditions under which I have produced this thesis have greatly influenced the methodology and experiments. The decision to transfer my research into a domestic and partly isolated indoor environment has promoted a very subjective analysis of my personal space and, therefore, a very intimate design approach to prototype the spatial experiences defined in the previous chapter. Though I have tried to reflect all design and fabrication choices in the methods of this document, this chapter will evaluate all those experiences altogether. For that, I have decided to structure this discussion as an interview with myself, including the different alter egos—home dweller, graduate student, tech consumer, product stakeholder, prototype manufacturer, experience auditor—assumed during the development of this thesis. This interview will address the problems and concerns of engaging with an autobiographical design process (as discussed in section 2.5). It will also expose how my intentions and intuitions have steadily changed, shaping the different stages of the process. Since I have been the only user of all these technological spatio-mediated assemblages, this evaluation will represent a psychological panel of my affections, actions, and behaviors during the thesis. The conversations with my advisory team and peers have prompted most of these questions that I have later summarized and organized by their relevance to the thesis:

- How has the research question changed along with this thesis?
- Which community is this thesis addressing?
- Why did you choose your room as a site of research?
- What is the relevance of prototyping one's own technology?
- What were the challenges of prototyping in own's most intimate environment?
- Did your experience prototyping your own domestic smart technology change your perspective on those appliances?
- How would you define the *domestic* after this experience?
- Can the experiments of this thesis be considered spatio-mediated assemblages?
- Have these spatial interfaces offer a viable solution to screen-dominated environments?
- How have the assemblages and experiences answered the research question of this thesis?



4.1 Research Claims

How has the research question changed along with this thesis?

At the beginning of 2020, when I started to frame my interests into a possible research question, I was refining my technical and creative skills in between art and computational design courses towards defining a professional and ideological standpoint for my career. This search was happening *All over the space*, which later became the name of my first thesis proposal presented by May 2020. During this time, I coped with acquiring new skills while locating digital media art projects and speculative HCI prototypes that aligned with my preexisting ideas of the role of technology in our living environment. This evidences why my first research proposal focused on tracing a map of practitioners and examples to understand the community where I saw my thesis could fit best. The literature review—broadly influenced by phenomenological studies, art theory, and mixed reality technologies—as well as my background in architecture and design, framed my research question ahead of delivering a specific creative prototype:

Can architecture cast dynamic meanings onto the physical space through the design of spatial interfaces to effectively transfer data from the screen to the surface? (May 2020)

This warranted that future projects—produced during the coming semester—could be framed under that question. Meanwhile, the lack of a specific site of research—since the physical-digital twosome comprises a boundless site of intervention—motivated the continuation of an existing project—an interactive video projection robotic framework⁵² developed as part of the class *Introduction to Architectural Robotics* during fall 2019—to prove the validity of my research question. By the end of the semester, the COVID-19 pandemic was already forcing the university online enrolment, and I presented that thesis proposal to my cohort and different design, art, and architecture scholars via Zoom. Although the background at that stage seemed coherent and well-structured, reflecting on those ideas through the proposed material implementation caused some critical comments from the reviewers. In particular, one of them encouraged a contingent reevaluation of the proposal in the context of the pandemic, which I received with some denial motivated by my disbelief that those settings should not compromise the development of my thesis question.

52. For more information visit: poliarpobaquera.com/works/6-dof/ or vimeo.com/378980300

During the summer, my living habits had already changed from those previous to the pandemic due to the intermittent regional lockdowns and the inability to attend in-person classes or socialize naturally with my friends. In addition, the university access restrictions and the lack of material resources to continue the experimentation with robotic systems eventually persuade me from prototyping within that technical space and encourage my thesis to take a critical perspective towards the technology I used in my closest environment. Even with a sustained interest in researching the future of spatial interfaces and multidirectional interactions, I changed my thesis question once again:

How can we reclaim our attention towards the space we occupy and relearn the art of lingering in the anxious journey of the self fading amidst a pandemic? (December 2020)

This new framework introduced new qualifiers to my research interests: attention as the most important cognitive resource that determined the quality of my interactions with technology and my inability to entertain myself in a domestic environment through non-digitally-mediated experiences. This question also highlights my anxiety about confronting never-experienced circumstances and acknowledges some lost quality of my domestic behaviors that need to be restored. During the consecutive draft submissions of this thesis, I used my research question as a psychological portrait of my aspirations and motivations to work and research in the design field from a personal perspective. The transferring of the educational experience to a remote setting and the isolation suffered during that last year inflated the tone of that latter question. While those circumstances did endorse the autobiographical methodology as the best approach to prototype from my home, they did not change the superior interest of this thesis: *reevaluate the current use of pervasive and screen-based devices across various human-computer interaction scenarios*.

For this document to have an independent existence out of its temporal context, I stripped my thesis' question from explicit qualifiers that could set the tone of future discussions coining the site of research as a self-defined place —the *Multiplexer Room*— that fostered the reader's curiosity to find out more about it but did not make universal claims on the nature of the domestic environment:

How can I design the non-visual interactive environment of the Multiplexer Room through Spatio-Mediated Assemblages? (April 2021)

Which community is this thesis addressing?

As a design practitioner and creative individual, the *impostor syndrome* is a constant that — in my own experience— manifests in a quarterly fashion throughout long and extensive research and design ventures. This has strongly affected my ability to address one specific community during this thesis since I felt that my techniques did not belong to one single academic field but formed an overarching set of aesthetics and practices to solve material-informed design problems. The different alter egos acquired during the design and prototyping process have also greatly encouraged such uncertainty towards choosing a particular community. Nonetheless, a committed effort to review literature from art theory and design scholars on the agency of the work as a speculative apparatus has clarified this inquiry: *this thesis is dedicated to those that have struggled to frame their practice in between art and technology, action and reflection, creation and critic, hardware and software, the physical and the virtual, and all those counterparts that lead the path of the 21st-century practitioner that navigates in the contentious institution of scientific creativity.*

4.2 Autobiographical Hacks

Why did you choose your room as a site of research?

The domestic space has been widely studied by scholars, design practitioners, and artists throughout history. The perspective of the home as a site of production and innovation has also been surveyed along with the evolution of computer systems from the HCI community. In this research, the choice of my room as the object of study was motivated by the educational shift to our homes due to the COVID-19 pandemic. However, despoiled from human experience, *space* is only a location with no meaning; on the contrary, *place* —shaped by human behaviors— is more than a simple location (Tuan, 1977).

My site could not simply be *my room*, but it needed to be *qualified* within my behaviors in that space. The search for this *place* became clear after the performance of the video piece *360 Ings* (see section 3.1)—solely included in this thesis since it helped to reveal the tensions that started to surface between the material and the mental boundaries of the domestic confinement experience. The video served as a visual metaphor of a space overlapped by different behaviors that —yet distant in time in reality— did feel closer in my memory: I started to be unable to differentiate where and when domestic and working tasks happened in my house. The last step in this search was to find a conceptual framework that could encompass my motivations and claims sustained

in the thesis question. And so I decided to nickname the space in the same way one chooses to name memorable places where one has lived: my room turned into the *Multiplexer Room*. This meaning characterization helped to construct the idea of a place over the dimensional properties of the physical space and situate the thesis question within a specific range of personal intuitions about our domestic environment during the lockdown: the fuse of public and private behaviors, the expropriation of the intimate life, my role as an intermediate auditor of information processes, or the permeability of ideas of efficiency towards non-productive activities. The early adoption of this strategy in the research process helped shape *Blackout Dongle* —the first formal project framed within the *Multiplexer Room*— and take some critical distance from the mixed nature of my room as a living and working environment. Nonetheless, it was a *hyperbolic* claim —discussed in the next questions— that lost credibility just as the following prototypes started to add different meanings to the new domesticity of my room.

What is the relevance of prototyping one's own technology?

From a very early point in this research, I strongly determined that I would design and fabricate several material artifacts as a vehicle of communication to *reflect* on the existing digitally-interfered domestic infrastructure and *propose* new speculative paradigms aligned with my previous practices and progressive ethics.

'Making prototypes is a way to extend an idea into its materialization. Prototypes move ideas out of the mind off the page and into the hand. We prototype to render and materialize ideas so that they can be shared and tested and allowed to circulate.' (Bleecker, 2011)

By prototyping, manufacturing, documenting, advertising, and showcasing ideas, we are closer to achieving an embodied experience of the technology we design and, therefore, respond to our initial queries. While this standpoint serves as a general commitment to *world-making* (Goodman, 1975), prototyping one's own technological frameworks and artifacts provides new implications to the design experience. Being the creator and end-user of the final assemblages gave me full flexibility in every iteration to analyze my needs and correct the designed versions along the ideation process. It also brings an *empowering awareness* of being in control of the technology that I use, thus breaking the directional distribution stream of the supplier-consumer economy. Per contra, this comes with the difficulty of reporting a detailed and objective narrative of the events that shaped the final assemblages (as discussed in section 2.5).

Lastly, the act of *assembling* for my own interests can also be read as a reaction to the immense living friction that I confronted during the COVID-19 pandemic. I —and generally speaking, many of us— have felt how the channels of communication that used to bring us new experiences, stories, gossip, and overall newness to our life, are now saturated with the same old contents. To cope with this situation, individuals have to recover forgotten passions —such as home decor, gardening, jogging—, enroll extravagant hobbies —craft homemade kimchi, raise sourdough, pet kombucha scobies— and boost social communication behaviors through all kinds of video conference platforms, audio clubs, and streaming formats. Assembling my own hardware devices has also been a way for me to salvage some lost craftsmanship to my design practice, now dazing among the pronounced endless space of online virtuality.

4.3 The *Domestic* as a Lab

What were the challenges of prototyping in own's most intimate environment?

Designing from my room has been a polarizing experience during this thesis. On one side, it is a privileged position to analyze and speculate over domestic technologies. It provides an uninterrupted stream of inspiration to iterate over previous ideas and yields proximity to observe those ideas perform in a real scenario.

'Living in a prototype means to be surrounded by the project, to be physically immersed in the thing that is being designed and built. This particularity transforms the maker/user's perspective by providing constant cues, no matter where he or she is looking, for what could be improved, changed, redesigned, or crafted in a better fashion.' (Desjardins & Wakkary, 2016)

On the other side, by donating the bedroom as a research site, I no longer studied what I used to understand as *domestic*. When I coined my room as the *Multiplexer Room*, I was unconsciously desacralizing this space while altering its intimate nature. The technological devices that surrounded me were no longer under my possession but were items to be surveyed and objects to be found in the reconstructed narrative of my research. This analytical approach invaded my behavior in the house: I became obsessed with following strict organizational standards and specific distribution

patterns along the surfaces of my room. *Entering the Multiplexer Room* stopped being a refuge to a long working day but a symbol of resuming my duties within this thesis.

At this very right moment, I am not writing these lines from my room. These last two months I have started to write this thesis from my kitchen with a double purpose: acquire physical distance towards the place that spurs my obsessions and oppresses my behaviors, and maintain some conceptual distance from the site that I am researching as a means to restore its domesticity. For that, I think that anyone that dares to choose the home as a probe for oneself's speculations should consider watchfully the intricacy of such exercise and avoid the dispossession of their intimacy in favor of the research method.

Did your experience prototyping your own domestic smart technology change your perspective on those appliances?

Inevitably, designing is an empowering exercise of control and determination over one's ideas. Either from an imaginary idealization or a factual implementation, prototyping one's own assemblages reduces the breach between consumer knowledge and proprietary closed-source technologies. Theoretically, there is a vast market of open-source computational tools —Arduino ecosystem, Raspberry Pi modules, Linux OS, Python programming language— that are available for anyone to manufacture their own devices and craft their own solutions. In reality, only those that take this practice as a hobby can spend the economic and time resources needed to achieve functional prototypes that serve a real purpose in their homes. For example, the *Cardinal Recorder* prototype took a total of 100 hours —the first schematic development took 40 hours, its final implementation and fabrication 30, and the documentation process another 30 hours. On the economic side, acquiring commercial components in individual quantities involved a cost of around 200 USD —even when most of those components were only used in the testing phase, their purchase was needed to test their compatibility and features within the system.

Although I initially believe that my experiments could optimize and improve the smart ecosystem of my ultra-connected home during the pandemic, soon they proved that no information-enhanced appliance is unable to solve the distress of the productive individual in the digitally-interfered home. Technology is an addictive antidote for the same illness it induces.

How would you define the *domestic* after this experience?

For me, the domestic space has always been a place of great introspection. Returning home defines the completion of a working day, the closure of a social event with friends, the end of a

distressing experience, and so, the place where one is protected and life is paused to reflect on the exteriority that exists outside. This definition is often entwined with one's own family background, psychological portrait, physical conditions, cultural manifestations, geographic location, and generational belonging. The idea of domesticity that I had as a Spanish middle-class citizen born in the 90s in a small coastal town of the Mediterranean sea —different from the industrialized vision of the late 20th-century American home— was constructed around a concrete, enclosed, and long-lasting physical place coined as the *family house*. However, in 2004 this vision was challenged when my parents decided to install an Internet network in our apartment. A year later, I earned my first non-smartphone, and the 2000s prophecy of *Intel Architecture Lab* became a reality:

'The connected home is a good place to live. An invisible pulse flows through every room... the pulse is the Internet... The connected home empowers the people who live in it... The connect home facilitates and enhances the thousand daily interactions that make a family close, make friendships work and businesses prosper and communities thrive. From PC- connected devices within the home to outside links, the web of connections is seamless and natural... Connection is many things. It is a basic human need, and at the same time, our highest calling, follow this calling and you'll find yourself home.' (IAL, 2000)

The idea of the home entirely changed once I moved out of my hometown to study in Madrid. There, I stopped defining home as an immutable and permanent material setting but an ambulatory virtual assemblage that I could carry along with the memories stored in a cloud computing service and a monthly subscription to an Internet connection to communicate with my family and friends. The following years —growing, living, studying, and working in different cities— did nothing more than contributing to this perspective.

Previously, the home was defined as a private space in contrast with the public street; there, the domestic referred to the characterization of the private life experience in the comfort of that space. The *liquid shift* (Bauman, 2013) —that turned us into ceaseless *streams of data*— and the utter digitalization of human-to-human services and duties transferred to the human-computer interaction space—purchasing groceries, opening a bank account, falling in love, learning new skills— confirmed a restructuration of the private and public spheres of Western societies towards a non-tangible reality. The immutable thruple domestic-private-home was finally divorced into

three independent entities and for so, we are hopelessly required to redefine the boundaries of our public and private domains in every conversation and interaction with others.

The *Multiplexer Room*’s framework has aimed to condense this tension in a one-single spatial act. You —the reader— are the public and on your side is this thesis and its experiments. What you understand as *domestic technology* is so because I have contoured a fictional space that has some of those old familiar features that our homes used to have. But that domesticity is a fantasy. The use of my home as a speculative site of research has required an exercise of *defamiliarization* (Bell et al., 2005) of the space to observe it from an external perspective. In this effort, I have altered the nature of the object of study —its domesticity— thus inevitably disqualifying these claims as a contribution to this thesis. Instead, my real domesticity has shifted away from any technological augmentation that my room had —my smartphone, computer, smart speaker— towards a tangible re appraisalment of the non-digital materiality of my room. The *domestic* space is all that is not surveyable through this study and what I have kept private from this thesis —due to the nature of my experiments— outside of the room that you have seen.

4.4 Assemblages and experiences

Can the experiments of this thesis be considered spatio-mediated assemblages?

Based on the ideological and technical fulfillment of the different experiments, we can evaluate their strategies in correlation with the *mediated tactics* derived from the characterization of various examples that respond to the *Spatio-Mediated Assemblage* model. Despite personal biases, I have tried to depict through the following table an approximate depiction of the experiment’s commitment as to the base model’s metrics:

	Infrastructural Disclosure	Fictional Deconstruction	Formless Interfacing	Tangible Reliability	Experiential Immersion
	ID	FD	FI	TR	EI
360 lngs	●	○	○	○	●
Blackout Dongle	○	○	●	●	○
Cardinal Recorder	○	○	●	●	○
Six-Part Galliard	○	●	●	●	●
LSD Cognition	○	●	●	●	●

Metric evaluation of the different projects

As signaled by this analysis, except for *360 Ings*—which cannot be considered a fully spatio-mediated assemblage since it operates within the cognitive limitations of a *pseudo-immersive* 360 video streaming platform—, none of the assemblages addresses the technological infrastructure of the *Multiplexer Room* in a direct and contestatory manner. This is a direct consequence of the experienced technological distress and social isolation in the midst of this research which the next prototype —*Blackout Dongle*— resolve through an optimization operation that purposefully tried to resolve the idiosyncrasy of my digital interactions and —as discussed in the next question— could also not considered a propositional spatio-mediated assemblage.

The rest of the artifacts were created under an enforced proclivity to explore the digital otherness of my medium and propose additive spatial interactions to the digitally-interfered space. The introductory background sections in each of these prototypes also signal the origin of each of the assemblages in childhood experiences, prior interests, and *Pataphysics* —the science of imaginary solutions.

This evaluation also reveals my strong interest in finding formless interfacing mechanisms in digital experiences that escape screen-based interactions and efficiency-centered implementations. While the *Cardinal Recorder* remains a modest and realistic proposal of a sensory augmentation device for the techno-avid individual of the *Multiplexer Room*, the last two assemblages —*Six-Part Galliard* and *LSD Cognition*— show a mature understanding of the spatio-mediated assemblage model and grant the user a fictional and experiential immersion into the extra-dimensionality of their domestic space.

Have these spatial interfaces offer a viable solution to screen-dominated environments?

The three assemblages presented through this thesis have incremented the digital dimensionality of the interactive space of the *Multiplexer Room*. While I initially expected that this additive operation could displace digital anxieties and virtual interferences from the room, they only contributed to broaden anarchy in my domesticity during the COVID-19 pandemic. Therefore, I could not affirm that they have offered a *viable* solution to this environment but a *shared regime* where the screen has been dispossessed from a sovereign agency to dominate the digital behaviors in my domestic space.

And perhaps that is exactly what I was desiring from the yet unintelligible and ignorant claims that I stated at the beginning of this thesis. My hardware inclinations to prototype almost hyperrealistic products and recreate polished marketable aesthetics showed thqwat strong

commitment to physicalize alternative systems to scale down our visual addiction to screen interfaced devices and productivity-enhance tools. But in case these technologies were functional enough to be distributed in a real use case scenario, they would not do less than increase the dependence on themselves and defeat the very same ethics of this thesis: reclaim a spatio-experiential behavior in the living tangible medium. For now, this *shared experiential ecosystem* is all these experiments can offer to the screen-dominated space.

How have the assemblages and their experiences answered the research question of this thesis?

The first prototype —*Blackout Dongle*— was ideated and created to answer a particular question: stream my attention towards one singular image in the screen-based interface workflow of my room. Though the interaction between my phone and my computer monitor was happening in the immaterial volume defined between those devices, it did not add new textural qualities to that interactive space. For that reason, I found it difficult to categorize this artifact as a spatio-mediated assemblage, and I knew that this prototype could not answer my research question. The demo also displayed an animation that temporarily eclipsed the image of my monitor as if it aimed to negate the digital visual spectrum of my computer-enhanced working environment. This vision was very influenced by the struggle and discomfort of spending all my day sitting in front of that screen. The prototype was ideated and assembled as a reaction to those conditions as a quick speculative artifact. However, after showcasing this project in public, I noticed that it was mostly interpreted as an *optimization* solution to the computational entanglement across software and hardware devices. Soon, the project inspired no *rebellious reflectiveness* but *enhanced effectiveness*, and I abandoned that area of speculation since it was conflicting with one of my germinal thesis' stances: the aversion against the introduction of concepts of efficiency in the domestic space (as discussed in section 3.2).

As a result of this diversion, I decided to reconsider the spatial dimensionality of the *Multiplexer Room* —as an exploratory space to prototype new interactive textures in the tangible-digital frontier— and orient my experiments towards a more subjective and biographical design practice. The *Cardinal Recorder* and *Six-Part Galliard* constitute a sequential exploration of geomagnetic orientation as an interactive and cognitive material to construct the idea of a new sensory augmented domesticity. While they are presented as an iterative assemblage, both were executed in parallel, expecting different outcomes from their experiential frameworks.

The *Cardinal Recorder* was not only inspired by my previous practice of orienteering but a

personal obsession for being aware of my memories. While I normally record thoughts and ideas in different formats —notebooks, Post-its, reminders, voice recording apps, and digital notes— I often need a secondary layer of contextual information to locate that memory in this extended interface of embedded information. As an example of this, my iPhone’s built-in voice memo app shows each voice note title next to a secondary label indicating an approximate location —street and number— where the memo was recorded. This little UI element has become a key feature for me to retrieve those voice notes back. The *Cardinal Recorder* tried to mimic this feature using the different cardinal directions of my room, and contingently, the furniture scenes located in each of these directions. While the recorder is not designed itself as a *problem-solving product* that I would aim to use daily, it made me immensely aware of my orientation in the room and —still today— of my heading in any indoor space that I visit. Being aware of one’s spatial geomagnetic orientation while performing a cognitive task —such as working in this thesis or remembering a citation to add to this document— has encouraged me to build mental associations between concepts and their beared cardinal directions. However, I no longer think of this assemblage as a memorization productive tool but a fortuitous artifact that encourages a less functional reading of our domestic environment from a traditional division of rooms by functions.

This last finding made me question if there was still any legitimacy in splitting the home by uses, or perhaps it may be more preferable to reorganize our behaviors in oriented scenes. *Six-Part Galliard* built on that last idea composing a noise background to each of those scenes in my room. This interactive navigational sound framework initially aimed to build a sonic layer that could characterize these oriented scenes with different voice regions extracted from a polyphonic renaissance dance. During the evaluation of this assemblage, I discovered that audio spatialization not only helped to build an extra sonic dimension on top of the physical space but also amplified the perception of the other known 3 dimensions of reality. The *Multiplexer Room* started to be more *seamful* (Chalmers et al., 2003) —the room scenes were more contrasted. Their divisions were more demarcated, aligning with Weiser’s recommendations on experience design and interactive augmentation of domestic technologies (as discussed in section 2.3). This experiment also showed how I could exonerate my spatial cognition from all-visual cues towards a more holistic perception shared with an artificially augmented location-specific audio spectrum. While *Six-Part Galliard* happened in enclosed and controlled conditions, audio spatialization in domestic settings could lead us to a new generation of less screen-dependent interactive technology.

The last experiment —*LSD Cognition*— was only developed as an early technical implementation of a location-specific interaction framework for domestic environments. However,

during its testing, I discovered that this technology was accurate enough to fully integrate with computer-based interactive software such as TouchDesigner or OpenFrameworks. This could lead domestic technology to a truly location-specific awareness of smart devices that could interact with light, sound, tactile, or motion features to its close environment in a *synchronous* way—in contrast with other location-aware technologies such as passive NFC tags.

During this thesis, the scale of these experiments has been limited to my personal experience prototyping. Thus, my methods and results should be considered discreetly as an effect of my technical limitations to design spatio-mediated assemblages from a domestic setting. In retrospect, the proposed assemblages have answered the research question by *questioning* if our living environment could potentially be augmented with unexploited features—such as orientation, audio spatialization, and location-based awareness—that could interface our behaviors with accidental associations between our memory and our bodily presence.

5

Contributions & Future Work

Placed in the intersection of arts and HCI research, this thesis has created a discursive and reflective space to encourage a revision of the role of embedded information technologies for the digitally-interfered home. Through an autobiographical and a materially-informed prototyping process, I have prototyped several spatio-mediated assemblages as discursive vehicles to explore new spatial affordances to interface our physical environment with virtual counterparts. From the critical self-evaluation of these experiments, I have outlined some conclusions and opportunities that future design scholars and practitioners could see relevant for their own research:

- User-centered research and interaction design standards —often used in UI and UX practices— could benefit from media art theory and architecture history to integrate material and spatial-informed methods in designing physical-virtual interfaces. The model of the *Spatio-Mediated Assemblage* described in this thesis offers an open-ended rationale — yet sufficiently detailed typology— to encompass both scholarly and informal projects and installations from art, architecture, speculative design, and human-computer interaction fields. Through that model, I have enumerated a series of *mediated tactics* for the ideation and enhancement of future spatio-mediated experiences.
- The study of domesticity from a first-person experience requires an exercise of *defamiliarization* (Bell et al., 2005) of one's personal space that alters the nature of the object of study. In the case of this thesis, the analysis of domestic technologies required a preceding identification of personal biases on ideas of *efficiency* and *usability* embedded in ubiquitous smart devices. An autobiographical approach was chosen as the most viable solution to pervade such an intimate environment and design fine-grained digital experiences. Nonetheless, this method required a strict doctrine to discern truthful design intentions, document technical iterations, and report a veracious evaluation of the experiments.
- A fictional characterization of the site of study —in this thesis, the *Multiplexer Room*— can help identify concerns, situate claims, and motivate potential experiments in exploratory research ventures of well-known spaces. In parallel, a hyperrealistic fabrication of tangible prototypes can deploy research propositions in familiar scenarios. Both approaches have shown to raise personal awareness on revealing new interaction affordances in environmental-reactive settings.
- Both cardinal geomagnetic-orientation awareness and audio spatialization are underused interfacing affordances in digital-tangible interactions. They offer a screenless but *seamful* approach to distributing information and actions across various mediums.

- Real-time location-aware networks provide a less invasive alternative to computer-vision-centric frameworks for tracking our position and motion in domestic environments.
- Spatial interfaces require a dimensional study of their interactive spaces. In this thesis, the prototypes have operated in a 1-dimensional cardinal space, a 2-dimensional polar space, and a 6-dimensional vector space.
- Broadly, the information-enhanced assemblages prototyped in this thesis were unable to solve the distress of the productive individual in the digitally-interfered home. Instead, they have offered a *shared experiential ecosystem* to the screen-dominated regime.

The ideas and assemblages here presented still have an enormous space for refinement from a theoretical perspective and their technical implementation. The deadline constraints of this research have impeded to secure in more literary excerpts my critical standpoint against screen-based culture or how one's digital presence affects the cognitive mechanisms involved in decoding spatial interfaces. The experiments would also have benefited from machine-learning methods to analyze wider sets of data from my interactions within my room and predict future behaviors and affordances from beneath the textural qualities of my medium. From a presentational perspective, this thesis could have evolved into a publicly showcased exhibition where visitors could test by themselves the different prototypes and experience the spatio-mediated assemblages in a replica of the *Multiplexer Room*. An alternative to this would have entailed a durational performance in the room virtually exhibited through a streaming platform such as Twitch —or in a more fragmented way, through *tweets* or *stories*. However, one could argue that these experiences and experiments cannot exist without the time conditions and spatial contingencies surrounding this thesis: the COVID-19 pandemic, my domestic space, my role as creator and end-user of the prototypes. For this reason, this exploration can only continue beyond the limits of the room towards new spaces and foreign environmental settings that could help broaden my vocabulary of spatial interactive affordances.

In the next years, I wish to continue surveying the space defined across physical and virtual reality while questioning the legitimacy of deploying ideas of efficiency and productivity into the digitally-interfered human environment. For now, I hope this thesis could inspire practitioners to integrate spatial-informed aesthetics and autobiographical methods in their creative and research ventures exploring the future of reactive environments.

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Appendix

Cardinal Recorder.ino (Arduino code)

```
/*
///////////////////////////////////////////////////
///////////////////////////////////////////////////  CARDINAL RECORDER  ///////////////////////////////////////////////////
///////////////////////////////////////////////////

Created 9th Dec 2020
by Policarpo Baquera
Carnegie Mellon University */

/////////////////////////////////////////////////// MICRO SD CARD ADAPTER ///////////////////////////////////////////////////
The Micro SD Adapter is connected to the Arduino board as follows:
Nano: CS: D10 | SCK: D13 | MOSI: D11 | MISO: D12 | VCC: 5V | GND: GND
Mega: CS: D10 | SCK: D13 | MOSI: D11 | MISO: D12 | VCC: 5V | GND: GND */

#include <SD.h>
#include <SPI.h>
//const byte pinSD = 10; // Arduino Nano
const byte pinSD = 53; // Arduino Mega 2560 Pro

/////////////////////////////////////////////////// AUDIO LIBRARY ///////////////////////////////////////////////////
TMRpcm Library Usage and Information on
https://github.com/TMRh20/TMRpcm/wiki/Advanced-Features#wiki-recording-audio
In order to run this code, edit the file pcmConfig.h
(usually in C:\...\Documents\Arduino\libraries\TMRpcm)
1. On Uno or non-mega boards, #define buffSize 128. May need to increase.
2. Uncomment #define SD_FULLSPEED
3. Uncomment #define ENABLE_RECORDING and #define BLOCK_COUNT 10000UL
Once edited, assign the microphone and speaker connections as follows:
Nano: MIC OUT: A0 | SPEAKER IN: D9
Mega: MIC OUT: A0 | SPEAKER 1: D11 | SPEAKER 2: D12
*/

#include <TMRpcm.h>
TMRpcm audio;
//const byte pinSpk = 9; // Arduino Nano
const byte pinSpk1 = 11; // Arduino Mega 2560 Pro
const byte pinSpk2 = 12; // We also defined Speaker 2 although not in use
const byte pinMic = A0;

/////////////////////////////////////////////////// RGB LED SETUP ///////////////////////////////////////////////////
LED Light fade and blink Library
https://robotsbigdata.com/docs-arduino-light.html */
#include <RBD_Timer.h>
#include <RBD_Light.h>

//Arduino Nano
//const byte pinR = 2; // Red LED pin
//const byte pinG = 3; // Green LED pin (PWM)
//const byte pinB = 4; // Blue LED pin

//Arduino Mega 2560 Pro
const byte pinR = 40; // Red LED pin
const byte pinG = 42; // Green LED pin (PWM)
const byte pinB = 44; // Blue LED pin
RBD::Light light(pinG);

/* /////////////////////////////////////////////////// BUTTON SETUP ///////////////////////////////////////////////////
Button Event managing Library
https://github.com/mickey9801/ButtonFever */
#include <BfButton.h>
//const byte pinButton = 5; // Arduino Nano
const byte pinButton = 34; // Arduino Mega 2560 Pro
const int longPress = 1000;
BfButton btn(BfButton::STANDALONE_DIGITAL, pinButton, false, HIGH);

/////////////////////////////////////////////////// MODES ///////////////////////////////////////////////////
enum modes{magnetomode, recordMode, playMode, eraseMode};
enum modes mode;

/////////////////////////////////////////////////// CARDINAL ORIENTATION ///////////////////////////////////////////////////
```

```

String cardinalNames[] = {"north", "northeast", "east", "southeast",
                          "south", "southwest", "west", "northwest"};
byte recordings[8] = {0, 0, 0, 0, 0, 0, 0, 0};
char* files[8] = {"0.wav", "1.wav", "2.wav", "3.wav",
                 "4.wav", "5.wav", "6.wav", "7.wav"};
byte orientation = 0; // Current cardinal slot
bool state = false; // State of the current slot: False -> empty | True -> full

/* ////////////////////////////////// 9DoF SENSOR //////////////////////////////////
BN0080 IMU Library
https://github.com/sparkfun/SparkFun_BN0080_Arduino_Library */
#include <Wire.h>
#include "SparkFun_BN0080_Arduino_Library.h"
BN0080 myIMU;

//////////////////////////////// SETUP //////////////////////////////////
void setup() {
  // RGB LED Setup
  pinMode(pinR, OUTPUT);
  pinMode(pinG, OUTPUT);
  pinMode(pinB, OUTPUT);
  digitalWrite(pinR, HIGH); delay(500); digitalWrite(pinR, LOW);
  digitalWrite(pinG, HIGH); delay(500); digitalWrite(pinG, LOW);
  digitalWrite(pinB, HIGH); delay(500); digitalWrite(pinB, LOW);

  // Initializes the serial for debugging purposes
  Serial.begin(115200);
  while (!Serial);
  LEDBlink(1);
  // Audio Setup
  audio.speakerPin = pinSpk1;
  pinMode(pinSpk2, OUTPUT);
  audio.CSPin = pinSD;
  // SD Card Setup
  initSDCard();
  LEDBlink(2);
  // Button Setup
  btn.onPress(pressHandler)
    .onDoublePress(pressHandler)
    .onPressFor(pressHandler, longPress);
  // Magnetometer Setup
  initMagnetometer();
  LEDBlink(3);
  // Mode Setup
  mode = magnetoMode;
}

void initSDCard() {
  // Initializes the SD Card
  SD.begin(pinSD);
  Serial.println("Initializing SD Card...");
  // Checks the card is functioning correctly
  if (!SD.begin(pinSD)) {
    digitalWrite(pinR, HIGH);
    Serial.println("Initialization failed. Check:");
    Serial.println("1. Is a card inserted?");
    Serial.println("2. Is your wiring correct?");
    Serial.println("3. Did you change the 'pinSD' to match your module?");
    while (true);
  }
  // Reads the existing audionotes and updates the recording log.
  //Serial.println("Reading files...");
  for(int i = 0; i < 8; i++) {
    if(SD.exists(files[i])) {
      recordings[i] = 1;
      Serial.print("Found ");
      Serial.print(recordings[i]);
      Serial.print(" audionote to the ");
      Serial.println(cardinalNames[i]);
    }
    else {

```

```

        Serial.print("Found ");
        Serial.print(recordings[i]);
        Serial.print(" audionotes to the ");
        Serial.println(cardinalNames[i]);
    }
}
Serial.println("Done.");
Serial.println("_____");
}

void initMagnetometer() {
    Wire.begin();
    while(myIMU.begin() == false) {
        Serial.println(F("BN0080 not detected at default I2C address."));
    }
    Wire.setClock(400000); //Increase I2C data rate to 400kHz
    myIMU.enableRotationVector(50); //Send data update every 50ms
}

void lightW(bool s) {
    //White LED light
    if(s) {
        digitalWrite(pinR, HIGH); digitalWrite(pinG, HIGH); digitalWrite(pinB, HIGH);
    } else {
        digitalWrite(pinR, LOW); digitalWrite(pinG, LOW); digitalWrite(pinB, LOW);
    }
}

void LEDBlink(byte times) {
    // White blink used for initial checking of sensors and debugging
    for(byte i = 0; i < times; i++) {
        lightW(true); delay(100);
        lightW(false); delay(50);
    }
    delay(300);
}

void pressHandler (BfButton *btn, BfButton::press_pattern_t pattern) {
    Serial.print("Button ");
    switch (pattern) {
        case BfButton::SINGLE_PRESS:
            Serial.println("single pressed.");
            //A single press plays the audio note in magnetoMode
            if(state && mode == magnetoMode) {
                mode = playMode;
            }
            //A single press stops the recording in recordMode
            if(mode == recordMode) {
                mode = magnetoMode;
            }
            //A single press stops the playback in playMode
            if(mode == playMode) {
                audio.stopPlayback();
            }
            break;
        case BfButton::LONG_PRESS:
            Serial.println("long pressed.");
            //A long press writes or overwrites on an empty or full orientation slot
            if(mode == magnetoMode) {
                mode = recordMode;
            }
            break;
        case BfButton::DOUBLE_PRESS:
            Serial.println("double pressed.");
            //A double press erases a full orientation slot
            if(state && mode == magnetoMode) {
                mode = eraseMode;
            }
            break;
    }
}
}

```

```

//////////////////////////////// LOOP //////////////////////////////////
void loop() {
  if (mode == magnetoMode){
    searching();
  }
  if (mode == recordMode){
    recording(orientation);
  }
  if (mode == playMode){
    playing(orientation);
  }
  if (mode == eraseMode){
    erasing(orientation);
  }
}

void searching() {
  // Reads the orientation of the sensor and returns its state
  state = recordings[readOrientation()];
  if(state && mode == magnetoMode) {
    lightW(false);
    light.fade(500,50,1000,50,1000);
    byte initial = readOrientation();
    while(initial == readOrientation() && mode == magnetoMode) {
      light.update();
      btn.read();
    }
    light.off(); delay(200);
  }
  if(!state && mode == magnetoMode) {
    light.off();
    lightW(true);
    byte initial = readOrientation();
    while(initial == readOrientation() && mode == magnetoMode) {
      btn.read();
    }
    lightW(false); delay(200);
  }
}

void recording(byte i) {
  //LED Animation before recording
  delay(100); digitalWrite(pinR, HIGH); delay(200); digitalWrite(pinR, LOW);
  delay(100); digitalWrite(pinR, HIGH); delay(200); digitalWrite(pinR, LOW);
  delay(300);
  //Red LED light while recording
  digitalWrite(pinR, HIGH);
  audio.startRecording(files[i], 16000, pinMic);
  Serial.print("Recording...");
  //The audio is recorded until the user press the button or its length is 1min
  unsigned long startTime = millis();
  while(mode == recordMode && ((millis() - startTime) < 60000)) btn.read();
  digitalWrite(pinR, LOW);
  audio.stopRecording(files[i]);
  Serial.println("end");
  recordings[i] = 1;
  mode = magnetoMode;
  delay(300);
}

void playing(byte i) {
  //Plays a recording
  digitalWrite(pinG, HIGH);
  audio.play(files[i]);
  //If single button the playback stops and returns to magneto mode
  while(audio.isPlaying()){
    btn.read();
  }
  digitalWrite(pinG, LOW);
  mode = magnetoMode;
  delay(300);
}

```

```

void erasing(byte i) {
    //Erase recording in the specified cardinal slot
    if(SD.remove(files[i])) {
        recordings[i] = 0;
        Serial.print("Erase 1 audionote to the ");
        Serial.println(cardinalNames[i]);
    }
    else {
        Serial.println("Error: Audionote does not exist");
    }
    mode = magnetoMode;
    delay(300);
}

byte readOrientation() {
    //Reads the current cardinal orientation
    byte reading = 0;
    float angle = 0;
    if (myIMU.dataAvailable() == true) {
        //Convert yaw / heading to degrees
        angle = (myIMU.getYaw()) * 180.0 / PI;
        if(angle < 0) angle = 360 + angle;
        angle = angle - 250;
        if(angle < 0) angle = 360 + angle;
        Serial.println(angle);
        if (0 < angle && angle <= 45) reading = 4;
        if (45 < angle && angle <= 90) reading = 5;
        if (90 < angle && angle <= 135) reading = 6;
        if (135 < angle && angle <= 180) reading = 7;
        if (180 < angle && angle <= 225) reading = 0;
        if (225 < angle && angle <= 270) reading = 1;
        if (270 < angle && angle <= 315) reading = 2;
        if (315 < angle) reading = 3;
        orientation = reading;
        Serial.print("Heading to ");
        Serial.println(cardinalNames[orientation]);
    }
    return orientation;
}

```

LSDCognition.ino (Arduino code)

```
/*
////////////////////////////////////////////////////
// LSD COGNITION ///////////////////////////////////
////////////////////////////////////////////////////

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//////////////////////////////////////////////////// ESP32 WROOM SETTINGS ///////////////////////////////////
Tools > Board: Adafruit ESP32 Feather
Tools > Upload speed: 115200
*/

//////////////////////////////////////////////////// BNO080 IMU Sensor ///////////////////////////////////
#include <Wire.h>
#include "SparkFun_BNO080_Arduino_Library.h"
BNO080 myIMU;

//////////////////////////////////////////////////// BLUETOOTH SERIAL ///////////////////////////////////
#include <BluetoothSerial.h>
BluetoothSerial SerialBT;

#define RXD2 16
#define TXD2 17
String message;

void setup() {
  Serial.begin(115200);
  // BNO080 Initialization
  Wire.begin();
  if (myIMU.begin() == false)
  {
    Serial.println(F("BNO080 not detected at default I2C address."));
    while (1)
      ;
  }
  Wire.setClock(400000); //Increases I2C data rate to 400kHz
  myIMU.enableRotationVector(1); //Sends data update every 50ms
  SerialBT.begin("ESP32");
  //Decawave DWM1001 Initialization
  Serial2.begin(115200); //DWM1001 require 115200 baud
  Serial2.write(0x0D); // "Enter"
  Serial2.write(0x0D); // "Enter" (gets into Shell Mode)
  message = Serial1.readString(); //Reads the response from dwm1001
  Serial2.write(0x6C); // "l"
  Serial2.write(0x65); // "e"
  Serial2.write(0x70); // "p"
  Serial2.write(0x0D); // "Enter" (Sends the message "lep" to show position of tag)
}

void loop() {
  //DWM1001 Position
  SerialBT.print(Serial2.readStringUntil('\n')); //Print position in Serial Monitor
  SerialBT.print(F(", "));
  //BNO080 Orientation
  if (myIMU.dataAvailable() == true)
  {
    float roll = (myIMU.getRoll()) * 180.0 / PI; //Convert roll to degrees
    float pitch = (myIMU.getPitch()) * 180.0 / PI; //Convert pitch to degrees
    float yaw = (myIMU.getYaw()) * 180.0 / PI; //Convert yaw to degrees
    SerialBT.print(roll, 1);
    SerialBT.print(F(", "));
    SerialBT.print(pitch, 1);
    SerialBT.print(F(", "));
    SerialBT.print(yaw, 1);
    SerialBT.println();
  }
}
```