Space, people, networks: Exploring the relationship between built structures and seamless wireless communication infrastructures

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Abstract

In this thesis, I investigate wireless communication from an architectural perspective. I am using design prototypes to explore possibilities for interaction and designing with *wirelessness* in mind. The public primarily regards wireless networking technology as a technical infrastructure that should provide a seamless flow of information across a network of base stations, access points and mobile devices. From this perspective, wireless infrastructure is evaluated in terms of network availability and speed, and is continuously optimised. Researchers explored some other perspectives on wireless communication technology: they used computational spatial analysis to measure signal propagation in space. Some ethnographic studies explored its effect on the use of public space. Wireless connectivity was also explored through the philosophical framework of radical empiricism. All this points to the fact that wireless network infrastructure is a complex topic, spanning multiple fields of expertise and interest (engineering, architecture, urban studies but also sociology and philosophy). It is rarely explored from a plural perspective, as each study typically focuses on the one aspect within its expertise.

I propose a more complex view of wireless connectivity, encompassing these different perspectives through an intellectual framework that is based on the notion of *architecturality*. *Architecturality*, a property common to all architecture but exceeding the limits of built artefacts, is a measure of the effect something has on the experience of space. Through the lens of the built environment, I expose the complex transactions that take place between networks, people and space.

In order to evaluate *architecturality* of wireless communication signals, I conducted a series of practical design experiments, involving people and interactive installations, and using data gathered from mobile devices and wireless access points. The design of these experiments relies on the principles described by human-computer interaction (HCI) researchers as *seamful* design. *Seamful* design reveals underlying structures and relationships behind what appears as a utilitarian infrastructure. The design experiments contribute to the discussion on the use of design artefacts in practice-based research methodologies, thus challenging the different agents of knowledge production and the superiority of established research traditions.

The insights gained from this complex examination of wireless networks are important for architectural design, as a way to account more adequately for signal propagation through buildings. The experience of internalising wireless networks in the process of design engenders a designer's sensitivity towards the presence of wireless communications in space. This sensitivity, similar to the one we have for the distribution of natural and artificial lighting, will be needed in the ever more challenging design of the built environment. The sensible designer can account for, and envision, more dynamic environments that are able to accommodate change and information in completely new ways.

Keywords: Wireless connectivity, Architecturality, Experience of space, Prototyping, Design, Seamful design, Tactical networking, Knowledge production, Research through design

Résumé

Cette thèse porte sur la communication sans fil dans une perspective architecturale et explore les modèles de design interagissant avec les ondes sans fil. La technologie de communication sans fil a souvent été considérée du point de vue technique, en tant que fournisseur d'un flux d'information continu à travers un réseau fait de stations de base, points d'accès et d'appareils portables. Ainsi, cette infrastructure est appréciée pour sa disponibilité et sa vitesse de transmission, et elle est optimisée en continu. D'autres perspectives sur la technologie de communication sans fil ont également été étudiées. Des chercheurs par exemple travaillant sur l'analyse spatiale informatique ont développé des outils pour mesurer la propagation des signaux dans l'espace bâti. Des études ethnographiques ont également permis d'évaluer leurs impacts sur l'usage de l'espace public. La connectivité sans fil a aussi été abordée en philosophie telle qu'auprès du courant de l'empirisme radical. Tout ceci démontre le fait que l'infrastructure des réseaux sans fil est un vaste sujet regroupant des thèmes complexes, des domaines d'expertise et d'intérêts variés (ingénierie, architecture, études urbaines, mais aussi sociologie et philosophie). Toutefois, les réseaux ont rarement été examinés dans une perspective plurielle; chaque étude se focalisant sur leur propre expertise.

Je propose alors un nouveau regard sur la connectivité sans fil doté d'une plus grande complexité et cherchant à englober l'ensemble de ces différentes perspectives fondé sur l'idée d'architecturalité comme cadre réflexif (ou conceptuelle ou heuristique). Cette dernière est née d'une caractéristique que toute architecture possède, mais qui dépasse les limites du cadre bâti ou urbain. Le concept introduit ici d'Architecturalité parle surtout et avant tout de l'expérience de l'espace. Ce nouvel angle d'approche permet de (re)considérer la complexité des interactions entre les individus, les réseaux et l'espace.

Pour évaluer l'architecturalité des signaux de communication sans fil, une série d'expériences a été organisée, comprenant des installations interactives et des individus invités, en utilisant les données collectées par les appareils portables et les points d'accès en proximité. La réalisation de ces expériences est basée sur le principe décrit par les chercheurs des interactions homme-machine (IHM) comme « la conception couturé » (« seamful design »). Une telle approche à la conception révèle les structures sous-jacentes et les relations cachées, occultées par une infrastructure utilitaire. Ces expérimentations contribuent également au débat sur la recherche en architecture basée sur la pratique du projet utilisant les objets issus du design, tout en questionnant les différents agents de la production de la connaissance et les diverses traditions de la recherche établie.

L'appréciation de ces investigations sur les réseaux sans fil assure un apport important dans la conception architecturale, offrant une manière pour mieux répondre à la demande de connectivité et de la propagation de signaux autour des bâtiments. L'expérience de la conception avec des réseaux sans fil intériorisés rend les individus plus sensibles à la présence des communications sans fil dans l'espace. Cette sensibilité, similaire à celle que nous avons aujourd'hui pour la diffusion de la lumière naturelle ou artificielle, peut devenir un outil nécessaire dans la conception architecturale contemporaine. Le

concepteur initialement sensibilisé pourra répondre aux besoins de l'environnement de façon plus dynamique tout en pouvant accueillir les constantes transformations ainsi que les évolutions de l'information d'une manière novatrice.

Mots clés : Connectivité sans fil, Architecturalité, Expérience de l'espace, Prototype, Design, Seamful design, Tactiques d'interconnexion, Production de la connaissance, Recherche par la pratique du projet

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1. Introduction

The tale of *The Emperor's New Clothes* is a story about collective compliance to an imaginary. It exposes a consensual group illusion of people in a small town, facing the risk of questioning their competence, intelligence and position in the community. The emperor is obviously naked, and people can see it with their own eyes. Yet, they incorrectly assume that others can see the clothes and go along with the myth. Thus, the phrase "emperor has no clothes" became a byword for human vanity and pluralistic ignorance[1]. Numerous authors have used this phrase in their work, ranging from popular culture to scientific books such as the sceptical examination of artificial intelligence by Roger Penrose, *The Emperor's New Mind*.

Similar to the town situation in the tale, Natalie Jeremijenko observed in 1997 how Cyberspace became a "collective hallucination of immateriality"[2]. Disregarding the machinery that it runs on, Cyberspace was often referred to as spiritual, transcendental and immaterial, for the sake of maintaining its novel character. Jeremijenko's observation was incorporated into the discourse

1) Maria Tatar, *The Annotated Hans Christian Andersen*, 1st ed (New York: W.W. Norton, 2008).

2) Natalie Jeremijenko, 'Database Politics and Social Simulations', *Technology in the 1990s*, April 1997, http://tech90s.walkerart.org/nj/transcript/nj_04.html.

on media materiality, currently pursued in contemporary media minded circles[3]. It also sets the ground for discussion on wireless networks through the "emperor's new..." metaphor.

In an environment overcrowded with people, animals, cars, buildings, networks, all types of exchanges and traffic between them, we rely on a large network of antennas and devices connected through wireless-communication infrastructures to provide us with a seamless flow of information. We only pay attention to the performance of this network when it fails our expectation of availability or speed. How do these signals actually propagate in physical space? How do they perform? How does our experience of space change when the performance of these waves is brought to the foreground? What is their relevance for architecture?

Wireless networks are *invisible* to our eyes (and other senses), which is why we sometimes consider them *immaterial*. The diversity of meanings *invisible* and *immaterial* invoked when talking about cities, spaces and architecture gives rise to a multitude of discussions about the presence of signals in our environment. For some, invisible is simply everything we cannot see and measure: dreams, memories, events inscribed into places. This is the approach taken by Italo Calvino in the ambiguous *Invisible Cities* book. This exploration of the author's own moods and reflections uses the *city* as a metaphor for a mix of psychological, physical and sensory states. It is a hunt for the hidden reasons that bring men to cities, in light of what the author perceives as the crisis of the overgrown metropolis[4]. Calvino transformed everything into a city: books, exhibitions, personal discussions. At the same time, everything makes a city for him: memories, desires, words. Such an opaque and personal perspective on cities inspired numerous art projects and events (for example, the *Invisible Cities* opera produced in 2013). This parallel unfortunately also conflates the *invisible* with *non-measurable* or that which cannot be sensed, the *un-sense-able*. It conflates moods and desires with electromagnetic radiation.

This thesis is attuned towards the objective presence of electromagnetic signals more than towards speculative effects of moods, memories and dreams on places. I create some order in the general understanding of wireless-communication infrastructure and seamless connectivity from the perspective of the space they occupy.

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3) Materiality of communications was explored in parallel with the immaterial accounts of cyberspace typical for the writing of Manuel Casells and his contemporaries. Starting with Jean-François Lyotard's 1985 exhibition Les Immateriaux, which will be discussed later in this chapter, we can trace this thought throughout the numerous publications that address materiality from the philosophical, sociological or media theory perspective, most notably in Hans Ulrich Gumbrecht and Karl Ludwig Pfeiffer, eds., Materialities of Communication, Writing Science (Stanford, Calif: Stanford University Press, 1994)., Matthew Fuller, Media Ecologies: Materialist Energies in Art and Technoculture (Cambridge, Mass.; London: MIT, 2007)., Jussi Parikka, What Is Media Archaeology? (Cambridge: Polity Press, 2012). and Paul R. Carlile et al., eds., How Matter Matters: Objects, Artifacts, and Materiality in Organization Studies, 1st ed, Perspectives on Process Organization Studies, v. 3 (Oxford: Oxford University Press, 2013).

4) Italo Calvino, 'Italo Calvino on "Invisible Cities"', *Columbia: A Journal of Literature and Art*, no. No. 8 (Spring/Summer 1983) (1983): 37–42.

Figure 1.1: Wind, an invisible feature of the environment, rendered visible by a bending tree

In our surroundings, there are many phenomena that cannot be seen with our eyes – temperature, moisture, wind, electrical charge of machines, availability of networks, etc. Most of these have a physical effect on our experience. For example, temperature is an invisible feature of our environment that we are clearly sensitive to, but we have subjective experiences of hot and cold. Whereas we have no physical sensitivity for the availability of networks, we do have an *appetite* for networks and bandwidths. Our bodies are not attracted to *connectivity* but our brains are.

Engineers design infrastructures that remain in the background and enable seamless functioning of systems they are engineered for. We could say that systems become infrastructure when they work sufficiently well that we stop noticing them[5)] . Discussing infrastructures demands the extra effort of getting distance from something we are semi-consciously engaged with on everyday basis. An even greater problem is that we often do not understand how they work, apart from clicking the "connect" button on our screens or choosing a mobile operator for our smartphones.

We intuitively couple materialities of the *invisible city* and *immaterial architectures* - metaphors with suspiciously ambiguous meanings - without a deeper understanding of their properties and

5) S. L. Star, 'The Ethnography of Infrastructure', *American Behavioral Scientist* 43, no. 3 (1 November 1999): 377–91, doi:10.1177/00027649921955326.

implications. The relationship between built structures and wireless infrastructures is hence often uninterpreted in this misleading coupling of the *invisible* with the *immaterial*. My approach to wireless infrastructures accounts for the contemporary condition in which architecture and wireless connectivity are increasingly coupled, both in the home and in the office. This research is an attempt to understand the physicality of waves, their actual appearance shaped by and shaping the space of their propagation. Their physicality is manifested both as a consequence of our actions (exchange of information between our networked devices created by our conscious acts) and of the infrastructure permanently installed in the environment (the continuous machine-to-machine communication between devices authenticating each other).

Figure 1.2: Coop Himmelb(l)au, Basel Event: the Restless Sphere (1971).
Pneumatic architecture "as light as the sky" or an unusual encounter with the environment. From Coop Himmelb(l)au, http://www.coop-himmelblau.at

1.1. Wireless Networks in Architecture

Wireless communication has an ambiguous relationship with architectural design. On one hand, the expected equipment with wireless connectivity (ranging from card sensors, through Wi-Fi access points, to base stations and satellite signals) is provided by some kind of technical service - architects do not design space for *wirelessness*. On the other hand, we become increasingly aware of the effect connectedness – or disconnectedness – has on the use and functioning of spaces. In the *Code/Space* airport example, Kitchin and Dodge describe the check-in area as a space where functioning connectivity is more important for the use of space than its physical design[6]. Thus, the "emperor's new..." metaphor of pluralistic ignorance can be applied to the coexistence of wireless networks within architecture. With the increased availability of communication networks and the ease of seamless network switching, we are more and more ignorant of connectivity per se. Technology that is everywhere appears irrelevant to the use of a particular space and the experience of it. In reality it is quite the contrary – we simply have not yet developed proper models for evaluating this relevance. We collectively pretend that this is how wireless communication is supposed to be – invisible.

Rather than Calvino's *Invisible Cities*, I propose the 1985 exhibition *Les Immateriaux* (*The Immaterials*)[7], as a cultural reference to start with. The curators, Lyotard and Chaput, used the title *Les Immateriaux* to refer to the man's unceasing desire to become the master of matter[8]. Lyotard and Chaput developed a paradigm for looking at the contemporary condition (a transition from the modern to the postmodern), based on the communication model[9] that they map out through the selection of artworks and the design of the exhibition space[10]. Using the communication model, they worked towards extending the meaning of the word material (matériau) that encompasses *matières* (referents), *matériels* (hardware), matrices (*matrices*), and even *maternité* (maternity). They tried to include the immaterial in their definition of the

6) Rob Kitchin and Martin Dodge, *Code/space*, Software Studies (MIT Press, 2011).

7) *Les Immateriaux* exhibition was a collaboration between the French philosopher Jean-François Lyotard and the design theorist Thierry Chaput. It opened at the Centre Georges Pompidou in Paris in 1985.

8) Yuk Hui and Andreas Broeckmann, *30 Years After Les Immatériaux Art, Science and Theory* (Lüneburg: meson press by Hybrid Publishing Lab, 2015).

9) Lyotard develops a translation of the communication model based on five distinguished instances: the sender, the receiver, the code in which this message is written, the medium (support) on which is it written and the actual stuff of the message – the referent. He describes it through the example of architecture that has a sender (engendered by a maternity; author and investor), which aims at a recipient – thus it can be grasped by specific hardware, and is inscribed in its support medium according to a code; it has a referent - "that is, it *speaks* of something" Jean-François Lyotard, 'After Six Months of Work... (1984)', in *30 Years After Les Immatériaux Art, Science and Theory*, ed. Yuk Hui and Andreas Broeckmann (Lüneburg: meson press by Hybrid Publishing Lab, 2015), 31.

10) Lyotard, 'After Six Months of Work... (1984).'

"given" matter. Software is mind incorporated into matter; synthetic products are matter that results from knowledge. The communication paradigm is the completion of modernity, "modern project extends its communicational web to the totality of all possible "givens" so as to be able to control them by way of translation"[11]. At the same time, communication destabilises modernity, by technological infrastructure that undermines face-to-face situations and by a loss of hope in the ideas of the Enlightenment. Lyotard describes the post-modern space-time shift (from mechanical-industrial into electronic-nuclear) and asks, "What is the new space that is constituted today through these invisible networks?". The answer was to wait. Lyotard and Chaput propose patience as the strategy for grasping and practising this new system in which we are immersed. By now, I believe, we have waited long enough, to be able to propose new strategies for dealing with space constituted through invisible networks.

Wireless-network infrastructure is relevant to fields of expertise and interests as diverse as sociology, psychology, politics, philosophy, phenomenology, urban studies, architecture, computer science, electrical and communication engineering. All these fields use different instrumental lenses when evaluating the performance of networks. Technically, a network is evaluated in terms of availability and speed, and is continuously optimised. While gradually

Figure 1.3 The Internet machine film documents the usually invisible infrastructures of the Internet in a data center in Alcalá, Spain. It features server racks, routers, cables, corridors, relays and power generators, and transmits some of the noise and energy that exist around this infrastructure. A still from the film by Timo Arnall

11) Ibid., 32.

becoming indispensable, these infrastructures begin to figure as "sites of cultural contestation"[12], gaining significance as social or cultural infrastructures. Politically, this discussion raises not only questions of accessibility and distribution (Who can use the infrastructure and where?) but of political structures and societal models behind it (e.g., central service-providers as opposed to peer-to-peer networks[13]). Finally, it is the phenomenological discussion on (ambiguity of) perception (e.g., Merleau-Ponty's work on *The Visible and the Invisible*[14]) that inspired a large movement of structural and aesthetic inquiries into the properties of wireless communication. Following the philosophy of "one must see or feel in some way in order to think"[15] artistic and design practices have engaged in a myriad of ways to provoke thinking about *wirelessness.*

Barbara Tversky pointed out, in her discussion on visual thinking, that our world cannot be transcribed. Experience consists of more than that what is usually picked up in trial transcripts, "letters of law"[16]. Or, as complexity theory asserts, the whole is not the same as the sum of its parts. The phenomenon of wireless connectivity is difficult to grasp into a single perspective. In order to explore the subtle interactions between people, portable devices, physical space and wireless networks, we have to observe people, machines and waves interacting within an *imbroglio* of *actants*[17]. I have attempted to do this by designing systems that enable tracking of interactions between people, devices and network signals. These systems measure and map the amount of traffic that occurs in space, and then render it tangible through different kinds of interactive installations. Whether it is stretchable fabric or coloured light, the work undertaken attempts to bridge the physical-digital ideological divide by offering a physical experience of activity within the wireless communication layer. It promotes the observation and understanding of un-sense-able (invisible, inaudible, intangible) infrastructures.

The process of researching interferences and interactions between people, networks and space is strongly linked to a *research through design* methodology. It incorporates an iterative process of design prototypes that act as playful interfaces. Playful interaction design promotes *ludic* engagement with the artefacts and, through this, accommodates unexpected interactions. Researchers have already addressed the potential of designing spaces for play when exploring

12) A. Mackenzie, 'Untangling the Unwired: Wi-Fi and the Cultural Inversion of Infrastructure', *Space and Culture* 8, no. 3 (1 August 2005): 269–85, doi:10.1177/1206331205277464.

13) William Lehr and Lee W McKnight, 'Wireless Internet Access: 3G vs. WiFi?', *Telecommunications Policy* 27, no. 5–6 (June 2003): 351–70, doi:10.1016/S0308-5961(03)00004-1.

14) Maurice Merleau-Ponty, *The Visible and the Invisible* (Evanston [Ill.: Northwestern University Press, 1968).

15) Ibid., 146.

16) Barbara Tversky, 'Visualizing Thought: Topics in Cognitive Science(2010)', *Topics in Cognitive Science* 3, no. 3 (July 2011): 499–535, doi:10.1111/j.1756-8765.2010.01113.x.

17) *Bruno Latour, We Have Never Been Modern* (Cambridge, Mass: Harvard University Press, 1993).

our relation to the environment[18]. The transformative power of play makes it invaluable for open-ended inquiries into behaviours, relationships and interactions. With this work, this thesis contributes to a growing discourse on design-led research methodologies and the possibility for design practice to advance acquisition of knowledge.

1.2. Infrastructure Ground

Wireless-network infrastructure is an implementation of communication technology at the edges of telecommunications infrastructures[19]. It is attached to the surface of existing structures (walls, ceilings or furniture in building interiors; and on roofs, walls, towers at the exterior). It is a technology that coexists with built structures, altering in some ways the experience of these environments.

Traditionally, architecture is considered an additive practice of building, of concrete material intervention (or its proposal), and not of revealing something that is inaccessible to our senses. This research, however, looks at wireless communication signals as important constituents of our surroundings hence our experience of architecture and space. From a perspective on architecture attuned to building, the practice of revealing electromagnetic signals in space is not very architectural. We would nevertheless have to agree on the more basic premise that architectural design is the act of designing spatial experience. It is a mediation of spatial experience between buildings, people, and increasingly also information and communication technology[20]. From here, we can derive the importance that seamless infrastructures, un-sense-able to the human body, have for our everyday interaction with the built environment and with each other.

The propagation of electromagnetic signals that constitute this seamless infrastructure is, on one hand, determined by the laws of physics. On the other hand, it is regulated by international administrative bodies, such as the Institute of Electrical and Electronics Engineers (IEEE) that provides the Wi-Fi spectrum mask. Increasingly pervasive and commodified, wireless communication channels are becoming scarce. According to numerous technical reports, the

18) Karmen Franinovic, 'Architecting Play', *AI & SOCIETY* 26, no. 2 (May 2011): 129–36, doi:10.1007/s00146-010-0292-4.

19) Adrian Mackenzie, *Wirelessness: Radical Empiricism in Network Cultures* (The MIT Press, 2010).

20) Malcolm McCullough, *Digital Ground: Architecture, Pervasive Computing, and Environmental Knowing* (The MIT Press, 2004); Malcolm McCullough, *Ambient Commons: Attention in the Age of Embodied Information* (Cambridge, Massachusetts: The MIT Press, 2013).

available spectrum[21] is used about as efficiently as possible[22]. In addition to the spectrum's political administration, communication technology also reaches limitations in terms of propagation capacities and transmission power. The industry continuously proposes new technologies that rely on different communication algorithms and infrastructure distribution. This implies, for example, transferring to even smaller transmission areas and multiplying the number of base stations (picocells) or decentralising the base station network. Other proposals include the use of different transmission media, such as beams of visible light. Therefore, one important contemporary challenge, in the urban environment and beyond, is how these forecast needs for wireless-communication bandwidth will be satisfied and in what way new technologies will populate our environment. This discussion on current and future wireless-signals space occupancy is highly relevant to architectural and urban design.

1.2.1. Spectators of the Built Environment

With the increased presence of wireless-communication infrastructures in daily life, we gain familiarity and lose awareness. In his critique of theatre and its reform, Jacques Rancière calls this "the paradox of the spectator"[23]. One one hand, "being a spectator means looking at a spectacle", which is the opposite of knowing or acting. It puts us into a motionless, passive state lacking any power of intervention. This resonates with Guy Debord's critique of the spectacle causing passive immersion of (un-emancipated) spectators. Using infrastructures as given is similarly passive and entails the impossibility of manipulation and critique. From here, as logic (and Rancière) suggests, we could derive that the only way to resist this passivity is to abolish the infrastructure (or theatre) altogether. On the other hand, we could follow Rancière's more interesting proposal for a different theatre, frequented by the emancipated spectator and actor. The difference is not so much in the distribution of bodies or territories. Exchanging places of audience and actors or performing on the streets were strategies typical of the reformed theatre of 1960s. What Rancière proposes is a different reading of the activity involved in being a spectator, understanding that this is our normal situation in which we constantly make links and learn. Emancipation thus abolishes this passive-active dichotomy. Actors are spectators of the effect their skills have in the context of a particular situation, together with other spectators.

21) The Wi-Fi available spectrum is currently operating within unlicenced 2.4 and 5GHz limited spectrum bands, through the spectrum mask that has been defined by the IEEE 802.11 standard.

22) Robert W. Lucky, 'Wi-Fi and Cellular: Who's the Boss? - IEEE Spectrum', 16 August 2013, http://spectrum.ieee.org/telecom/wireless/wifi-and-cellular-whos-the-boss.

23) Jacques Rancière, *The Emancipated Spectator* (London: Verso, 2009).

Following on Rancière's argument, I propose here a research into what ethnographer of infrastructures, Susan Leigh Star, calls "the backstage of boring things"[24] . The focus on the backstage promises to , uncover the *agency*[25] that is inherent in the waves carrying signals and the possibilities of interacting with them in different ways. Rather than searching for fantastic effects of these waves, I will observe them through an emancipated lens, trying to recognise and reveal how awareness of their performance, along with people's activity, can change something in our experience of the built environment.

1.3. The Problem Statement

In this thesis, I focus on the many wireless-communication infrastructures that have surfaced the earth in the past twenty years. Taking a critical stance towards their proliferation and accessibility[26] , I will describe ways in which the performance of these wireless networks becomes relevant for the experience of space.

Waves carry data. How much data? Is there a difference in spatial behaviour of waves depending on the load and bandwidth? If so, where does this difference come from?

The first wireless network products appeared less than two decades ago. By 2005, 2 billion people had mobile phones across the world; in 2010 this number more than doubled and more than tripled as of 2015 (estimated to 6.878 billion). The number of wireless-network access points is measured in billions (see for example Wigle statistics[27]). Mobile-broadband subscriptions, introduced around 2010 grew from 800 million to 2.3 billion in the timespan of 4 years.[28]

The speed with which wireless-communication systems were implemented was so quick and so pervasive that we are still in some kind of shock. At the same time, we are witnessing a normalisation of connectivity into "sites of cultural contestation"[29] or cultural infrastructures. We expect connectivity and data flow everywhere all the time, in order to be able to conduct basic social transactions. We only notice the performance of this infrastructure when it fails our

24) Star, 'The Ethnography of Infrastructure.'

25) The idea of non-human agency, as discussed by Pickering (1995), Barad (2003) and Barandiaran (2009) describes the potential of something to adapt to and affect its environment. The notions of non-human *agency* and *performativity* of wireless signals are discussed more in detail in Chapter 3: Connectivity in Action/Form.

26) Mackenzie, *Wirelessness: Radical Empiricism in Network Cultures.*

27) https://wigle.net/stats, retrieved on the 04th of August 2015

28) Most information presented here is based on ITU report on key 2005-2014 ICT data for the world http://www.itu.int/en/ITU-D/Statistics/Documents/statistics/2014/ITU_Key_2005-2014_ICT_data.xls

29) Mackenzie, 'Untangling the Unwired.'

expectation of availability and speed. The normalisation of wireless communication opened a different perspective for the role of networking from the time when first wireless-communication standards such as Bluetooth were released. Back in the early 2000s, Bluetooth data-exchange was a novel thing, and the researchers were preoccupied with people's awareness and how they made sense of it; analysing the perceived hybrid space created by immersion of physical and social objects, people and social practices.[30] This approach was supported by what Chalmers articulated as *seamful* design[31] or careful and intentional design of seams that appear at the edges of connectivity, territories and digital tools. *Seamful* design is an approach that reveals underlying structures and relationships behind what appears as utilitarian infrastructure.

If today someone would talk about *seamful* design and create an application that beeps every time their phone is in the area of a particular wireless network (as was the case of the MobiTip app designed by Rudstrom and the team), the users would simply find this disturbing and irrelevant. We have lived too long with this technology to want to be constantly reminded of it. However, we have not lived with it long enough to actually understand its impact on us and on our interaction with the environment.

1.4. The Research Question

How do wireless networks perform architecturally in space?

The wireless environment changes dynamically and is hard to represent. Rendering the performance of wireless networks perceptible through aesthetic manipulation raises our awareness of their logic of propagation and the multitude of factors involved. This awareness of the materiality of wireless communication does not in fact change the experience of space; it changes the experience of communication.

In this thesis, I propose a complex view of wireless connectivity, encompassing the different perspectives of it through an intellectual framework that is based on the notion of *architecturality*. *Architecturality*, a property common to all architecture but exceeding the limits of built artefacts, is a measure of the effect something has on the experience of space. Through the lens of the built environment, I expose the complex transactions that take place between networks, people and space.

30) Åsa Rudström, Kristina Höök, and Martin Svensson, 'Social Positioning: Designing the Seams between Social, Physical and Digital Space', in *1st International Conference on Online Communities and Social Computing* (HCII 2005, Las Vegas, 2005).

31) Matthew Chalmers, 'Seamful Design and Ubicomp Infrastructure', in *Proceedings of Ubicomp 2003 Workshop at the Crossroads: The Interaction of HCI and Systems Issues in Ubicomp* (Citeseer, 2003).

The question about wireless-networks performance requires a discussion on the notion of *performativity* of the built environment – architecture and infrastructures included[32] . *Performativity* is the potential for both built and seamless structures and infrastructures to perform on each other; it is the inherent capacity to affect the constituents of the environment (including buildings, people and networks). It is about adapting to the conditions of the environment while *performing* towards a certain goal. Following the discussion on *performativity* I introduce the notion of *architecturality* - a property common to all architecture but exceeding the limits of built artefacts and urban spaces. The notions of *performativity* and *architecturality* are linked to the notion of non-human *agency*[33] ; it can be observed in the propagation of wireless signals throughout the built environment (see Chapter 3: *Connectivity in Action/Form*). These notions are used to evaluate the potential wireless networks have on affecting in a significant way the experience of space.

1.5. Introduction to the Thesis Chapters

1.5.1. Chapter 2: Research through Design, Art and Architecture. From the Research Question to Design Artefact

This research relies on exploratory and practice-based methodologies that look at the performance and perception of wireless connectivity in space. I created different design prototypes to explore possibilities for tangible interaction with wireless network traffic. These prototypes also contribute to the discourse of research through design.

Practice-based research methods have been the subject of a fierce debate across artistic-based and engineering-informed academic institutions. The basis for the current discussion are the publication of Frayling's influential treatise on research *into*, *through* and *for* art and design[34] , the introduction to artistic research by Balkema and Slager[35] , a further elaboration on artistic open-

32) Michael Hensel, *Performance-Oriented Architecture: Rethinking Architectural Design and the Built Environment*, AD Primers (Chichester, West Sussex: Wiley, A John Wiley and Sons, Ltd, Publication, 2013); Branko Kolarevic and Ali Malkawi, eds., *Performative Architecture: Beyond Instrumentality* (New York: Spon Press, 2005); Jan Smitheram, 'Spatial Performativity/Spatial Performance', *Architectural Theory Review* 16, no. 1 (April 2011): 55–69, doi:10.1080/13264826 .2011.560387; Karen Barad, 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter', *Signs* 28, no. 3 (2003): pp. 801–31; Chris Salter, *Entangled: Technology and the Transformation of Performance* (Cambridge, Mass: MIT Press, 2010); Chris Salter, *Alien Agency: Experimental Encounters with Art in the Making* (Cambridge, Massachusetts: The MIT Press, 2015); Keller Easterling, *Extrastatecraft: The Power of Infrastructure Space* (Brooklyn: Verso, 2014); Keller Easterling, *The Action Is the Form. Victor Hugo's TED Talk*, 1 edition (Strelka Press, 2012).

33) Andrew Pickering, *The Mangle of Practice: Time, Agency, and Science* (Chicago: University of Chicago Press, 1995).

34) Christopher Frayling, *Research in Art and Design* (London: Royal College of Art, 1993).
35) Annette W. Balkema and Henk Slager, eds., *Artistic Research*, Lier En Boog Series 18 (Amsterdam: Rodopi, 2004).

ended research methodologies[36], *The Artistic Turn: A Manifesto*[37], as well as Borgdorff's writing on the conflict of the faculties[38]. In design and architecture circles this discussion has divided the research scene: those who prefer to hold onto the methodology and terminology established with Simon's definition of *sciences of the artificial*[39], and those who work towards developing new, experience-oriented methods, sometimes delivering unexpected insights into phenomena they explore, at other times uncritically pursuing design practice as research.

In this chapter, I focus on the use of design or artistic artefacts in research, their role and potentials, as well as problems such research faces with reference to its legitimacy and contribution to knowledge. I will re-iterate major points in the existing literature in order to integrate some of the ideas in this discussion. Through a concrete example of a research project, from research question to design artefact , I will support the critique of the (r)evolving role of design artefacts in practice-based research will be supported. Finally, I will offer criteria for evaluation of these artefacts, in their specific relationship to this thesis.

1.5.2. Chapter 3: Connectivity in Action / Form. A Model for Evaluating the Effects of Wireless Communication on the Experience of Space

The discussion in this chapter is based on what at first appears as a weak argument: that *architecturality* of wireless communication infrastructure results from the fact that wireless signals, like architecture, incorporate *agency*. The weakness of this argument resides mainly in the fact that agency is not the most perceived property of architecture - it is a contested feature and requires complicated argumentation. Nevertheless, I will demonstrate how it is precisely here that we should build foundations of a model for evaluating the effects of wireless communication on the experience of space.

Wireless-network infrastructures - built from scattered devices, base stations, repeaters, access points and ' a bouillon of waves' that connect them - have a prominent place in our interaction with the environment and with each other. Whether or not this new layer reconstitutes our experience of the 'real' world or recomposes social interactions[40] - we have to recognize the

36) Mika Hannula, Juha Suoranta, and Tere Vadén, *Artistic Research: Theories, Methods and Practices* (Helsinki : Gothenburg, Sweden: Academy of Fine Arts ; University of Gothenburg/Art Monitor, 2005).

37) Kathleen Coessens, Darla Crispin, and Anne Douglas, *The Artistic Turn: A Manifesto*, Collected Writings of the Orpheus Institute Orpheus Research Centre in Music (ORCiM) 01 (Leuven: Leuven Univ. Press, 2009).

38) Henk Borgdorff, *The Conflict of the Faculties: Perspectives on Artistic Research and Academia* (Amsterdam: Leiden University Press, 2012).

39) Herbert A. Simon, *The Sciences of the Artificial*, first (Cambridge, Massachusetts: MIT Press, 1969).

40) Eric Gordon and Adriana de Souza e Silva, *Net Locality* (Chichester, UK: Wiley-Blackwell, 2011).

difficulty in reading its effect on space and people.

One way to address this problem is to examine waves as *agents* that deliver connectivity to people and devices across built environments. In order to do so, I introduce the term *architecturality*: it refers to a property common to all architecture but that exceeds the limits of built artefacts and urban spaces. I examine a*rchitecturality* through the notions of *performativity*[41] and form-giving action[42], as a potential for affecting the experience of space in a significant way.

Wireless communication signals partake in the production of urbanity as connectivity that is or is not available to people and devices. Ultimately, they outline a binary spatial configuration: connected and disconnected places. In this respect, relying on the post-humanist[43] and flat-ontological[44] discussion on non-human agency, I regard waves as structural infrastructure. I examine the materiality of connectivity - a phenomenon beyond mere functioning connection – the form given to *wirelessness* through action.

1.5.3. Chapter 4: Networks Present at Hand / in Space

In this chapter, I describe wireless signals in their materiality - physical properties of waves propagating with the purpose of communication, in the context of the built environment. From the early days of signal transmission across long distances (starting with Marconi's transatlantic communication experiments) to the current state where we are overloaded with wireless devices, wireless communication infrastructure has developed significantly. Does this electromagnetic environment reflect the physical space in which is it contained?

I discuss spatial relevance of wireless networks, revisiting three studies that focus on networks coverage and the dynamics of their use in specific settings (university campus, city centre)[45]. The studies find a correlation between space and signal propagation but also point at the complexity of its accurate representation and social implications. An account of the spatiality

41) Barad, 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter.'

42) Easterling, *The Action Is the Form. Victor Hugo's TED Talk.*

43) Katherine N. Hayles and Arthur Piper, 'How We Became Posthuman : Ten Years On An Interview with N. Katherine Hayles', *Paragraph* 33, no. 3 (November 2010): 318–30, doi:10.3366/para.2010.0202.

44) Levi R. Bryant, 'Imbroglios of Objects', *Larval Subjects*, 20 August 2009, https://larvalsubjects.wordpress.com/2009/08/20/imbroglios-of-objects/.

45) Three studies discussed here used different spatial analysis tools to asses the use of networks: Andres Sevtsuk et al., 'Mapping the MIT Campus in Real Time Using WiFi', in *Urban Informatics*, 2008; Teresa V. Heitor et al., 'Synchronizing Spatial Information In Complex Environments: A Crossover of Space Syntax and Spatial Information Visualization', in *6th International Space Syntax Symposium, İstanbul, 2007* (Istanbul, 2007), 1–18; Paul M. Torrens, 'Wi-Fi Geographies', *Annals of the Association of American Geographers* 98, no. 1 (February 2008): 59–84, doi:10.1080/00045600701734133.

of wireless connectivity is also given in ethnographic studies on the use of networks in public space, parks and cafés for work and other everyday practices[46] These studies put forward more daring conclusions then previously mentioned inquiries in network distribution, stating that wireless networks reconfigure space in a number of ways.

Wireless communication is characterised by the expectancy of its complete obscurity to our perception. Infrastructure is anything that resides in the background of other work. I will examine some basic properties of infrastructures, through the ethnographic work of Suzanne Leigh Star[47] and Armand Mattelart's political and strategical account of network evolution[48] . I will then address the notions of affordance and perception of connectivity in the tradition of Gibson's ecological approach through the experience of technology[49] and more specifically, wireless networks[50] .

1.5.4. Chapter 5: Ruptures in Seamless Infrastructure

Systems become infrastructure when they work sufficiently well that we stop noticing them[51] . Wireless communication networks (Wi-Fi, Bluetooth, NFC, GSM, 3G, 4G) are part of such a system, functioning in the background and enabling ubiquitous computing to be seamlessly embedded in the environment.

To counter the trend of seamless connectivity, I put the concept of *seamful* design, as introduced by early human-computer interaction (HCI) researchers and designers in advocating the intentional design of seams that appear at edges of connections and territories. Such design encourages user engagement[52] and the understanding of the resulting combined space[53] . In her

46) Two most prominent studies that applied ethnographic methods appeared around the same time: Laura Forlano, 'WiFi Geographies: When Code Meets Place', *The Information Society* 25, no. 5 (8 October 2009): 344–52, doi:10.1080/01972240903213076; Laura Forlano, 'Making Waves: Urban Technology and the Co–production of Place', *First Monday* 18, no. 11 (27 November 2013), doi:10.5210/fm.v18i11.4968; Keith Hampton et al., 'The Social Life of Wireless Urban Spaces', *Contexts* 9, no. 4 (1 September 2010): 52–57, doi:10.1525/ctx.2010.9.4.52.

47) Star, 'The Ethnography of Infrastructure.'

48) Armand Mattelart, *Networking the World, 1794-2000* (Minneapolis, Mn: University of Minnesota Press, 2000).

49) John McCarthy and Peter Wright, *Technology as Experience* (Cambridge, Mass: MIT Press, 2004).

50) Mackenzie, *Wirelessness: Radical Empiricism in Network Cultures*.

51) Paul Graham Raven, 'An Introduction to Infrastructure Fiction — Improving Reality 2013 | Infrastructure Futures | Futurismic', *Futurismic*, 31 October 2013, http://futurismic.com/2013/10/31/an-introduction-to-infrastructure-fiction-improving-reality-2013/; Star, 'The Ethnography of Infrastructure.'

52) Paul Dourish, *Where the Action Is: The Foundations of Embodied Interaction* (Cambridge, Mass.: MIT Press, 2001).

53) Rudström, Höök, and Svensson, 'Social Positioning: Designing the Seams between Social, Physical and Digital Space.'

account of the power of software, Inke Arns observed information hiding implied in software transparency as opposed to transparency in everyday language[54]. Some contemporary design practitioners oppose the myth of immateriality and disappearance of interfaces[55]. Smoothing out the edges and seams entails a loss of agency for designers and computers, as well as for users.

I will use the concept of *seamfulness* to discuss possibilities for re-engaging with wireless communication. I will offer a reading of such practices as *tactics*[56] in de Certeau's tradition[57], placed against the infrastructural aspect of antennas and providing of signals, which is a *strategic* activity. To conclude, I will discuss ways to imagine possible future interactions in the wireless communication spectrum that is already used about as efficiently as possible. I will consider Raven's *Infrastructure Fiction*[58] and similar approaches to explore future connectivity demands.

1.5.5. Chapter 6: Probing the Network: *Architecturality* of Wireless Infrastructure in Works of Media Art and Design

Every new technology is subject to inflated expectations. Scholars, writers, artists and architects have explored how the new digital layer, created through proliferation of wireless-enabled gadgets, could *reconfigure* our experience of space and *recompose* social interactions in it.

In reality, although significant, the effect of wireless technology has not been that spectacular. In this chapter, I will discuss a number of design and artistic practices attuned to understanding and articulating the interplay of social, digital and physical infrastructures. These artistic and design artefacts outline a tangible territory of interactions and contribute to our understanding of the physicality of wireless communication and its coexistence within the built architecture. Aesthetic experiments, playful interventions and critical designs all conceptualise interactions with an otherwise un-sense-able infrastructure. I will identify common threads in the ways these artworks manipulate the wireless *material*, with a focus on the underlying motivation and resulting outcomes. Using this, I will discuss these practices in the light of their relevance for and reference to architecture.

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54) Inke Arns, 'Read_me, Run_me, Execute_me: Software and Its Discontents: Or It's the Performativity of Code, Stupid!', in *Read_me Software Art & Cultures*, 2004, 177–93.

55) Timo Arnall, 'No to NoUI', 13 March 2013, http://www.elasticspace.com/2013/03/no-to-no-ui.

56) *In "The Practice of Everyday Life", de Certeau introduced the notions of tactics* and *strategy* as two states of power which are not mutually exclusive or binary oppositional. 'Strategy' belongs to a subject with will and power. 'Tactics' are creative ways of quietly subverting time, facilities and infrastructures. One gives rise to the other.

57) *The Practice of Everyday Life* (University of California Press, 1984).

58) Raven, 'An Introduction to Infrastructure Fiction — Improving Reality 2013 | Infrastructure Futures | Futurismic.'

1.5.6. Chapter 7: Projects and Prototypes

Before introducing the practical investigations in the scope of this research, I describe the conceptual underpinnings of my approach to what is generally termed *research through design* methodology. I will focus particularly on identifying the design artefact's contribution to this methodology.

These design artefacts are interactive prototypes, involving physical surfaces, light, sound and movement as *interactants* between people and network traffic. For the majority of tests and presentations, data were collected using a smartphone (Android) application that serves as a location-aware traffic counter.

I have presented the results of these design investigations to the public in different settings - some were tested at research symposia, others were shown at cultural events, others yet in internal lab settings. All these presentations were followed by discussions, in the form of open-ended interviews. I used notes from the presentations (interviews and behaviour observations), together with network traffic data generated by the same audience, to make generalisation on how people, networks and space perform together and on each other.

1.5.7. Chapter 8: Discussion and Conclusions

The relationship between the way wireless signals spread in the environment and the space they occupy is not simple. The signal's actual propagation is the difference between the signal-propagation model, the permeability of buildings, the movement of bodies and people's communication activity. It is thus necessary to preserve an *irreductionist*[59] view of the phenomenon of waves propagating through space.

To account for all the different *actants*, I constructed a conceptual framework (intersecting the fields of architecture theory, digital humanities, science and technology studies) and a practical framework (interactive prototypes coupled with a measurement tool).

The design artefacts I developed over the course of this research afford unexpected insights but also bring certain risks involved with such openness. They provide an explicit feedback about their use and the experience they invoke. In terms of design, they are like code with a many debugging statements. The process of design is minimally linear and is usually characterised by

59) Following Latour's discussion on irreducibility of the world to representations we normally use in scientific and theoretical analyses, the irreductionist perspective became widely adopted in studies of complex topics that cannot be discussed within the "purifyingly modern scientific method that uses a singular disciplinary lens" Latour, *We Have Never Been Modern*.

decisions changing along the way, what Krogh and colleagues called *drifting*[60]. Research through design is giving *agency* to artefacts.

The insights gained from this complex examination of wireless networks are important for architectural design, as a way to better account for the desired signal propagation through buildings. The experience of internalising wireless networks in the process of design engenders a designer's sensitivity towards the presence of wireless communications in a given space. This sensitivity, similar to the one we have for the distribution of natural and artificial lighting, will be needed in the ever more challenging design of the built environment.

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At the end of the thesis, four appendices provide technical details on the prototypes, notes from the presentations and visualisations of data on network traffic. This documentation should enable full reproducibility of experiments. My motivation for this is less an ambition for legitimising scientific reproducibility of results, and more about sharing of information and tools with the Open Source community from which this technical development stemmed and to which it wishes to contribute.

60) Peter Gall Krogh, Thomas Markussen, and Anne Louise Bang, 'Ways of Drifting—Five Methods of Experimentation in Research Through Design', in *ICoRD'15 – Research into Design Across Boundaries Volume 1*, ed. Amaresh Chakrabarti, vol. 34 (New Delhi: Springer India, 2015), 39–50.

2. Research through Design, Art and Architecture: from the Research Question to Design Artefact:

Research through design demarcates a field of inquiry that draws upon the centrality of practice (prototype, artefact, project) for research process. It is a field shaped by many, often contradictory, research practices that work towards defining its distinct contribution to knowledge.

The use of design or artistic artefacts in research raises important questions about legitimate knowledge production. We are witnessing an inflation of proposals and projects that aim to cross-breed the fields of art, design and architecture with different research practices. At the basis for the current discussion were the publication of Frayling's influential treatise on research *into*, *through* and *for* art and design[1)] , a further elaborations on the open-ended methodologies of artistic research[2)] and Borgdorff's debate on research in the arts[3)] that codified the fierce debate across European academic institutions.

1) Frayling, *Research in Art and Design*.

2) Hannula, Suoranta, and Vadén, *Artistic Research*; Coessens, Crispin, and Douglas, *The Artistic Turn*.

3) Henk Borgdorff, *The Debate on Research in the Arts* (Kunsthøgskolen i Bergen, 2006).

The debate can be narrowed to two important questions: What are legitimate ways for producing knowledge? How does institutional support or an imperative for research in art and design contribute to artistic and design practice?

In an attempt to answer these questions and to focus on bringing out the essence of the debate, I will use art, design and architecture somewhat interchangeably while discussing the particularities of the research methodology. It is not my intention to confuse these practices or state them as equal. It also makes little sense to introduce here an artificial formula to describe their differences. Their relationship with research stems from different traditions. Institutional debate around the restructuring of higher education in the past twenty years gave rise to an interest in artistic and practice-based research methods for acquiring and sharing knowledge. Design and research have a longer relationship, dating back to design research studies in the 1960s. Architecture's relationship to research is complicated by the habit of relying on methods of other sciences, be it geography, sociology or engineering. Architecture almost traditionally looks at these related, but very different disciplines, in search for scientific rigour and legitimacy. However, if we look back at these practices through the prism of research, engaging with art or design or architecture all are unorthodox, risky, speculative, perhaps messy and certainly original methods for arriving at research findings. They all rely on the production of some kind of artefact or project with distinct aesthetic or usability values. In the attempt to clarify the expectations of research through design, Gaver elaborates a list of activities that are most likely to constitute research through design: pursuit of some variation of user-centred design, open-ended explorations of scenarios, appreciation for craft and detail, and most importantly, discovery through the practice of making[4] . I would add that art, design and architecture all strive to open perspectives on phenomena they observe, rather than to generalise their findings through analytical thinking.

2.1. Are There (il)Legitimate Means of Producing Knowledge?

Legitimacy is a basic academic problem. Pragmatist philosopher Richard Rorty showed how it often suffices for the legitimacy of scholarly research to be recognised by one's peers. Rorty's project was a larger dismissal of the reign of truth and quest for certainty, embodied in analytical philosophy. His *Philosophy and the Mirror of Nature*[5] is a critical analysis of the pervasive western idea of epistemology. Rorty criticised Kantian and neo-Kantian understanding of philosophy as a theoretical and ethical grounding for other disciplines. In his opinion, this put truth and knowledge

4) William Gaver, 'What Should We Expect from Research through Design?' (ACM Press, 2012), 937, doi:10.1145/2207676.2208538.

5) Richard Rorty, *Philosophy and the Mirror of Nature*, 1. paperback print (Princeton, N. J: Princeton University Press, 1980).

at an equally questionable and relative stance. For Rorty, certainty was more dependent on a social construct than on an interaction with non-human reality[6]. Following the sceptical line of thought, most important continental thinkers have examined the possibility for attaining absolute truth (Wood's and Medina's *Truth*[7] would be a good reading to start with). For example, Paul Feyerabend's radical theory of methodology can be summed up in his proposed principle "anything goes". Developed in more detail throughout his writings[8], this principle implies that methods and standards of a discipline cannot make such prescriptive judgements as to guarantee progressions and alterations in scientific theory – thus, anything goes. Another Feyerabend's observation, even more important for this discussion, is his view of innovative scientific work as essentially intuitive and based on contingencies, and therefore not categorically different from art.

Through the work of pragmatist philosophers sceptical of mainstream epistemology, methodologies anchored in practice began to emerge. Numerous scholars involved with practice-based research questioned the idea of legitimate academic knowledge grounded in armchair reflection, and proposed a more involved approach. Circulating between the subjectivity of art practice and legitimacy of different agents of knowledge production, this discussion has touched upon epistemology, philosophy, art theory and history, cultural theory but also institutional bureaucracy.

The arguments in this discussion are scattered around fields of expertise or familiarity of theoreticians, who often speak from the perspective of distinct practices of art[9] or design[10], or architecture[11]. What unites the voices is the outside perception of opponents who see this as "pretend science of the project" that confuses the practice of design or art and the practice of research. If we adopt Rorty's approach to scientific legitimacy (achieved through a social contract), then we could say that practice-based research gains credibility through a network of

6) Ibid., 157.

7) David Wood and José Medina, eds., *Truth: Engagements across Philosophical Traditions*, Blackwell Readings in Continental Philosophy (Malden, MA: Blackwell Pub, 2005).

8) Paul Feyerabend, '"Science." The Myth and Its Role in Society', *Inquiry* 18, no. 2 (June 1975): 167–81, doi:10.1080/00201747508601758; Paul Feyerabend, *Against Method*, 3rd ed (London ; New York: Verso, 1993).

9) Hannula, Suoranta, and Vadén, *Artistic Research*; Coessens, Crispin, and Douglas, *The Artistic Turn*; Borgdorff, *The Conflict of the Faculties*.

10) Frayling, *Research in Art and Design*; Ilpo Koskinen et al., *Design Research through Practice: From the Lab, Field, and Showroom* (Waltham, MA: Morgan Kaufmann/Elsevier, 2011); Christopher Crouch and Jane Pearce, *Doing Research in Design*, Reprint (London: Bloomsbury, 2014).

11) Jeremy Till, 'Three Myths of Architectural Research', First Research Position Paper (Architectural Research Futures, Edinburgh: RIBA, 2005); Murray Fraser, ed., *Design Research in Architecture: An Overview*, Design Research in Architecture (Burlington: Ashgate, 2014).

peers who engage with it and serve to evaluate its results. In a discussion on experimental design research, Brandt and Binder[12] rightly ask: "on what grounds we can become each other's peers"? his brings up the problem of fallibilism, or being justified in holding incorrect beliefs.

Design research in architecture is one of the first books that explored research through design methodology in the context of architecture[13]. Bryan Lawson dismissed these efforts as "pretend-research" in his review[14]. He referred to decades of research practice that explored the process of designing[15] and studied the work of outstanding designers as a tradition that deserves the name design research. Although the book discussed by Lawson exhibits some weaknesses in its conceptual grounding, particularly because of the attempt to simply adopt existing methods developed in design for architecture, the "pretend-research" critique does not hold either. It dismisses efforts to articulate a method of inquiry that affords understanding of phenomena that exist outside of design practice, through the particular approach to knowledge making that takes advantage of the way designers think.

Another weak point in the discourse on *research through design* and *artistic research* is the communicability of results. While some theoreticians argue for an outside perspective when evaluating design artefacts, closer to the classical design resaerch, others propose communication of findings within the artefacts itself[16]. There is arguably not a lot to gain from a self-referential exploration of an artist's practice by him or herself. Such non-discursive, artefact oriented practice, more characteristic for the beginning of artistic research discussion[17], undermined the legitimacy of artistic research for a broader scientific audience. Fortunately, there is a growing body of research done by artists and designers that work constructively on communicability of findings through design or artistic artefacts, while exploring more general philosophical questions.

12) 'Experimental Design Research: Genealogy – Intervention – Argument' (International Association of Societies of Design Research IASDR07, Hong Kong, 2007).

13) Fraser, *Design Research in Architecture*.

14) Bryan Lawson, 'Book Review: Design Research in Architecture: An Overview', *Design Studies* 36 (January 2015): 125–30, doi:10.1016/j.destud.2014.11.002.

15) Studying the methods and process of designing was the initial focus of the Design Research Society founded in 1966

16) Christopher Frayling, RTD 2015 Provocation by Sir Christopher Frayling Part 7: Design-led research - the next chapter on Vimeo, interview by Abigail Durrant and James Price, 2015, https://vimeo.com/129780632.

17) Coessens, Crispin, and Douglas, *The Artistic Turn*.

2.2. From Design Research to Research *through* Design: Origins and Approaches

We can trace the beginnings of design research as a field to the post World War II reconstruction period and particularly to the boom of mass production and mass markets. From standardisation to diversification, design practice was increasingly coupled with research. This research was, at first, aimed at optimising the design processes and results but it gradually unfolded in different directions. The outputs of these efforts contributed to different intellectual niches.

Comprehensive overviews of the history, development and directions taken by design research exist already. The same is true for artistic research articulation and critique. I will nevertheless re-iterate some major points in literature in order to integrate their ideas in this discussion.

In the 1960's Herbert Simon argued for a scientific legitimacy of design research by introducing a distinction between two types of sciences - the *natural sciences* (science as we knew it) and the *sciences of the artificial*, or research activity centred around man-made artefacts[18]. While natural sciences kept an objective view of natural phenomena, which they treated analytically, sciences of the artificial are characterised by synthesis and the ambition to intervene in the way things are, "changing existing situations into preferred ones"[19]. By separating artificial from natural sciences Simon created space for a hierarchical interpretation of *scientificity* in these approaches while setting the outcomes of design research close to practice.

Initially the focus of design research was on knowledge in the area of design problems, methods and processes relevant to improvement of the practice. The first conference on design methods was held in 1962 in London[20]. It marked the launch of a new subject of academic inquiry, design methods. This new field was concerned with the process of designing and improvement of design practice[21]. The recognition of design methods as an academic field of study led to the founding of Design Research Society in the UK in 1966, which continues to organise events and publish extensively on the topic. Their outputs focus on improving design practice through the research of design processes and methods.

18) Simon, *The Sciences of the Artificial*, 1969.

19) Ibid., 111.

20) John Chris Jones, *Design Methods*, 2. ed (New York, NY: Wiley, 1992).

21) N. Cross, 'A History of Design Methodology', in *Design Methodology and Relationships with Science*, ed. M. J. Vries, N. Cross, and D. P. Grant (Dordrecht: Springer Netherlands, 1993), 15–27.

In his seminal text on research in art and design, Christopher Frayling argued for recognition of design research as a professional practice, or as he puts it 'research with a big R'[22]. He described research *into* and research *through* art and design as existing research practices that look at design from an outside perspective or use design to address a previously defined problem, respectively. Nevertheless, the third category that he today calls design *as* research[23] and that favours cognitive tradition in fine art and design as an under-explored strategy is the one that stays fuzzy in the text. Frayling identified research into design and art with historical and theoretical inquiries into artefacts and archives from an outside perspective. Research *through* design or degree by studio project[24] is characterised by research findings obtained through the activities of art, craft or design but driven by a question outside of design. Frayling distinguishes design as research from research written with a small 'r', leading simply to the production of an artwork or design piece. Frayling insists design *as* research, or what we call today *research through design* (a recent conference RTD2015 Frayling was also part of, confirms this subtle shift in wording) is different to doing design. It requires an academic setting and an audience that understand the particular procedures that are applied to design with the particular research purpose[25].

Koskinen, Zimmerman, Binder, Redstrom and Wensveen offer a comprehensive contextualisation of practice-based research in design that takes place in the lab as well as in the showroom[26]. Resolving the confusion around the difference between research *through* and research *for* design, they introduce a new term, *constructive design research*, aimed particularly at framing the experience of integrating the fields of design and research. Constructive design approach underlies that something was built within the research process and put to use for research purposes.

Research through design is widely accepted today with reference to research that relies on production of design and artistic artefacts as an integral part of the research process. This shift in meanings - what for Frayling was research *for* design is considered research *through* design[27] or *constructive design research*[28] – did not do much favour to the clarity of the field. Frayling's

22) Frayling, *Research in Art and Design*.

23) Frayling, RTD 2015 Provocation by Sir Christopher Frayling Part 7: Design-led research - the next chapter on Vimeo.

24) Royal College of Arts (RCA) of which Frayling became rector a few years following the publication of his treatise "Research in art and design", awards the research degree by studio project since 1990s

25) Frayling, RTD 2015 Provocation by Sir Christopher Frayling Part 7: Design-led research - the next chapter on Vimeo.Ibid.

26) Koskinen et al., *Design Research through Practice*.

27) Krogh, Markussen, and Bang, 'Ways of Drifting—Five Methods of Experimentation in Research Through Design.'

28) Koskinen et al., *Design Research through Practice*.

writing from 1993 was more of a call for debate than a set of practical guidelines for research. Nevertheless, researchers have picked up on this discussion and some guidelines for research through design have established over time.

2.3. How Can Research Contribute to the Artistic or Design Practice?

Improvement of practice was central to the research efforts in theorising designing at the beginning of the 1960s[29]. Researchers adopted exploration of practice through observation and reflection as a general strategy for arriving at theories on design methods. As the multitude of literature in design research shows, they always kept their scope close to improvement or understanding of design practice.

More recently, the discussion on artistic research and practice-based research in general, took a different focus. Firstly, it is hard to identify one central point of these research efforts. Secondly, improvement of practice is not or not as clearly stated as the goal of practice-based inquiries. Rather, researchers often cite recognizing different kinds of knowledge[30], gaining of unexpected insights[31], or contributing to an open-ended methodology[32] as their goal.

Frayling was eager to distinguish design *as* research from the inquiry normally undertaken prior to the design process. This should not imply that design practice is incompatible with research. To the contrary, Frayling was attempting to clarify the distinct objectives of design practice and design *as* research.

Both research and design have sometimes felt disrespected in the debate on practice-based research. On one hand, academic institutions are hesitant to simply admit artistic, design and architecture practice amongst legitimate research fields. They assert that research is not a side effect of an artist's activity in preparation for the production of an artwork; it is an intentional and a sovereign practice. Research outputs should be clearly contributing to new knowledge. They should be shareable among the research community and beyond. This raises sometimes difficult questions on the role of practice in practice-based research and on the format of its outputs communicated to the research community. On the other hand, artistic practice has been unsympathetic towards efforts to intellectualise and institutionalise its product. Artists are often

29) Jones, *Design Methods*; Cross, 'A History of Design Methodology.'

30) Borgdorff, *The Conflict of the Faculties*.

31) Jens Badura, 'Explorative Practices in Dialogue. Art-Based Research at the Interface of Arts, Sciences and Design', in *Biornametics*, ed. Barbara Imhof and Petra Gruber (Vienna/New York: Springer, 2012).

32) Hannula, Suoranta, and Vadén, *Artistic Research*.

resistant towards rationalisation of their objectives and activity, seeing this more as an obstacle to expression than as a way to share their experience.

Resistance towards *academisation* of artistic, design and architecture practice is probably one of the reasons there is so little input in the current discussion coming from actual art practice. Henk Borgdorff, music theorist and philosopher responsible for establishing artistic research across institutions in The Netherlands and Scandinavia, elaborated on the introduction of the term *academisation* in the debate. According to him, it sometimes implies a loss of artistic distinctiveness in the "dispirited reality" of universities; at other times, it has a completely neutral connotation, such as in the official institutional efforts to introduce research in art schools in Flanders[33]. Most of the theory on *research through design* is written by philosophers or art and design theoreticians. Less frequently do practitioners daring in the realm of research produce theoretical outcomes of a global significance. This leaves us with little evidence that art and design as activities have anything but funding to gain from engaging with research.

In the rest of this chapter I will identify possible gains, through discussion on the role of the artefact in the research process, as well as through the example of conceptualisation of one concrete research project.

2.4. How Does Research *through* Design Generate (Design or Artistic) Knowledge?

Whether or not research through design contributes to knowledge specifically in the field of design or not, its contributions are scattered around individual research efforts and, thus, harder to generalise. I have identified two important strands in the discussion on practice-based methods. Firstly, they are concerned with experience, both the experience of the process of research, and the experience of the design or artistic artefact by whomever the researchers designate as their audience[34]. Secondly, researchers see the process of *drifting* through the different steps in design as beneficial for this methodology, as opposed to its perception as an inconsistent, uncontrolled or illogical in classical research processes[35].

In the beginnings of design research studies, we find in Simon's writings, a well established idea that the purpose of design research is to improve design practice, with the focus on design process. Simon distinguished scientific from what he called "professional knowledge" (knowledge of *doing*

33) Borgdorff, *The Conflict of the Faculties*.

34) Hannula, Suoranta, and Vadén, *Artistic Research*; Coessens, Crispin, and Douglas, *The Artistic Turn*; Jens Badura, 'Experience Catalyst Research', *Unpublished*, 2013.

35) Krogh, Markussen, and Bang, 'Ways of Drifting—Five Methods of Experimentation in Research Through Design.'

something, as opposed to knowledge *about* something) and stated that engineering disciplines, design included[36], mainly focused on sharing practical skills. He described contemporary design knowledge as intellectually soft, intuitive, informal, and cook-booky[37]. Thus, the need to make design theory explicit and less vocational, in order to teach a science of design[38].

Nigel Cross saw the application of design research in the area of practice too. According to him, design research focuses on the study of principles, practices and procedures of design in order to contribute to the improvement of design practice[39]. More recently, Kroes and Dorst agreed on the utilitarian function of design research for design practice. Kroes described design research as normative and process oriented[40]. He made a clear distinction between scientific and design research, the former driven by logical positivism and product oriented (with empirical claims, laws, theories and explanations as their outcome, typically). Conversely, centring on the process conforms to the improvement of design practice as the objective of research. The focus of design research is on the design process itself, thus the outcome is knowledge in the area of this process.

Zimmerman offered a more open interpretation of the way design research can lead to design theory[41]. He recognised two types of theory that can come out of design research: theory *on* design and theory *for* design. According to Zimmerman, theory is rarely the main focus of design research, but arrives as a by-product, implicit or emergent from reflection. Theory that comes out of design research is focused on improving design practice, thus its focus resides in the field it explores. This is theory *for* design. Research through design is suitable to explore more general societal or philosophical problems that cannot be easily reduced. Thus *research through design* has potentially a more general theoretical outreach, generating theory *for* and *on* design as well as theory applicable to disciplines the research touches upon.

Krogh and colleagues' generalisation on the methods in *research through design* brought out the theory of *drifting* as a way of arriving at an original research contribution. *Drifting* is described

36) Simon's research was funded by various private and governmental bodies. It is particularly indebted to his collaborations at the RAND Corporation during the 1950s and 60s. Simon fostered a view of design and architecture as part of engineering disciplines oriented towards problem solving Dj Huppatz, 'Revisiting Herbert Simon's "Science of Design"', *Design Issues* 31, no. 2 (April 2015): 29–40, doi:10.1162/DESI_a_00320..

37) Simon, *The Sciences of the Artificial*, 1969, 112.

38) Ibid., 114; Huppatz, 'Revisiting Herbert Simon's "Science of Design".'

39) Nigel Cross, ed., *Developments in Design Methodology* (Chichester ; New York: Wiley, 1984).

40) Peter Kroes, 'Design Methodology and the Nature of Technical Artefacts', *Design Studies* 23, no. 3 (May 2002): 287–302, doi:10.1016/S0142-694X(01)00039-4.

41) John Zimmerman, Erik Stolterman, and Jodi Forlizzi, 'An Analysis and Critique of Research through Design: Towards a Formalization of a Research Approach', in *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (Designing Interactive Systems, Aarhus, Denmark: ACM, 2010), 310–19.

as "pursuing alternative opportunities in the vicinity of one's work is an embedded way of arriving at relevant and high quality work"[42]. *Drifting* occurs in five loosely defined forms: accumulative, comparative, serial, expansive and probing, each illustrated in Krog's paper through one or two concrete design theses. Through continuous adjustment of experiments and learning from findings, a designer-researcher determines the meandering path for each specific research question that permit not only answering the research question but at times also gaining insights unintended by its original pursuit[43].

The artistic research discourse bares a similar pluralism of interpretations. Henk Borgdorff published widely on the theoretical and political rationale of these endeavours. Like many others, Borgdorff stressed the fact that mainstream scientific research also relies on negotiation of appropriate research methods, rules and validity[44]. Still, there is a certain idea of rigour, which does not simply allow biologists to study the process through which biologists arrive at designing experiments for the purpose of studying the process of design in biology[45]. Conversely, in the Manifesto of *The Artistic Turn*, the authors stated exactly this: "The practice of artistic research offers a kind of meta-practice, a research-practice that reflects on the artist's own artistic practice with all the rigour and focus of the research mentality but from an interior, experientially-informed perspective"[46]. The authors further elaborated on communication of artistic research findings: artistic practice is explored through making art, by artists who cannot but disseminate their findings in the form of artworks[47]. The argument circulating between practice and research without a clear goal, along with their relaxed position regarding research (using examples of existing artworks to demonstrate the possibilities for artistic research) has done more damage than good to the perception of practice-based inquiries. Borgdorff, on the contrary is very clear about this point: to qualify as research, the practice-based investigation has to be always intentional. He also saw it as necessarily relevant to the research context and the art world, effectively shared or appropriately documented and disseminated[48]. This creates space for setting a formal framework and standards of rigour in artistic research.

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42) Krogh, Markussen, and Bang, 'Ways of Drifting—Five Methods of Experimentation in Research Through Design.'

43) Ibid.

44) Borgdorff, *The Debate on Research in the Arts*.

45) This illustration is meant not only to raise the question of competence artist or biologists have for studying their own work – which is normally done by social science oriented inquiries, such as as Sociology of Scientific Knowledge (SSK) or Science and Technology Studies (STS). It also aims to show how self-referential or redundant such knowledge can appear.

46) Coessens, Crispin, and Douglas, *The Artistic Turn*, 91.

47) Ibid., 114.

48) Borgdorff, *The Conflict of the Faculties*, 43.

Experience continues to be one of the central concepts in the epistemological discussion about the specificity of practice-based research. Hannula, Suoranta and Vaden wereinspired by John Dewey's writing on understanding of art through the continuity between refined and intensified forms of experience of art and the everyday[49]. From the experience of research artefacts by the audience, to the experience of the process of research itself, Hannula and colleaguesfocused on their pluralistic character as something specific to art practice. Comparing experience and methods to political systems of democracy and anarchy, the authors advocate an abundance (anarchy) of methods and a pluralism (democracy) of experiences.

The idea of internalising one's methods and research questions is indeed specific to the process of making, as described in *The Artistic Turn*[50]. The artist-researcher internalises the question of learning drawing as a technique, a method for expressing oneself and disseminating this understanding. Once the whole process is so internalised and only articulated through artworks, communication of research findings can become ambiguous. Mark Johnson[51] explains this internalisation in the light of epistemological dualism – the knowing "how" and knowing "that", which characterises experiential and cognitive knowledge, respectively. For a solid account of knowing "how" and knowing "that" one should revisit Ryle's writing on The Concept of Mind[52] where he illustrates the difference between two types of knowledge through an example of a clown – the clown knows *how* to make us laugh, tripping and tumbling as a clumsy man would do; the clown does not however know "what is funny" - he embodies the action of tripping with his body and mind. Returning to the "how" and "that", Johnson's aim was to restore the link between knowledge and lived experience, which is often neglected in the Western intellectual tradition.

The discussion on artistic or design research methodology continuously oscillates between the attempt, on one side, to stress its idiosyncrasy - such as its capacity to deliver insights other disciplines could not provide; on the other side there is a tendency to identify similarities and parallels between mainstream scientific practice and practice-based research approaches for the sake of legitimacy. Both tendencies are part of contemporary discourse on research through design and art and will probably continue to shape the discussion.

The lack of concrete framework and evaluation criteria remains. There is a general agreement on the importance of this type of research among researchers and professionals. For example, a study by Zimmerman et al. showed research *into* design as the most commonly mentioned type of

49) *Artistic Research*.

50) Coessens, Crispin, and Douglas, *The Artistic Turn*.

51) "The Stone That Was Cast out Shall Become the Cornerstone": The Bodily Aesthetics of Human Meaning, *Journal of Visual Art Practice* 6, no. 2 (3 October 2007): 89–103, doi:10.1386/jvap.6.2.89_1.

52) Gilbert Ryle, *The Concept of Mind*, University of Chicago Press ed (Chicago: University of Chicago Pres, 1949).

design research, but it was 'this other approach' (research *through* design) that is considered the most true to the nature of design practice[53]. The compatibility with design practice is a valuable incentive to dedicate more attention to the role of artefacts in design research.

I will engage with this problem by discussing in detail the role of artistic and design artefacts in scientific research. I will describe an aesthetic strategy that is based on empirical methods that have been used in this research, namely the *experience catalyst*. I will then raise questions on the process of evaluation of artistic and design artefacts in research projects. How are the criteria here different from a real-life evaluation? Do usability and aesthetic still play an important role in judging this experience? What are the values of the project that are most important to the researcher? How do they differ from the values cherished by the artist?

2.5. The Role of Design Artefacts in Research Process

When the purpose of research activities is generating guidelines for improvement of design practice, and the focus is on the process of design, the analysed artefact(s) can be existing design objects. "*Given* an airplane, or *given* a bird, we can analyse them by the methods of natural science without any particular attention to purpose or adaptation"[54]. However, when the process of design is an integral part of research, the artefact is not *given*. Researchers conceive of it according to the research scope and question. The design artefact is a source of data for analysis and generalisation, and not an external object to theorise about. If the process and design object are inextricably linked[55], then we understand the design artefact created within research through design or constructive design research, in the light of its subject.

Depending on research focus, criteria for a successful research artefact are more or less aesthetic or utilitarian. If we adopt Brandt and Binder's[56] idea that a research question has the same role in research through design as a design brief has in the practice of design or architecture, we quickly arrive at evaluation criteria that are far from a successful or usable design product. Nevertheless, following Simon's account that design puts us in the preferred situation, Brandt and Binder recognize the effect of research artefacts: "any experiment, which is worth considering as a contribution to research inquiries, must somehow involve an intervention in the world"[57].

53) Zimmerman, Stolterman, and Forlizzi, 'An Analysis and Critique of Research through Design: Towards a Formalization of a Research Approach.'

54) Herbert A Simon, *The Sciences of the Artificial* (Cambridge, Mass.: MIT Press, 1996), 6.

55) Kroes, 'Design Methodology and the Nature of Technical Artefacts.'

56) Brandt and Binder, 'Experimental Design Research: Genealogy – Intervention – Argument.'

57) Ibid.

Before going into more detail about the nature of design artefacts produced in the context of research, let us look once more into the different views of design artefacts in design research literature. From the distinction on *natural* and *artificial* as mutually exclusive metaphysical categories, Simon develops his argument of equally valid research subjects - nature and artefact[58]. Artefact is an *interface* between the inner and outer environments, the former defined as the artefact's inner organisation and substance, the latter as the surroundings in which it operates. Following on this, Kroes investigates "the dual nature of design artefacts", considering their functional (input) and structural (output) properties[59]. It implies a dual conceptualisation in design practice. Designers are professionally trained to bridge this gap and to address both aspects.

Hooker and Farrell argue that design and science do not produce metaphysically distinct types of things[60]. They criticise the interpretation of the Simon-Kroes model that implies a significant difference in the way design and science come up with artefacts. It is true that scientists do not produce the natural world through their investigations of it, while designers do produce artificial objects through design. This distinction is at the root of this disjunctive discourse. However, both designers and scientists produce artificial things - while the former synthesise design solutions, the latter come up with technological solutions and artefacts (dye-sensitized solar cells[61], autonomously walking quadrupedal robots[62], soft modular matter[63] to name a few).

Building on Simon's notion of the *interface* we can look at design research artefacts as the interface between the research question and the mechanisms it uses to give insights into phenomena. Nevertheless, the separation on *analytic* and *synthetic* sciences does not help understand either of them, as both mental processes are part of *research through design*. If we keep the division on *analytic* and *synthetic* in the discussion on research artefacts, we are facing the same problem identified above - there are either two distinctive sciences, or there is science and design practice, as two distinct professions. Either way, they would belong to intellectually distant paradigms and would be unable to communicate. What I propose instead is to recognize

58) Simon, *The Sciences of the Artificial*, 1996.

59) Kroes, 'Design Methodology and the Nature of Technical Artefacts.'

60) Robert Farrell and Cliff Hooker, 'The Simon–Kroes Model of Technical Artifacts and the Distinction between Science and Design', *Design Studies* 33, no. 5 (September 2012): 480–95, doi:10.1016/j.destud.2012.05.001.

61) Michael Grätzel, 'Dye-Sensitized Solar Cells', *Journal of Photochemistry and Photobiology C: Photochemistry Reviews* 4, no. 2 (October 2003): 145–53, doi:10.1016/S1389-5567(03)00026-1.

62) Marco Hutter et al., 'Walking and Running with StarlETH', in *The 6th International Symposium on Adaptive Motion of Animals and Machines (AMAM)*, 2013.

63) Sehyuk Yim and Metin Sitti, 'SoftCubes: Towards a Soft Modular Matter', in *Robotics and Automation (ICRA), 2013 IEEE International Conference on* (IEEE, 2013), 530–36.

a tradition of an integrative approach to research, which includes producing design artefacts as part of research activity. How can we design *analytically*?

2.5.1. From Research Question to Design Artefact

The process of developing and presenting experiments in the field of design for the purpose of scientific research is characterised by several distinctive qualities. It is less utilitarian and more conceptual; it usually involves several phases of refinement; it is aimed at a particular audience, interested in the research process and findings, rather than the artefact's usability. Brandt and Binder[64] describe this: "In design research we do not however want to make finished designs for their own sake [...] One may say that where the program is a means for the designer to be able to pursue a particular line of design, the program is to the design researcher the suggestion that must be substantiated through experiments".

In order to better understand this process, I will look into examples of design artefacts that were produced in the context and for the purpose of research. How are research questions translated into design briefs? Furthermore, how are these translated into tangible design products? I will particularly focus on a research project that came out of an inquiry into perception of shifting infrastructures, developed in the framework of SINLAB research laboratory.

SINLAB was an experimental laboratory based at EPFL (École Polytechnique Fédérale de Lausanne), physically residing in La Manufacture, HETSR (Haute École de théâtre de Suisse romande). It was situated at the intersection of performing arts, architecture, science, engineering and philosophy[65] . It was conceived as a place for collaboration of doctoral and post-doctoral researchers with stage designers, theatre directors and choreographers who came in as artists in residence.

The following discussion will present one research process, or the transformation from a research question into the design brief and then into different prototypes. I will detail design and research decisions made along the way. Finally, I will evaluate this process from a research and from a design perspective. The research project described was chosen because of a clear yet changing research question it addressed; the diversity of prototypes and their levels of completeness; and because of personal familiarity with the project development that came from involvement in all of its phases.

64) Brandt and Binder, 'Experimental Design Research: Genealogy – Intervention – Argument.'

65) Sinlab, 'About', *SINLAB*, 2012, http://www.sinlab.ch/about/what/.

The Research Context

SINLAB's intellectual tradition was closer to philosophy and performance studies than to design. The successive iterations of work attempted to explore three important themes that revolved around time and space perception, man-machine relations and intermediality in the stage context.

My main interest in these explorations was the design of tangible experiences, reconfigurable spaces and materialisation of unstable infrastructures. I expected from this design activity to offer novel and unexpected insights into the spatial experience of wireless connectivity. This approach was particularly fitting to answer the research question set forth by this thesis, exploring how wireless networks perform architecturally in space. The work that followed concentrated on the experience of activity within the wireless network infrastructural layer through interactive prototypes.

Parallel to my practical inquiries addressing wireless networks, a project titled *Moving wall* was devised in the lab. It had for its objective to address the first SINLAB area of interest, the transformation of perception and experience of time and space. The SINLAB researchers imagined the project as a reflection on the idea of reconfigurable spaces. It was going to be an *experience catalyst*[66] , hinting at new types of constellations in relation between humans and (cultural) infrastructures. The public increasingly sees these infrastructures as shifting and changing, reflecting the perceived instability of contemporary life, the first project brief detailed. As opposed to them, walls are seen as a symbolic order representing the concept of the solid as such and standing for stability, permanence and safety. But walls do at the same time signify shelter and prison; while they provide safety they also inhibit and isolate movement, perception, connection. The idea of the moving wall was thus "attacking" this opposition of permanent vs. temporary, stable vs. changeable, passive vs. (inter)active.

The Prototyping Process

The design development focused on the intersection of aesthetics and technological development. For the *Moving Wall*, SINLAB researchers envisioned producing a complex interactive installation made of brick-like units that seemingly belong to a flat wall surface but are able to move and respond to external impulses.

An early stage prototype was built and tested in the lab environment. It demonstrated basic interaction principles using scrap materials like cardboard and wires, and simple electronic controls. The prototype performed sufficiently well as a demonstration of a tectonic effect of estranging our surroundings with unexpected interaction. However, it did not go much further at

66) Badura, 'Experience Catalyst Research.'

that, than for example the work with interactive wallpapers[67]. Most importantly, the experience of the *Moving Wall* was not imagined to be significantly more tangible than a projection, even when scaled up.

Taking from this experience, I focused my design activity on materialising the information on wireless network traffic. I developed a technical framework for measuring and representing wireless communication signals. It was instrumental in the design of *playful* interactions with *wirelessness*. Playful interaction design is neither only serving a utilitarian purpose of visualising signal availability and use nor is it purely without constraints. Whether play occurs in an everyday context (following Schechner's approach) or in strict spatial separation from ordinary life (as defined by Huizinga), researchers have identified the importance of the physical structure of the environment[68]. A playful design has to address the research question while promoting *ludic* engagement with the artefacts and accommodating unexpected interactions.

My design efforts produced three generations of prototypes. Each was also presented to the public, in various settings. The presentations were points of collecting data from observations on user behaviour, channelled discussion and quantitative data on network usage. A comprehensive discussion of each project can be found in Chapter 6. *Projects and prototypes*. Full technical descriptions are available in the Appendices 1-3. What I will briefly discuss here is simply the process of translation from the research question into the design decisions.

Starting from the perception of shifting, invisible, infrastructures, it was evident that the person would have to be unconditionally influenced by the changes in the prototype. An interactive surface that can be observed from a side – such as the *Moving Wall* - was therefore not an option. I envisioned a small rectangular space instead. An interactive cuboid shape with changeable height (according to activity of the related wireless network) was produced. It was called *RKNFG* and presented to the audience of a media art exhibition in Linz, Austria.

Following this first experiment, a more complex and larger prototype was needed to represent network activity in a more playful way. I produced two *Quadricone* prototypes (a 2.5x7m installation and with a scaled model of approx 1:7) using similar tools to *RKNFG* but occupying more space and generating a more complex effect. This effect was again tied to a surface (a reconfigurable ceiling). I demonstrated the scaled model at a research symposium in Zurich and the installation as part of an exhibition in Lausanne.

In the attempt to avoid predetermined shapes that repeatedly proved insufficient as a way to represent and contain network activity, I abandoned physical structure entirely. For the

67) Jeffrey Huang and Muriel Waldvogel, 'Interactive Wallpaper' (ACM Press, 2005), 172, doi:10.1145/1086057.1086142.

68) Franinovic, 'Architecting Play.'

first two versions of the *Connect or Not* model, I worked only with interactive light and ambient situations whose experience was driven by complex network activity recorded through visitors mobile devices. This approach to data collection proved to open more potential for an interesting interaction beyond simple recognition of the dynamics of traffic. In order to re-examine the potential of such a setup to render a tangible experience, I reintroduced the large *Quadricone* structure in the last *Connect or Not* experiment and presented it at the IST Lisbon university campus.

2.5.2. Evaluation of Design Artefacts

In their research into culturally embedded computing and perception of artefacts, a group at Cornell University concluded that the perceived context and expectations of an artefact (an interactive display for example) strongly determined its experience. "When people approached the display as a tool for improving awareness of affect, they were somewhat frustrated with not being able to match input to output. However, when people approached the display as art, they were more comfortable"[69]. The interpretation of displayed interaction was ambiguous and frustrating when the goal was to accurately represent affect; when simply playing with it, people were more comfortable and open to interpretations. Thus, expectations play an important role in the experience and evaluation of research artefacts.

Koskinen, Zimmerman, Binder, Redstrom and Wensveen find that "Research sets some requirements for prototypes at odds with doing good design"[70]. For them, a successful research design artefact helps clear up most important competing explanations. It does not necessarily produce a good design product.

Zimmerman reflected on projects that come out of research through design, "not in terms of outcome, but instead in terms of characteristics of each project that made them ripe for knowledge development"[71]. How do we evaluate this *ripeness*? To which extent does the artefact need to work or satisfy its functional, aesthetic and ethical preconditions in order to be considered successful? Or to be useful for research? Research designs have to allow for interesting and unexpected features to become prominent research topics, like in the case of Breazeal' Kismet[72] or Sengers

69) P. Sengers et al., 'Art, Design & Entertianment - Culturally Embedded Computing', *IEEE Pervasive Computing* 3, no. 1 (January 2004): 18, doi:10.1109/MPRV.2004.1269124.

70) Koskinen et al., *Design Research through Practice*, 61.

71) Zimmerman, Stolterman, and Forlizzi, 'An Analysis and Critique of Research through Design: Towards a Formalization of a Research Approach.'

72) Kismet was an experiment with humanoid robots which explored their social cues and the possibility of an affective relationship with the machine Cynthia L Breazeal, *Designing Sociable Robots* (Cambridge, Mass.; London: MIT Press, 2004).

Influencing machine[73]. We have seen in the example of the *Moving Wall* that fed into the *RKNFG* and *Quadricone* projects, how such approach makes it hard to write up a *design brief* that will define research procedures and leave enough space for what seem as dead-ends to become paths of exploration.

More recently, Danish researchers studied existing research through design work, assessing different evaluation strategies for the design artefacts[74]. Knowledge production needs scientific foundations, thus the need to find a balance between epistemological autonomy (insisting on specificity of design research) and scientific grounding in established research traditions. The researchers restated that the concept of the *preferable* situation, which can be used to evaluate user-centred, problem-solving design is not a valid evaluation criterion for research artefacts. In his contribution to the analysis in design research, Koskinen established connections between more established research traditions and design research. These models of evaluation are applied in the four identified cultures of analysis in design research: statistical analysis (natural sciences, psychology), analytic induction (influenced by social sciences), explanation (borrowing from humanities) and finally art and design-based evaluation relying on subjective judgement[75]. Unlike Koskinen, Markussen and colleagues took an intra-disciplinary approach, looking for evaluation practices in the existing work in research through design[76]. The study identified five evaluation strategies used in the research analysed, namely *repercusive*, *relational*, *serial*, *expansive* and *eclective*, which could be partially mapped to their previously defined methods for conducting research through design, the five ways of *drifting*[77]. This sheds light on concrete methods, specific to *research through design* and contributes to clarity in planning, performing and evaluating doctoral work. Most importantly, the actual examination of existing research promises to answer the long standing question of the intellectual gain from research through design. As opposed to theorising about the kind of knowledge that could be attained through practice-based research, Markussen's approach takes a direction towards more concrete answers, while normalising *research through design* as a research practice.

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73) The Influencing machine was an experiment designed by the Culturally Embedded Computing Group at Cornell to test the mutual emotional influences between users and the interactive installation Phoebe Sengers et al., 'The Enigmatics of Affect' (ACM Press, 2002), 87, doi:10.1145/778712.778728.

74) Thomas Markussen, Peter Gall Krogh, and Anne Louise Bang, 'On What Grounds? An Intra-Disciplinary Account of Evaluation in Research through Design' (IASDR 2015, Brisbane, AU, 2015).

75) Ilpo Koskinen, 'Four Cultures of Analysis in Design Research', in *The Routledge Companion to Design Research*, ed. Paul A Rodgers and Joyce Yee (London [u.a.]: Routledge, 2015).

76) Markussen, Krogh, and Bang, 'On What Grounds? An Intra-Disciplinary Account of Evaluation in Research through Design.'

77) Krogh, Markussen, and Bang, 'Ways of Drifting—Five Methods of Experimentation in Research Through Design.'

The objective of the work described in this thesis was not improvement of design practice, though it could be seen as one of its results. I could have focused on understanding Wi-Fi propagation through buildings in order to create guidelines for design that facilitates network access. Instead, as demonstrated above, research conducted within the SINLAB framework was inclined to allowing more general insights in the constitution and perception of space and connectivity as two inseparable entities. It did so through construction of settings that foster tangible experience and facilitate discussion about the phenomenon under observation[78]. These settings served as experience catalysts[79], seeking to catalyse a particular sensation or experience that can be discussed in the realm of design and architecture studies.

With the experience from the aforementioned and many more projects developed in research context, we can conclude that the success of a design artefact can be measured by the level of ambiguity and the focus on experience instead of design itself. When the discussion moves from design decisions onto the experience of the artefact, we may consider it *ripe* enough to answer some of the research questions. However, whether or not this will happen depends not only on the design of the artefact but also on the presentation context. Discussion tends to focus more on design decisions when the presentation context is closer to research. Conversely, in an exhibition context a similar artefact gets a different attention and is much more *experienced*.

2.6. Synthesis

In this chapter, I introduced the question of legitimacy of knowledge making, discussing the most prominent sceptical accounts towards methodology[80] and truth in general[81]. This was a logical step towards the debate about legitimacy of artistic research, *research through design* and related research practices. Although these practices do not always agree on the method or procedures, the main common thread is the centrality of the artefact to the research process. This centrality is still difficult to generalise and numerous authors that work in the field of practice-based or practice-centred research discuss the origins, potentials and benefits of this research approach. Indeed, most of the literature on *research through design* begins with a brief recapitulation of the field, a lot of energy going into defining it rather than discussing any particular findings. However, in the last few years there has been more discussion on evaluation of design and artistic

78) Andrew Sempere et al., 'Experience Catalyst and Architecture: Towards a New Tradition', in *Future Traditions: Rethinking Traditions and Envisioning the Future in Architecture through the Use of Digital Technologies*, ed. José Pedro Sousa and João Pedro Xavier (Porto: Porto: FAUP Publicações, 2013).

79) Badura, 'Explorative Practices in Dialogue. Art-Based Research at the Interface of Arts, Sciences and Design'; Badura, 'Experience Catalyst Research.'

80) Feyerabend, *Against Method*.

81) Rorty, *Philosophy and the Mirror of Nature*.

research artefacts, which promises to take the debate further from the "why?" towards the "how?".

I made a clear difference between design research, a relatively established field that studies design as a practice, and *research through design*, which enables novel and diverse insights into phenomena, through the production of design artefacts. How exactly does this happen? I discussed this through a concrete example of a research process that I have both participated and lead. The example describes the transformation of a research question into a design artefact and decisions that have been made in the process. It demonstrates the *drifting* nature of this process, as described in a recent discussion on methods of experimentation in *research through design*[82].

Finally, I discussed the evaluation of design artefacts. Evaluation of design research artefacts is specific to the particular research process and project. It cannot be conditioned by commercial, utilitarian or ergonomic values. Zimmermann offered a useful concept of *ripeness* of the artefact to provide more or less clear insights into the phenomenon under observation. I have offered some indicators of this *ripeness*, such as the focus of the audience's attention on the experience instead of design decisions. I also warned about different readings different audiences will make of an artefact and the need to account for the presentation context in artefact evaluation.

82) Krogh, Markussen, and Bang, 'Ways of Drifting—Five Methods of Experimentation in Research Through Design.'

3. Connectivity in Action / Form. Towards a Model for Evaluating the Effects of Wireless Communication on the Experience of Space

The central concept I introduce in this chapter is the notion of *architecturality*, an architectural quality that is more general than the physical properties of the built environment, but related to them. *Architecturality* will be instrumental for the evaluation of the effects of wireless communication on the experience of space. In order to explain this, I will I rely on the notion of *agency*. *Agency* is fundamental to the observation of the impact of non-living things[1)] on their environment.

1) When clarifying the concept of an *actant* in the well known but often misinterpreted Actor-Network-Theory, Latour insisted on the capacity of non-living things to act in systems or networks of objects and persons. Latour however, used the word "agency" very scarcely in his writing.

3.1. Defining Agency

In contemporary humanities discourse (Science and Technology Studies, Digital Humanities) and in ontologically-minded philosophical frameworks (Latour's flat ontology Harman's object-oriented philosophy, Bryant's onticology), *agency* is the inherent property of a token (a unit, an object, a thing) by means of which it is granted activity[2]. *Agency* can also be understood in terms of cognitive sciences, which originally used the concept to discuss the possibility for artificial intelligence[3]. Next to this, *agency* is an elastic concept that can be suitably applied to questions of the effect that something (a roundabout, an urban plan, a computer in a call shop or a wireless signal transmitting data[4]) has on something else.

Agency acts as "a conceptual currency across different sub-disciplines"[5] - a kind of intellectual interdisciplinary glue. Barandiaran et al. gave a comprehensive overview of the evolution of different definitions of *agency*, in the context of synthetic robotic research. They used this discussion to develop a generative definition of *agency*, determining the minimal template organisation – a system – where *agency* can be observed. According to their definition, an agent is "at least, a system doing something by itself according to certain goals or norms within a specific environment." Through their analysis, I will show how the understanding of *agency* has evolved in time. From anthropomorphic expectations that evaluate consciousness and volition in living and artificial systems, the concept of *agency* has expanded to include non-living, non-volatile things that interact with other things. We can thus discuss the *agency* of imperceptible phenomena such as wireless communication signals.

Robotic research engages with the cognitive evaluation of systems, including their effect on the environment. Nevertheless, it often has an anthropomorphic perspective on these systems, looking to prove the existence of some sort of consciousness in the combination of software and electronic circuitry. The first definitions of *agency* that came out of these efforts could not accept wireless signals as agents: for example, the Russell and Norvig's 1995 account of an agential system as "anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors". Wireless signals have no built-in

2) Bruno Latour, *The Pasteurization of France*, 1. Harvard University Press paperback ed (Cambridge, Mass.: Harvard Univ. Press, 1993); Bruno Latour, 'On Actor Network Theory', *Soziale Welt*, 1996; Bruno Latour, 'The Trouble with Actor-Network Theory', *Om Aktor-Netvaerksteroi. Nogle Fa Afklaringer Og Mere End Nogle Fa Forviklinger* Vol. 25, no. N° 3 (1996): 47–64.

3) X. E. Barandiaran, E. Di Paolo, and M. Rohde, 'Defining Agency: Individuality, Normativity, Asymmetry, and Spatio-Temporality in Action', *Adaptive Behavior* 17, no. 5 (1 October 2009): 367–86, doi:10.1177/1059712309343819.

4) This list is compiled from the topics covered at a symposium on *Agency*/Agents of Urbanity held at the time of writing this thesis http://contour.epfl.ch/agency

5) Barandiaran, Di Paolo, and Rohde, 'Defining Agency.'

sensors or effectors. Other definitions are less attuned towards a perception of the environment and more towards realizing goals: for example Maes (1994) defines agent as "a system that tries to fulfil a set of goals in a complex, dynamic environment"; Beer (1995) states "any embodied system [that pursues] internal or external goals by its own actions while in continuous long-term interaction with the environment in which it is situated"; Christensen and Hooker (2000) define agents as "entities which engage in normatively constrained, goal-directed, interaction with their environment". This can be applied to waves if we regard normativity as reflected in the physical laws of wave propagation; the goal is to provide connectivity and the interaction is the propagation throughout the environment. Barandiaran's final generative definition, "an agent is an autonomous organization capable of adaptively regulating its coupling with the environment according to the norms established by its own viability conditions"[6], leaves enough room for an interpretation of *agency* in wireless signals.

Both the humanities studies of science (such as Sociology of Scientific Knowledge (SSK), Sociology of Scientific Institutions (SSI), Science and Technology Studies (STS))[7] and the more general movement in social sciences towards posthumanism[8] have embraced the discourse about *agency* in things. This had a strong influence on the development of philosophical frameworks that questioned the primacy of humans in the organisation and functioning of the world. The scepticism towards human primacy emanated from efforts in sociology to study and accurately convey the complexity of large technical systems[9]. Latour introduced the principle of irreducibility[10] to account for this complexity. Ontological theories such as the object-oriented philosophy[11], onticology[12] or Latour's own flat ontology put people and non-living things in perspective that makes them fundamentally indistinguishable from each other. It is only through "uncertain, fragile, controversial and ever-shifting ties" that their relationships are established[13].

6) Ibid., 8.

7) Sophia Roosth and Susan Silbey, 'Science and Technology Studies: From Controversies to Posthumanist Social Theory', in *The New Blackwell Companion to Social Theory*, ed. Bryan S. Turner (Oxford, UK: Wiley-Blackwell, 2009).

8) Katherine N. Hayles, *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics* (Chicago, Ill: University of Chicago Press, 1999); Katherine N. Hayles, *My Mother Was a Computer: Digital Subjects and Literary Texts* (Chicago: University of Chicago Press, 2005); Barad, 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter.'

9) Bruno Latour, *Aramis, Or, The Love of Technology* (Cambridge, Mass: Harvard University Press, 1996).

10) Latour's 'principle of irreducibility' states: "Nothing is, by itself, either reducible or irreducible to anything else." Latour, *The Pasteurization of France*, 158.

11) Graham Harman, 'Tool-Being: Elements in a Theory of Objects' (DePaul University, 1999)

12) Levi R Bryant, *The Democracy of Objects* (Ann Arbor: Open Humanities Press, 2011).

13) Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network-Theory*, Clarendon Lectures in Management Studies (Oxford ; New York: Oxford University Press, 2005), 28.

3.2. The Posthumanist Turn or the Agency of Everything

The past twenty years have brought an inflation of non-anthropocentric theories and studies in a wide range of fields. Literary studies have seen titles like *Alien Chic Posthumanism*[14] or *My Mother was a Computer*[15]. Simultaneously, ontologically oriented philosophical frameworks (such as Harman's metaphysical project, object-oriented philosophy [16] and Bryant's onticology[17]) developed around objects as central ontological units. Transdisciplinary scholars began reflecting on *Posthuman* and Spatial *performativity*[18]. This turn originated in several different discourses, most notably as a consequence of Norbert Wiener's cybernetics and complexity theory[19] and Latour's irreductionist account of the world of non-human interactivity[20]. All these different intellectual efforts are in fact part of a larger project dismissing the scientific paradigm of a linear cause and effect in favour of the theory of complexity.

It is important to note here that posthumanism should not be confused with transhumanism, with which it does share some common ground. Ranisch and Sorgner offered a good account of this distinction[21]. Transhumanism is a techno-optimist movement, attuned at transforming human condition through technological enhancement of human intellectual, physical and psychological skills – the human perfection. Posthumanism is a worldview in which anthropocentrism is challenged in favour of a distributed, non-hierarchical view on people and things[22].

As much as it is difficult to define or describe the scope of *posthumanism*, the most important underlying threads are the challenging of logical positivism in science and the efforts to dismantle the common anthropocentric worldview. Katherine N. Hayles describes *posthumanism* as a process in which "Enlightenment inheritance that emphasized autonomy, rationality, individuality and

14) Neil Badmington, *Alien Chic Posthumanism and the Other within* (London: Routledge, 2004).

15) Hayles, *My Mother Was a Computer*.

16) Harman, 'Tool-Being: Elements in a Theory of Objects'; Graham Harman, 'Technology, Objects and Things in Heidegger', *Cambridge Journal of Economics* 34, no. 1 (1 January 2010): 17–25, doi:10.1093/cje/bep021.

17) Bryant, *The Democracy of Objects*.

18) Barad, 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter'; Smitheram, 'Spatial Performativity/Spatial Performance.'

19) Hayles and Piper, 'How We Became Posthuman.'

20) Latour, *We Have Never Been Modern*; Graham Harman, *Prince of Networks: Bruno Latour and Metaphysics* (Prahran, Vic.: Re.press, 2009).

21) *Post- and Transhumanism: An Introduction*, First edition, Beyond Humanism: Trans- and Posthumanism, vol. 1 = Jenseits des Humanismus: trans- und posthumanismus (Frankfurt am Main ; New York: Peter Lang, 2014).

22) Hayles, *How We Became Posthuman*; Francesca Ferrando, 'Towards A Posthumanist Methodology: A Statement', *Frame 25.1*, no. Narrating Posthumanism (May 2012).

so forth, was being systematically challenged and disassembled — in a whole variety of fields"[23]. Taking from cybernetics, particularly complexity theory, she roots *posthumanism* in the awareness "of being located within a large-scale complex system characterized by multiple recursive feedback loops". The notion of the feedback loop is useful when assessing the different relations and actions between and within organisations and systems.

Ranisch and Sorgner describe posthumanism as "an umbrella term for ideas that explain, promote or deal with the crisis of humanism"[24], related to post-modern and continental philosophy, science and technology studies, cultural studies, literary theory and criticism, post-structuralism, feminism, critical theory and post-colonial studies.

The radical re-conceptualization of *agency* in philosophical and cybernetician discourse goes back to Deleuze and Guattari's argument for recognition of *agency* in cellular automata and non-living units that make up our world. The cells that are "completely mechanistic, computational, and non conscious but nevertheless display complex patterns that appear to evolve, grow, invade new territories, or decay and die out"[25] are a perfect unit for a rhizomatic (non-arborescent) organisation[26].

One of the central questions in discussions on non-human *agency* is: does *agency* imply consciousness? The answer depends on the lens. In the view of cognition scientists, it was primarily interesting to identify the different levels and forms consciousness can take[27]. In fact, the concept of non-human *agency* has been often used as a way to discuss the existence of Artificial Intelligence (AI)[28]. Hayels calls this "a crisis of *agency*". According to her, this discussion has not only failed to prove the intelligence of non-living systems but actually challenged whether *agency* can be securely located in the conscious mind. The mind, reduced to a mechanistic network in this AI discourse, can be challenged in the same way artificial systems are. Consciousness - a feature of mind – is not equal to *agency*. If *agency* does not instantiate consciousness, then consciousness is not required for something to have *agency*.

Outside of the AI discourse, the question of consciousness in agents becomes less critical. In contemporary philosophical tradition, it is clear that consciousness is not the only *thing* that

23) Hayles and Piper, 'How We Became Posthuman.'

24) Ranisch and Sorgner, *Post- and Transhumanism*, 14.

25) Hayles, *My Mother Was a Computer*.

26) Gilles Deleuze and Félix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia* (Minneapolis: University of Minnesota Press, 1987).

27) Barandiaran, Di Paolo, and Rohde, 'Defining Agency.'

28) Hayles, *My Mother Was a Computer*.

has an impact on other *things*, to borrow one of the slippery terms used to name epistemological units[29] in a worldview. For example, opposing the typical Kantian view on objects that are products of human cognition, object-oriented philosophy puts things at the centre[30]. In contrast to causal relations typical for Newtonian paradigm, it advocates instead "to think imbroglios of difference"[31]. We read here again Latour's influence in the rejection of intentionality in the action of an actor, because "an actor is what is made to act by many others"[32]. Latour's definition, however, entails certain mechanistic determinism.

From a perspective at the intersection of cognitive sciences, robotics and philosophy of mind, Barandiaran, Di Paolo and Rohde constructed a detailed but flexible framework for evaluation of *agency* in systems[33]. Through vivid examples, they explored *agency* in systems where intentionality and individuality become hard to pinpoint. Their discussion confirmed that *living* is not a necessary requirement to recognize *agency* in systems.

How might we evaluate *agency* of the non-living, not-intelligent and non-consious wireless network signals? That signal availability is acting on people to make them change their location has been demonstrated in numerous studies in the past ten years[34]. Psychologists continue to write about the "Internet addiction disorder", a contested medical condition[35]. Outside of these two poles of impact, I will look at *action* (as defined by Easterling[36]) of wireless signals. I will look to unravel something much more subtle and at the same time more plausible than the *intelligence* of *wirelessness*. What I am searching for is the agential effect of waves on space, where space is seen as an experience of both people and networks. A purposeful change in space can result from the waves propagation.

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29) The list here is made of units that are not interchangeable but do refer to some fundamental units in different philosophies: Whitehead's occasions, Latour's *actants*; object-oriented philosophy's objects, Barad' phenomena)

30) Harman, 'Tool-Being: Elements in a Theory of Objects.'

31) Bryant, 'Imbroglios of Objects.'

32) Latour, *Reassembling the Social*.

33) 'Defining Agency.'

34) Gordon and de Souza e Silva, *Net Locality*; Markus Montola, Jaakko Stenros, and Annika Wærn, *Pervasive Games: Theory and Design* (Amsterdam ; Boston: Elsevier/Morgan Kaufmann, 2009).

35) Daria J. Kuss and Mark D. Griffiths, 'Online Social Networking and Addiction—A Review of the Psychological Literature', *International Journal of Environmental Research and Public Health* 8, no. 12 (29 August 2011): 3528–52, doi:10.3390/ijerph8093528; Kimberly S. Young, *Caught in the Net: How to Recognize the Signs of Internet Addiction--and a Winning Strategy for Recovery* (New York: J. Wiley, 1998).

36) *The Action Is the Form. Victor Hugo's TED Talk*.

3.3. *Performativity* of Architecture

Performativity in this discussion is a quality constituent to any entity capable of actively and purposefully acting on or adapting to its environment. This means that it derives its way of being in the world from an interaction with its surrounding. When we look at performativity of something – be it a word or a building, we assume its ability to change the meaning or the experience of the context in which it performs.

As a general trend, the performative turn is a reaction to the limitations imposed by a representational worldview in social constructivism, which was the dominant intellectual trend throughout the 1960s. John Austin's influential theory of Speech Act (1962) inspired performance studies in performing arts and theatre[37] rooting also in the discourse of natural and economic sciences and science technology studies (STS) throughout 1990s and 2000s.

The ongoing critique of representations and constructivist worldview, as in the work of Karen Barad, challenges the positioning of materiality as either a given or a mere effect of human *agency*[38] . Materiality is evaluated through experience, not mere measurement. Promising to "sharpen the theoretical tool of performativity" Barad destabilises the idea of accurate world representation in scientific knowledge and the process of its acquiring. She proposed studying phenomena as primary epistemological units constitutive of reality. Phenomena are produced "through agential intra-actions of multiple apparatuses of bodily production." These intra-actions may or may not involve humans.

The performative paradigm entered architectural discourse from different grounds in relatively recent years. Schechner's performance studies, as well as optimisation of building's performance, have both played a significant role. This lead to an extraordinary multitude of meanings and a complete lack of consensus on how performance, performative and performativity relate to architecture. For example, a chapter of Chris Salter's book *Entangled*, titled *Performative Architectures* details what we are going to discuss here through a similar list of reference points[39] . However, his reading of these points, attuned at the theatrical performance, is reading the sources through this sometimes distorting lens. This is the case with most architecture informed literature that simply picked up on the sufficiently ambiguous term *performativity*, and applied it to the way buildings could save energy or simply decay with time.

37) Richard Schechner, *Performance Theory*, vol. 10 (Psychology Press, 2003).

38) Barad, 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter.'

39) Salter, *Entangled*.

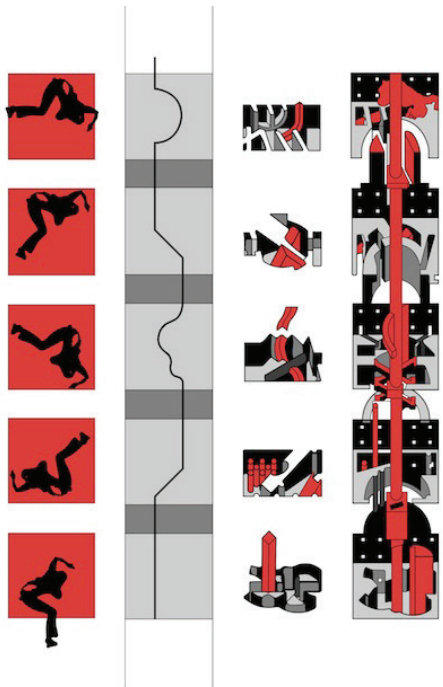

Figure 3.1 Manhattan Transcript 3 (1980), Bernard Tschumi. How can movement 'carve' space? How can space carve movement, in turn? A succession of volumetric exercises of form. From Bernard Tschumi, *Archtiecture et Disjonction*, HYX, 2014

3.3.1. Carving and Performing the Architectural Envelope

From a relational perspective on space, architecture is a product of the activity that takes place within it. We can trace the origins of these ideas to Lefebvre (space is a product of some form of social interaction[40]) and the Situationist International, to whom performance was instrumental in challenging city structures. Inspired by this concept, other artists and architects took it to their practice to find a way of interpreting spatial practices architecturally and socially. Bernard Tschumi's early work, for example, engaged with immaterial, performative architecture, in order to subvert constraints of materiality and thus circuits of capital[41] .

After form divorced from function in post-modernist practice, there were attempts in technologically minded circles to establish a "form follows performance" logic. Architects who embraced digital form-making tools, sometimes also focusing on energy efficiency,understood

40) Henri Lefebvre, *The Production of Space* (Blackwell, 1991).

41) Bernard Tschumi, *Architecture and Disjunction* (Cambridge, Mass: MIT Press, 1994).

performance as something that can be simulated and assessed qualitatively and quantitatively by digital technologies[42]. This view stemmed from Leatherbarrow's observations on *weathering* of buildings in time, or the acknowledgement of the interplay between the architectural project, its construction, maintenance, and the natural forces. Accounting for the life of buildings in time, Kolarevic advocated an approach to the design of buildings that perform together with the environment. The experience of architecture makes it performative, Kolarevic recognized. Similar to Tschumi, he observed that the movement of people around a building gives architecture its performative capacity. Although this discourse promised to answer some of the basic questions on how architecture performs, the notion of performativity stayed closer to a design principle than to a method for evaluation. It fed into the deterministic form-oriented architectural discourse driven more by economic and environmental than philosophical concerns.

More recently, Michael Hensel wrote about performance-oriented architecture, synthesizing the discussion on performance in the humanities' performative turn and the work of Kolarevic and Malkawi, Grobman and Neuman but also Bernard Tschumi, Kengo Kuma, and Diller and Scofidio[43]. Jan Smitheram defined a similar intellectual ground for her discussion on spatial performativity and performance, including Russian Futurists and Cubists, Tschumi and Goffman[44]. Finally, Keller Easterling discussed performativity of infrastructures from a political and spatial perspectives, offering a unique understanding of complexities involved in the relationship between the urban fabric and telecommunications[45].

3.3.2. How Architecture Comes to Matter?

It is not new or unusual to say that architecture is a result of a performance, or that it itself performs on this world. Nevertheless, an important distinction exists among the theories discussed above. *Performative* is opposite of representational, but it is also different from performance. For example, in the work of Koolhaas and Tschumi, performance and event invert the additive process of design into a process Tschumi calls *carving*[46] - architecture is thus an *envelope* for an event, not an actively performing entity. On the other hand, *performative* denotes a *potential* for action and emphasizes experience. Philosopher and gender theorist Judith Butler distinguished between performance, which presumes a subject or some-body performing; and *performativity*

42) Kolarevic and Malkawi, *Performative Architecture*.

43) Hensel, *Performance-Oriented Architecture*.

44) Smitheram, 'Spatial Performativity/Spatial Performance.'

45) Easterling, *The Action Is the Form. Victor Hugo's TED Talk*; Easterling, *Extrastatecraft*.

46) Bernard Tschumi, *The Discourse of Events*, ed. Nigel Coates (London: Architectural Association, 1983); Janet McGaw, 'Performative Spatial Practices in the Urban Realm: A "tactic" for Transcendence' (time.transcendence. performance, Monash University, 2009).

which contests the very notion of the subject - it exists in action, it is made through discourse[47]. Butler's idea of *performativity* was central to the feminist critique of deterministic social roles but, as Smitheram observed, proved inspiring for dismissal of other types of determinisms, such as the *givennes* of architecture. In this context that explored architecture as an active performative agent, Butler's notion of the inherently discursive subject (one that is disciplined through regulatory power of discourse) was often lost. This does not, however, devalue the resulting architectural framework: a composite of performance and performativity.

Hensel identified a shift in architectural thinking from a representational way of knowing into acting, time-based, location specific and eventual. He defined performance-oriented architecture "based on the understanding that architecture unfolds its performative capacity by being embedded in nested orders of complexity and auxiliary to numerous conditions and processes: such architectures are essentially non-discrete"[48]. The key to understanding performativity of architecture in this performance-oriented context is its environmental and social embeddedness; its active exchange with these auxiliary processes.

According to Smitheram: "[performativity in architectural discourse] is used to critically re-describe how we experience space, as being of equal importance to the end product of architecture"[49]. Making a bridge between Butler's writing on space and her interpretation in the contemporary critical architectural discourse, Smitheram proposed the concept of a composite between performance and performativity: between a constructivist subject and a performing subject. Spatial performativity, observed through the experience of the build environment is "a way to understand how power relations structure, and are embodied and performed, in relation to architecture". This is close to Easterling's argument about the performativity of infrastructure space. Easterling describes what she calls *active form* as an "updating platform unfolding in time to handle new circumstances, encoding the relationships between buildings, or dictating logistics". It is information itself that organises buildings. For her, (this) action is form[50].

As we have seen, the performative paradigm is unfolding in architectural discourse in three distinct directions - as architecture performed by bodies (carving, void), as a complex interaction with the environment and finally as performativity of non-human actors, architecture included.

47) Smitheram, 'Spatial Performativity/Spatial Performance.'

48) Hensel, *Performance-Oriented Architecture*, 30.

49) Smitheram, 'Spatial Performativity/Spatial Performance.'

50) Easterling, *The Action Is the Form. Victor Hugo's TED Talk.*

Agency residing in architectural entities is clearly debatable, but it is nevertheless evident when evaluating spatial experience defined by the architecture[51]. It is through this *agency* that architecture realises its performative capacity to structure flows of energy and people in space.

3.4. Architecturality

The term "architecturality", instead of the adjective "architectural", designates a property that is inherent to built artefacts, such as buildings and urban spaces, but extends beyond those. I will argue that *architecturality* is in direct relationship with *performativity* of architecture, which I evaluate in terms of its *agency* and experience it creates. I understand *performativity* in its broadest sense, as *agency* or capacity for action residing in objects, structures, infrastructures. With this in mind, I will make parallels between *architecturality* of wireless communication signals and *architecturality* of architecture or built artefacts.

Figure 3.2 Relating agency, performativity and architecturality

Although it might seem at first sight, it is not absurd to discuss *architecturality* of architecture. "The notion of *architecturality* is significant in the question of what makes architecture architectural?", Adrian Lo, the author of the blog "*Architecturality*" states[52]. Just as the suffix -ness in Adrian Mackenzie's concept of *wirelessness* conveys the notion of a state, condition, or mode of existence[53], Lo argues that -ity in *architecturality* re-forms it into an abstract noun that expresses a state or condition.

I use *Architecturality* here to evaluate the condition of affecting the experience of space in a significant way. It is obvious that architecture has this potential. I will try to explain this obvious fact through some tangible examples.

51) Smitheram, 'Spatial Performativity/Spatial Performance.'

52) Adrian Lo, 'Architecturality I', *Architecturality*, 3 September 2010, https://architecturality.wordpress.com/?s=architecturality.

53) Benedikte Zitouni, 'Into More-than-Human Worlds: Feeling Wireless Environments on the Fringes of Our Perception : Computational Culture', *Computational Culture. A Journal of Software Studies*, no. Issue One (2011), http://computationalculture.net/review/into-more-than-human-worlds.

What exactly is architecture able to perform?

In one of his early essays, Le Corbusier observed the effect of architecture on our senses: "By forms and shapes he [architect] affects our senses to an acute degree, and provokes plastic emotions". He continues with even more enthusiasm: "by the relationships which he creates, he wakes us in profound echoes, he gives us the measure of an order which we feel to be in accordance with that of our world, he determines the various movements of our heart and of our understanding; it is then that we experience the sense of beauty"[54]. It is the disposition and visual qualities of architectural elements that connect us to the world around us and determine our experience of it.

One of the better examples of Brutalist architecture in London, the infamous Robin Hood Gardens estate is currently awaiting demolition. Approved by the city council after a fourty year long legal battle, this demolition is one of many similar projects for the redevelopment of post World War II public housing estates. Tenants, who never appreciated the living conditions created by Robin Hood Gardens, took part in a fierce debate over therecall or preservation of Modernist and Brutalist public housing architecture. Regardless numerous attempts by heritage organisations to enlist it as cultural heritage[55], demolition was deemed the only solution for this large concrete structure.

Forty years ago, the spectacular implosion of St Louis Pruitt-Igoe housing estate was labelled by Charles Jencks as "the day modern architecture died"[56]. Pruitt-Igoe was notorious for problems of concentrated crime, poverty and racial segregation. Some twenty years after its completion all 33 buildings were detonated. The critique was often blaming large, disassociated corridors and disowned semi-private areas for facilitating criminal and generally irresponsible, antisocial behaviour[57]. What is striking about these examples is the recognition of the strong influence on people's lives by mere way of organising corridors and windows. The fact that these buildings needed to be demolished indicates the amount of *agency* they had by simply standing on the ground.

The examples above describe how buildings affect the experience of space. A wall is not just a passive entity in space - it actively stands in the way, it visually and functionally organises space.

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54) from *Engineer's Aesthetic and Architecture*, by Le Corbusier, 1923, in William W. Braham, Jonathan A. Hale, and John Stanislav Sadar, eds., *Rethinking Technology: A Reader in Architectural Theory* (New York, NY: Routledge, 2007).

55) The latest campaign, led by heritage organisation the Twentieth Century Society, has not resulted in Robin Hood Gardens's listing by the public body Historic England. This campaign was active since 2008 and included support of the majority of contemporary architects. http://www.c20society.org.uk/casework/robin-hood-gardens/

56) Charles Jencks, *The Language of Post-Modern Architecture* (New York: Rizzoli, 1977).

57) Oscar Newman, *Defensible Space; Crime Prevention through Urban Design* (Macmillan, 1972).

Richard Serra's Tilted Arc[58] provoked a similar controversy[59], which was also resolved by its removal. This confirms the observation made by Easterling, who insisted that activity is inherent not only in things that move (cars, people) but also in urban organisations and spaces, in general, residing in the relationship of its various parts[60]. "Infrastructure space is performing, and the changing shape of that stream of activities constitutes information."

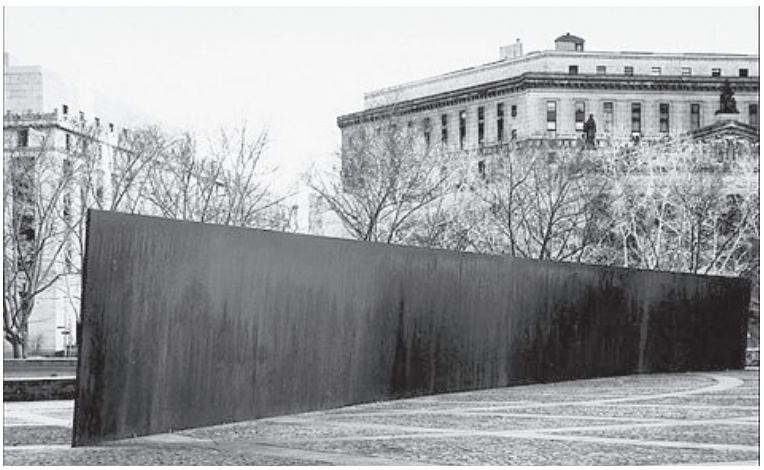

Figure 3.3 Tilted Arc, Richard Sera, 1981. The publicly commissioned artwork provoked a clash between people frequenting the square and the art world, resulting in its removal by the authorities. (public domain)

Architecturality has to do with organisation and structuring of both construction elements and people. It also has to do with the message built structures are trying to convey – whether it is an implicit political propaganda (people walking on top of the parliament as in Niemeyer's Brasilian Parliament, or Foster's German Reichstag dome), eclectic visual stimulation (typical of contemporary media façades) or purist and declared functionalism that is engineering lifestyles

58) Tilted Arc was a large public sculpture, commissioned by United States General Services Administration Arts-in-Architecture program for the Foley Federal Plaza in lower Manhattan, NY. It was installed in 1981, made from a solid, self-oxidising steel plate, 37m long and 3.7m high, slightly tilted across the plaza. Since the first day, it appeared as an obstacle to those who frequented the plaza, leading to a fierce public debate that lead to its final removal in 1989. On one side were those who found it disruptive to their daily routines; on the other, Serra and a large group of artists, historians, psychiatrists (including Philip Glass, Keith Haring, and Claes Oldenburg, to name a few) argued for its preservation at the plaza, defending the artist's freedom of expression and the site-specific nature of the work. The debate was resolved by a trial, held in 1985, with the jury voting in favour of its removal. Regardless Serra's appeal to the decision, the piece was finally dismantled and placed in storage by federal workers.

59) Richard Serra, 'Art and the Law: Suppression and Liberty the Tilted Arc Controversy', *Cardozo Arts and Entertainment Law Journal*, no. 19 (2001): 39–49.

60) Easterling, *The Action Is the Form. Victor Hugo's TED Talk*.

together with the rhythm of windows (as in the case of Brutalist housing projects).

In this respect, we can measure *architecturality* of architecture as the extent to which it is able to actively shape the flow of activities, objects and people, as well as to affect their experience or perception of space. Far from aesthetically-minded observations of Le Corbusier cited above, but agreeing that our emotions are plastically shaped by different architectures (hardware and software architecture, information or cytoarchitecture[61] included), the analysis of *architecturality* in this chapter focuses on activity inherent in what Easterling calls *spatial products*. Easterling is often constructing her arguments on computational metaphors. In this respect, *spatial products* are the outcomes of algorithmic performances on space. These algorithms are inscribed in both zoning rules and regulations, state legislation of free trade and master plans for a 'city in a box', 3D modelling software rendering these mater plans, the aesthetic of architectural designs. The algorithmic performance of space "privileges these repetitive activities and renders the act of making an individual house into a marginal gesture. What is really being made is something like a protocol or a non-digital spatial software that is both shaping and generating the activity of making houses"[62].

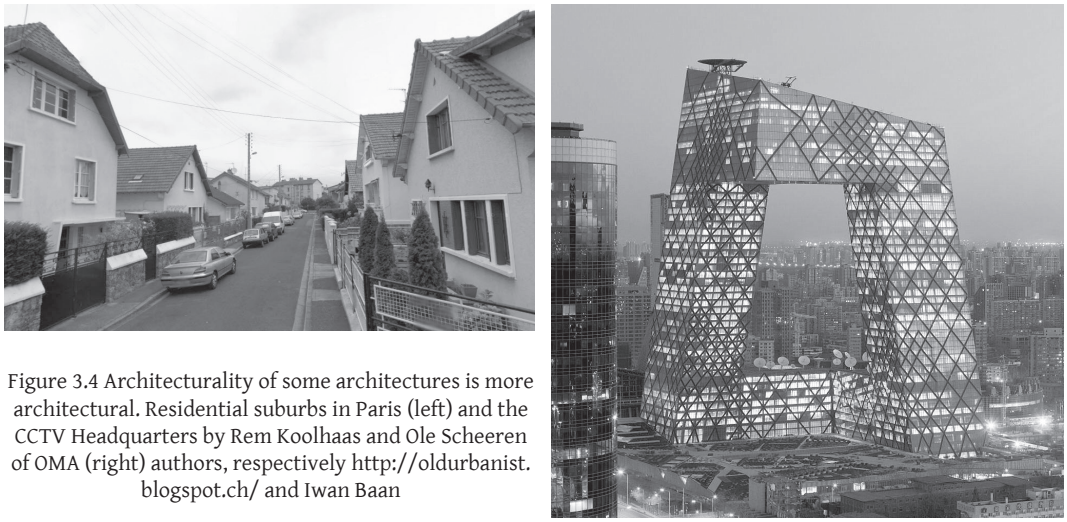

Figure 3.4 Architecturality of some architectures is more architectural. Residential suburbs in Paris (left) and the CCTV Headquarters by Rem Koolhaas and Ole Scheeren of OMA (right) authors, respectively http://oldurbanist.blogspot.ch/ and Iwan Baan

61) Cytoarchitecture is a field that studies cellular composition of the body's tissues, using a microscope

62) Easterling, *The Action Is the Form. Victor Hugo's TED Talk.*

3.5. Towards a Model for Evaluating Spatial Impacts of Wireless Communication

How can the notions of *agency*, *performativity* and *architecturality* help construct a model for evaluating spatial impacts of wireless communication? As it is the case with phenomenological inquiries - object, units, phenomena, *actants* are all already there, but we need to attune our senses to them in order to be able to grasp them intellectually. This is similar to Rancière's concept of emancipation. According to Rancière, emancipation does not imply a reformation, a change of positions or roles. It suggests a change of perspective, looking at acting as an act of spectating at the same time.

Bryant warns: "If something makes a difference then it is, but the degree to which a being makes a difference on other beings can range from nil to perhaps infinity"[63]. How much does connectivity make a difference in space? And how might we attune our senses to this difference?

One obvious answer is to measure signal availability with our numerous Wi-Fi enabled devices. A manifold of studies mapping signal availability and propagation in space sprouted with the appearance of first wireless communication standards (Wi-Fi and Bluetooth). For example, a research team at IST, Lisbon correlated the extension of AP signals with the physical space, using a space-use analysis model (SUAm) based on Space Syntax[64]. The Senseable City Lab researched the impact of WiFi on people's spatial preferences through real-time map visualisations illustrating space/time usage patterns[65]. Pervasive urban gaming projects also studied spatial preference, showing how people are likely to adapt their paths to signal availability (e.g. take the bus instead of the metro to stay online, as in Mogi game)[66].

If we take space, networks and people into account as ontologically equal, we are forced to think of connectivity as a phenomenon that is not contained within or limited to human perception and *agency*. In this way, one has to observe waves' interactions beyond human interactions - to observe a network that involves buildings, air moisture, wind, waves, people. Adrian Mackenzie offered a perspective on connectivity that focuses on the experience of relationships. Mackenzie

63) Bryant, 'Imbroglios of Objects.'

64) Heitor et al., 'Synchronizing Spatial Information In Complex Environments: A Crossover of Space Syntax and Spatial Information Visualization.'

65) Sevtsuk et al., 'Mapping the MIT Campus in Real Time Using WiFi.'

66) Montola, Stenros, and Wærn, *Pervasive Games*.

used William James radical empiricism[67] as an intellectual framework that he expanded to contemporary network media conditions[68]. In *Wirelessness*, he shows that "the sense of being connected occurs at the edges of our perception"[69]. Being connected is site-specific - as it passes through numerous intermediaries (mouses, keyboards, local interfaces, pop-ups, passwords, AirPort lists, reception details, etc.) and more complex than information on signal availability can explain. This sense of connectivity adapts to the state of the device, lighting up when it's working and disappearing when it's not. Thus, "it becomes geographically and ontologically more correct"[70] to locate these sensations in the realm of signals and devices. Mackenzie situated connectivity at the edges of consciousness, both ours and the infrastructure's[71].

How might we account for the expression of this infrastructure? Mackenzie gives us two useful tools to work with. One is the empiricist perspective on the equipment involved. The other is the notion of the *conjunctive envelope* formed out of wireless chipsets, radio frequency signals, algorithmic processes, space, time, etc. A conjunctive envelope is "a spatial-temporal fold that configures and concentrates" what Mackenzie calls "arrivals" and "departures"[72] or what we might interpret as different interactions with the infrastructure. It is the envelope that alters sensations of location and situation. In Jamesian terms, it alters the way "the world hangs together"[73].

Wirelessness was published at the time mobile broadband (3G) standard was just introduced, thus it does not account for a completely pervasive spatial connectivity – Wi-Fi is static and mobile connectivity is mobile. Although *conjunctive envelope* is a very spatial concept, Mackenzie offers us only hints at the spatial experience it accommodates, staying focused on a rather general notion of experience (of humans and of devices).

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67) William James was critical of the traditional epistemological dichotomies: objectivity/subjectivity, body/mind, external/internal... He putt forward the concept of the "pure experience" which regarded perception as direct, coordinating coalescence of perceptional and conceptual experience. Radical empiricism was also meant to turn the attention away from these dichotomies, while acknowledging thinking, reasoning and theorising as experience Harry Heft, *Ecological Psychology in Context: James Gibson, Roger Barker, and the Legacy of William James's Radical Empiricism*, Resources for Ecological Psychology (Mahwah, N.J: L. Erlbaum, 2001)..

68) Mackenzie, *Wirelessness: Radical Empiricism in Network Cultures*.

69) Zitouni, 'Into More-than-Human Worlds: Feeling Wireless Environments on the Fringes of Our Perception : Computational Culture.'

70) Ibid.

71) Mackenzie, *Wirelessness: Radical Empiricism in Network Cultures*.

72) Ibid.

73) Wiliam James, *Essays in Radical Empiricism* (Cambridge, Massachusetts, US: LONGMANS, GREEN, AND CO, 1912).

Keller Easterling discussed extensively the performance of infrastructures[74]. Her account of *action* which is form, is a spatial phenomenon, but with a very conceptual scope. She does not look at how a particular space is experienced but how an algorithm, in the sense of a procedure of operations prescribed by different actants, performs globally on space, generating repeatable spatial practices and experiences.

Easterling proposed a twofold view of architecture. There is water and there is a stone in the water[75]. This stone is normally what we consider architecture, single masterpiece objects, distinguishable form, representation of power or social order. Nevertheless, architecture creates spatial consequence as water as well, but it is architecture that is not *declared* as such, it is a flow of *spatial products* - an algorithmic pattern for design of houses, not a single house. Such architecture is information itself.

While architects often focused on object form and how it is generated, Easterling advocated recognition and design of active forms. *Active form* is the expression of activity and not its representation, as is the case with both architectural masterpieces and the proliferating *spatial products*. *Active form*, an algorithm itself, establishes what an organisation will be doing. Easterling called this *infrastructure space*, recognizing infrastructure as not only a substructure of built spaces but as the structure itself. "Infrastructure space is performing, and the changing shape of that stream of activities constitutes information"[76].

3.5.1. Wireless Signals: Agents of Connectivity

In this thesis, I observe wireless communication signals as *agents of connectivity*. Their goal is not to simply transmit *a* message but to exist as radiation, covering as much area as possible with as much signal strength. Connectivity is inevitably linked to a spatial configuration, connecting one point with another through mathematical propagation models. A wide range of devices (base stations, access points, smartphones, laptops, Bluetooth headphones) broadcast wireless communication signals, but the ideal propagation models used in infrastructure planning and disposition can never fully account for their actual propagation. Built space and people, as well as natural effects, have a significant impact on waves. On the other hand, connectivity has its own materiality, which is articulated through its continuous performance on space and people. I will try to account for these transactions, keeping the perspective on space, people and networks as ontologically equal, and examine the form given to *wirelessness* through action.

74) Easterling, *The Action Is the Form. Victor Hugo's TED Talk.*

75) Ibid.

76) Ibid.

Wireless network infrastructure consists of scattered devices, base stations, repeaters, access points and a *bouillon* of waves that connect them. It has a prominent place in our interaction with the environment and with each other. Whether or not this new layer is indeed "reconfiguring people, places and information" in space[77] we have to recognize the difficulty to read its impact on space and people.

This difficulty stems largely from the habit to evaluate connectivity from a purely utilitarian perspective. It is also caused by the lack of bridges between knowledge about wireless infrastructures, knowledge of urban form and architecture and knowledge about (the human) experience. Nevertheless, I identified some of the bridges in existing literature - most notably the writing of Mackenzie[78] and Easterling[79]. I then used their arguments to explore the notions of *agency* and performativity of architecture and wireless signals possess.

3.6. Real-time Interaction with Spatialised Network Information

What could be the form of wireless communication signals' action? How might we approach the design of this *active form*?

Interaction with wireless networks usually consists of connecting to an intermediary device in order to send or receive data from a remote location through this connection. A wireless client like a smartphone, for example, authentifies to a wireless network access point or a cellular base station. What all wireless communication systems work against – from radio transmission to near field communication – is distance. Thus they always act on space, allowing interaction between remote *actants* in real time. If we focus on Easterling's view of wireless network infrastructures, we can argue that its signals, together with the rest of the equipment, perform on space they propagate through, changing the stream of activities through (dis)connectivity.

This inquiry into non-human *agency* is in direct relationship with the method I used in this thesis to explore real time interaction with wireless signals. I used an interactive structure as a tool to re-experience waves - offering an *out-bodied* interactive model. *Out-bodied* interaction presumes an indirect relationship between information accessible to networked devices, people who use them and space they occupy. It gives equal *agency* to people and waves and allows to test

77) Laura Forlano, 'Codespaces: Community Wireless Networks and the Reconfiguration of Cities.', in *Handbook of Research on Urban Informatics: The Practice and Promise of the Real-Time City*, ed. Marcus Foth (Information Science Reference, IGI Global, 2008); Forlano, 'WiFi Geographies.'

78) Mackenzie, *Wirelessness: Radical Empiricism in Network Cultures*.

79) Easterling, *The Action Is the Form. Victor Hugo's TED Talk*; Easterling, *Extrastatecraft*.

Figure 3.5 Connect or Not installation. Pavilhao Civil, Campus Alameda, IST, Lisbon; September 2014

the perception of phenomena by both people and things. I devised a series of practical inquiries to enable this interaction. These experiments are discussed in detail in Chapter 7: *Projects and Prototypes* and documented in Appendices 1-3. I will use *architecturality* as a conceptual framework to evaluate the impact of wireless networks on space through the concrete example of *Connect or Not* installation as presented at Pavilhao Civil, IST Alameda campus in Lisbon in September 2014.

First of all, the design of *active form* asked for an interactive structure, in order to take into account the different *actants* at play (people, networks, space). This meant that the structure should react to both people's action and network action. People's action here is limited to the use of network traffic and space – communicating over wireless networks and changing positions in space. Space and people are at the same time obstacles to network signals propagation. I imagined the structure as an interface between the actions of people, signals and space. Thus, the reaction of the structure had to be spatial – a movement and a deformation that materialises the invisible actions – as well as social – inducing an action of communication (or disconnection) in the audience.

Connect or Not was a room-sized installation that acted as a reconfigurable spatial element, activated by motors that were stretching a large sheet of fabric according to the amount of wireless communication traffic. The installation comprised the structure made of stretchable fabric, a computing system that communicated the record of the network traffic from the smartphones, and the hardware that deformed the surface of the fabric. The information on network traffic was collected from the people's smartphones using a specially designed application.

Coming back to the idea of the *conjunctive envelope*[80], I imagined *Connect or Not* as an open form. It would start from a flat (or regularly deformed) surface and would then get deformed through action, by the force of motors attached to it. Aesthetically, the form was at the same time referring to a waveform (a standard representation of waves, or wireless signals) and to an architectural archetype – an arcade.

I gave a twofold appearance to the presence of wireless communication signals through this design experiment. Firstly, they were present as information they delivered to the communication devices and their users. Secondly, they were interpreted through the movement or deformation of the interactive structure that had a separate meaning from the meaning of the information they carried. The possibility to experience these two appearances simultaneously opened an interesting design problem of channelling the attention of the visitors. Clearly, people cannot have their attention equally on both the message and the movement of the structure, and they are more likely to choose to communicate than to observe the effect of this communication on something else. Still, creating this choice or dilemma was a step towards understanding the qualities and quantities of wireless network signals presence in space.

3.7. Discussion

At the beginning of this chapter, I explored the rise of the *posthumanist* discourse in humanities and STS as an introduction into the discussion on actants, objects, things, units from a de-centralised perspective. I put wireless communication signals, people who use them to communicate as well as space where these activities occur, at an ontologically equal level. This opened the door for an interpretation of *architecturality* through *performativity* of architecture, as it was extensively discussed by Smitheram[81]. I then further deconstructed *architecturality* through Mackenzie's empiricist discussion on the experience of connectivity[82] and through the action-minded account of Easterling's *active form*[83]. I built an account of connectivity as a phenomenon beyond mere availability of connection.

Wireless communication signals act as agents of connectivity. Just like any other infrastructure, they perform as *active form*. This means that their appearance - propagation is determined by algorithms that are inherent in their equipment and protocols[84]. This also means

80) Mackenzie, *Wirelessness: Radical Empiricism in Network Cultures.*

81) 'Spatial Performativity/Spatial Performance.'

82) Mackenzie, *Wirelessness: Radical Empiricism in Network Cultures.*

83) Easterling, *The Action Is the Form. Victor Hugo's TED Talk*; Easterling, *Extrastatecraft.*

84) Mackenzie, *Wirelessness: Radical Empiricism in Network Cultures.*

that they are in an active relationship with the rest of the environment, with the disposition to affect it similar to a ball on an inclined plane[85]. Through its own activity or performance, this infrastructure becomes structural. I made an attempt at demonstrating this structure at the end of this chapter through the concrete example of designing active form. This opened up questions about the design of attention and intentionality of communication.

85) Easterling, *The Action Is the Form. Victor Hugo's TED Talk*. Easterling illustrated Ryle's notion of disposition – an unfolding relationship between a potential and a propensity within a context – with the example of a ball on an inclined plate. The ball does not need to roll in order to possess the disposition to do so. Bringing together the discourses of Bateson, Latour and Ryle, Easterling concludes that disposition can be designed, which is important for understanding the implications of the design of active form – the algorithm that generates repeatable spatial products.

4. Infrastructure at Hand / in Space

When networking technology emerged as a means of personal communication, scholars believed that it was going to "liberate" people from space, or at least diminish the role of distances[1]. Globalisation theorists argued that, in compressed space, distances play no role any more. The critique of such oversimplification, with reference to infrastructures and their global distribution, appeared already in the work of their contemporaries such as Graham, Marvin[2] and Thrift[3]. Nevertheless, with the expansion of wireless network technologies, information became even more easily accessible - anywhere and at any time. Today, we no longer need to go to a particular place to retrieve a particular piece of information (such a birth certificate from city hall or a work of art in a museum).

1) Manuel Castells, *The Rise of the Network Society: Information Age, Economy, Society and Culture* (Blackwell Publishers Ltd, 1996).

2) S. Graham, 'The End of Geography or the Explosion of Place? Conceptualizing Space, Place and Information Technology', *Progress in Human Geography* 22, no. 2 (1 June 1998): 165–85, doi:10.1191/030913298671334137; Stephen Graham and Simon Marvin, *Telecommunications and the City: Electronic Spaces, Urban Places* (London ; New York: Routledge, 1996).

3) N. J. Thrift, *Spatial Formations*, Theory, Culture & Society (London ; Thousand Oaks, Calif: Sage, 1996).

The dispersal of mobile technologies has brought about a shift in the trend of location irrelevance[4]. What happened instead of the compression of time and space is a distribution of communication devices that augment locations. Caused by a similar proliferation of technology, this shift is primarily manifested in the fact that today a person is more likely to be online in a café, scrolling on a smartphone, than using a mouse and a keyboard at home. We are attracted to places by a combination of social and technical connectivity, and not by their mere function or a working connection. On top of this, our presence is extended to different realms of social spaces with the help of location-aware applications[5]. Although it is difficult to pin down the precise role of the physical environment, the properties of space do affect our mobile interactions[6]. At the same time, the propagation of wireless communication signals takes up actual space and has measurable physical properties.

Both wired and wireless communication technologies serve the same goal: telecommunication or transmission of messages across distances. Nevertheless, their physical presence in space is more difficult to compare. To a certain extent, they follow a similar structure: ownership of underground cables or ownership of channels in the electromagnetic spectrum; subject to regulations, protocols and network architecture[7]. However, cable infrastructure follows the logic of a flow (and can thus be interrupted by simply cutting a cable), whereas wireless networks broadcast signals. This broadcast happens in the radio spectrum, the invisible portion of electromagnetic radiation[8]. Electromagnetic spectrum is difficult to grasp and we often resort to tangible metaphors of roads or territories when talking about it[9].

Radio waves interact with surrounding matter, their propagation is primarily dependent on the conditions of the environment. Although imperceptible to the human senses, these signals cannot be considered immaterial as they are subject to the same laws of physics as X-Rays, radio waves and other electromagnetic radiation. The waves also play an important role in the information economy, as a resource that is rendered scarce through governmental regulations,

4) Gordon and de Souza e Silva, *Net Locality*.

5) Ibid.

6) see for example the work of Dan Hill and ARUP on the use of Wi-Fi in the State Library of Queensland. Dan Hill, 'Sketchbook: Wi-Fi Structures and People Shapes', *City of Sound*, 8 November 2008, http://www.cityofsound.com/blog/2008/11/wi-fi-structure.html.

7) Rachel O'Dwyer, 'Spectre of the Commons: Spectrum Regulation in the Communism of Capital', *Ephemera. Theory and Politics in Organzation* 13.3, no. Communism of capital? (2013): 5–34.

8) Radio spectrum is the range of frequencies between 1Hz and 3000GHz. Wireless communications I am discussing in this chapter use parts of this spectrum, e.g. 900Hz for GSM or 2.4GHz for Wi-Fi. More details on the use of different frequency bands are given later in the chapter.

9) O'Dwyer, 'Spectre of the Commons: Spectrum Regulation in the Communism of Capital.'

allocations and dispossession[10]. Still, there is more to this propagation than the laws of physics or economy can describe. Mackenzie defines *wirelessness* as "a sensibility attuned to a proliferating ethos of gadgets, services, opportunities, and enterprises that transmit and receive information via radio waves using Internet-style network protocols"[11].

The title of this chapter hints at a Heideggerian metaphor of networks as a service that can be either *ready-to-hand* or *present-at-hand*, depending on their functional status and the observer's point of view. Introduced into the HCI discourse by Winograd and Flores[12], this metaphor has been so pervasively used by researchers ever since that it became a philosophical token. It is easily applied to anything that can be *used*, from hammers to infrastructures. With the title *Infrastructure at Hand / in Space*, I am challenging the capacity of this metaphor to explain the condition of wireless networks in relation to space and people.

In the beginning of the chapter, I give a brief account of wireless signals in their materiality - physical properties of wave propagation and the infrastructure they rely on. I then introduce the way that the presence of wireless networks was examined in spatial analysis[13] and ethnographic studies[14]. Finally, I introduce the notion of *connectivity* from infrastructural[15], political[16] and empirical[17] perspectives.

4.1. The Propagation

Wireless communication signals are essentially couples of carrier waves and modulated information that's piggybacked[18] on them. Like any other electromagnetic wave, wireless communication signals are subject to laws of physics that characterize X-Rays, radio waves

10) Ibid.

11) Mackenzie, *Wirelessness: Radical Empiricism in Network Cultures*, 29.

12) Terry Winograd and Fernando Flores, *Understanding Computers and Cognition: A New Foundation for Design*, Language and Being (Norwood, N.J: Ablex Pub. Corp, 1986).

13) Heitor et al., 'Synchronizing Spatial Information In Complex Environments: A Crossover of Space Syntax and Spatial Information Visualization'; Sevtsuk et al., 'Mapping the MIT Campus in Real Time Using WiFi.'

14) Forlano, 'WiFi Geographies'; Hampton et al., 'The Social Life of Wireless Urban Spaces.'

15) Star, 'The Ethnography of Infrastructure.'

16) Mattelart, *Networking the World, 1794-2000*.

17) Mackenzie, *Wirelessness: Radical Empiricism in Network Cultures*.

18) Piggybacking is a data transmission technique in the network layer that relies on coupling of two signals in such way that one (carrier wave) is modulated with the other (input signal). In this way the signal can travel at higher frequencies and transmit more information.

and other electromagnetic radiation. Their propagation is affected by the environment's configuration and conditions. In a direct relationship with the waves frequency, signal strength, range and the effect of obstacles determine its propagation. High-frequency signals (like WiFi) will be significantly reduced when they encounter a barrier while low frequency's signal long waves propagate easier at bigger distances. For example, at a frequency of averagely 2.4GHz and wavelength of 12.5 centimetres wireless network signals broadcast by standard consumer routers propagate well indoor or outdoor but have difficulties penetrating walls and similar barriers. The propagation here is strongly influenced by the material the barrier is made of, as for example glass walls and windows have a lower impact on signal reduction than concrete or load bearing walls. Metal bars and surfaces made of conductive material have the effect of Faraday cage, blocking electric fields and shielding the interior from external electromagnetic radiation. According to networking professionals, at the heart of wireless networking is the air - it provides a medium for propagation of signals[19] . This is why changes in temperature and air moisture can have an impact on connectivity. This impact is, nevertheless, limited to exceptional conditions that mainly occur outdoors. Heat does not directly affect electromagnetic radiation but the resulting lower air density does. Thermal fading or refraction due to variations in air density can affect the paths of wireless signals, causing same frequency interference and coverage holes[20] . Rain has a pronounced effect on waves at microwave frequencies as signal power gets absorbed or dispersed by raindrops. In this way, weather and atmospheric conditions cause propagation impairments on radio links. This is confirmed in a proposal to use measurements of these attenuations for atmospheric observations[21] .

4.1.1. Brief History of Radio Wave Technology and Wireless Communication

Most of information we daily access is served wirelessly using radio waves – from FM radio, through satellite signals and mobile phones, to wireless Internet. First non-wired transmitted information was a radio broadcast. Since the 1864 Maxwell's radio-wave theorem and the subsequent transmission of the letter "s" from Britain to the United States by Marconi in 1903, radio technology was developed to transmit information between two distanced points. It did so in the form of modulated analogue audio signal. The topology of this network was static and, therefore, its effect on people's spatial practices was not significant. People did not instantly stop travelling because they had information delivered by the radio, nor did they necessarily stay at

19) James T. Geier, *Wireless Networks First-Step*, First-Step Series (Indianapolis, IN: Cisco Press, 2005).

20) John Thelen, Dann Goense, and Koen Langendoen, 'Radio Wave Propagation in Potato Fields', in *1st Workshop on Wireless Network Measurements*, vol. 2 (Citeseer, 2005), 331–38.

21) H. Messer, Artem Zinevich, and Alper Pinhas, 'Environmental Monitoring by Wireless Communication Networks', *Science* 312, no. 5774 (5 May 2006): 713–713, doi:10.1126/science.1120034.

home to listen to it. Radio signal did cross big distances and connect receivers of information with remote broadcasts. This had important implications for network infrastructure, as information did not have to be delivered through the limited capacity of undersea cables.

While radio broadcast is a one-way centralised transmission, with only licensed stations allowed to broadcast at specific frequencies, contemporary wireless communication systems allow for different models of exchange. Mobile telephony uses specially allocated frequencies for an exchange of information between cell towers and connected devices. Mobile operators buy rights to use these frequencies from national regulatory authorities (FCC in the United States, BAKOM in Switzerland). A relatively small portion of radio is reserved for the unlicensed spectrum, within which is possible to transmit from any location, and also share the spectrum across different protocols[22]. This is the way Wi-Fi and Bluetooth technology operates today.

Wi-Fi Technology

Wi-Fi[23] technology has the capacity to communicate multiple types of media over the same protocol: text, voice, images and video. Wi-Fi enabled devices most commonly operate in two frequency bands: 2.4GHz and 5GHz, split in overlapping channels[24]. The spectrum mask - the set of protocols that define different channels and regulate frequency use is provided by the Institute of Electrical and Electronics Engineers (IEEE). This spectrum mask is as an international standard that ensures device interoperability while minimising interference with devices that share the same frequency range – amongst them microwaves, Bluetooth gadgets, Zigbees, Baby phones and wireless surveillance cameras. Interference is not constant due to the application of diverse network techniques like frequency hopping (jumping between different frequencies), direct-sequence transmission (spreading the signal over a wide band of frequencies), and data rate modification (reducing data rate to lower the Bit Error Rate) in signal transmission[25]. The IEEE continuously develops the standards, multiplying the amount of channels that are provided openly or through special licenses by the spectrum masks.

The development of Wi-Fi technology moved back and forth between perfecting the communication standard and the transmitting equipment. The IEEE committee published the

22) Jon M. Peha, 'Spectrum Management Policy Options', *Communications Surveys & Tutorials, IEEE* 1, no. 1 (First Quarter 1998): 2–8.

23) Wireless Fidelity, Wi-Fi Alliance's technology standard for wireless data exchange http://www.wi-fi.org/

24) The 2.4GHz is split in 13 channels, broadcasting on following frequencies: 2.412, 2.417, 2.422, 2.427, 2.432, 2.437, 2.442, 2.447, 2.452, 2.457, 2.462, 2.467 and 2.472 GHz. Channels 1,6 and 11 are thus known as the non-overlapping channels. The 5GHz frequency band has more channels whose regulation varies in different countries.

25) HP, 'Wi-Fi and Bluetooth - Interference Issues' (HP Invent, January 2002), http://www.hp.com/rnd/library/pdf/WiFi_Bluetooth_coexistance.pdf.

first standard, 802.11 in 1997, followed by first devices that could transmit 2 Mbits of data per second. In order to standardise equipment and ensure interoperability, Wi-Fi Alliance was formed in 1999 (originally WECA) by a group of key companies in the industry. First Wi-Fi adapters were deployed in Apple's iBook the same year, using the updated 802.11b standard that permitted data transfer of 11 Mbit/s. The 802.11g standard still used today was introduced in 2003 and achieved 54 Mbits/s in the 2.4GHz band. Because radio waves propagate through the air freely, this traffic is physically available to everyone with a Wi-Fi enabled device within the range of a network. Wi-Fi technology allows for extending the network across devices. Wi-Fi routers can be configured in such a way to form a *mesh network* in which all connected nodes share the connection with nodes nearby.

Wireless networks come as either open or secured. Open wireless networks allow any device to authenticate with the access point and participate in the network traffic. Today, wireless networks mostly appear as secured, using WEP or WPA encryption integrated into the traffic between routers and end-user devices, for the reasons of privacy and security. This makes it impossible, not given the password, for a device to take part in communication, although it is technically capable and physically in its range and.

Cellular Technology

Cellular technology is based on the principle of *carpet coverage* rather than *last mile* connectivity (the later often associated with Wi-Fi applications). Contrary to Wi-Fi, cellular technology relies purely on corporate infrastructure that is not extendible by users. With this comes the expectation of coverage and seamless connectivity everywhere, without having to negotiate access between different cell towers.

Cells are usually arranged in a hexagonal grid which network engineers use for several reasons[26] . The hexagon layout requires fewer cells than other polygon grid would, while its propagation model is closest to the ideal – the circle. Even more importantly, hexagon supports frequency reuse that is used in cellular networks as a way to increase both coverage and capacity. The frequency band is split in seven segments. When arranged in a hexagonal grid, each cell is surrounded with six other cells that operate at a different frequency, two cells of the same frequency never overlap.

In reality a cell's coverage area is neither hexagonal nor circular but of closest to an amebous shape, deformed by the terrain morphology, built structures in the area as well as foliage. There are areas where two cells of the same frequency might be interfering with each other as well as some dead zones.

26) Ajay R. Mishra, *Fundamentals of Cellular Network Planning and Optimisation: 2G, 2.5G, 3G-- Evolution to 4G* (Chichester ; Hoboken, NJ: Wiley, 2004).

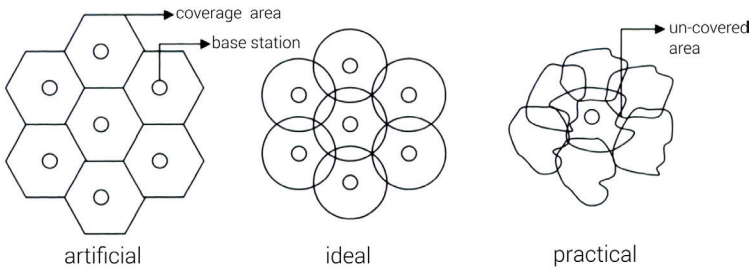

Figure 4.1 Cell coverage. Artificial model is based on optimal overlapping and channel distribution (left). The ideal model is how signal would propagate without interference with morphology, built structures and other obstacles (middle). The actual cell shape is of an irregular shape and includes some un-covered areas (right). From Ajay R. Mishra, *Fundamentals of Cellular Network Planning and Optimisation*

The first cell phone systems used analogue technology, with limited frequency allocations. Providers began to offer the service in the US in 1983 using the 1G analogue networks standard. These cellular networks were replaced by 2G or GSM (Global System for Mobile Communication) first deployed in Finland in 1992, soon forming a Pan-European network. GSM is a digitalised, internationalised cellular radio technology, which is still the major means of wireless communication throughout the world[27]. The third generation of mobile telecommunications technology was subsequently launched by 3GPP (January 2002, South Korea). It included, for the first time, the capacity to transmit wireless voice telephony, mobile Internet data, video calls and mobile TV. The UMTS (3G) standard was followed by fourth-generation (4G) LTE Advanced standards, first deployed in South Korea in 2007 and in Nordic countries in 2009. Information transfer rates got significantly higher[28]. Cellular telephony operates on multiple L band frequencies[29].

Today, Wi-Fi and different generations of cellular networking (3G and 4G) concurrently provide wireless access to voice and data traffic. Cellular networks provide individual, personal access to communication channels, based on per-megabyte or monthly subscription. Wi-Fi networks come in different kinds and under different conditions. Home networks that extend the signal from a wall socket onto a household are the most common implementation of Wi-Fi technology.

27) The number of users of GSM services went from 1 million in 1993 to 1 billion in 2004. Today, mobile-cellular population reaches 93 per cent globally, but is not evenly distributed across the globe Susan Teltscher et al., 'Measuring the Information Society Report 2014' (Geneva, Switzerland: International Telecommunication Union (ITU), November 2014), http://www.itu.int/en/ITU-D/Statistics/Documents/publications/mis2014/MIS2014_without_Annex_4.pdf..

28) From 3GPP 200Kbit/s to 100 Mbit/s for high mobility communication (while moving) and 1 Gbit/s for low mobility communication (not changing location).

29) The L band is the radio spectrum range between 1 and 2 GHz. Telecommunication mobile services use 850MHz, 900MHz, 1800MHz (UK) and 1900MHz (US) for GSM, as well as 2.1GHz(EU) for UMTS.

University campuses, companies, parks and public spaces, restaurants and bars are equipped with access points extending the network across their territory. Because of network security and otherwise convenience, Wi-Fi users prefer to secure their own network access, occupying space outside of their home with wireless signals protected with passwords. Nevertheless, free access to the Internet in exchange to personal information (mobile phone number) and agreement to the terms and conditions of use, is becoming a norm at transport hubs such as train stations, airports as well as cafés and restaurant chains (like in McDonald's or Starbucks).

4.1.2. Network Architecture

Before networks can transmit data, a common protocol, compatible with all devices involved, needs to be established. This protocol is a framework of specifications about network's components - a network architecture. Because of its complexity, network software is commonly layered into a hierarchy of protocols, seeking to promote communication (and not software) interoperability. In network communication language, an architecture decomposes a problem domain into a set of services. Network architecture regulates functional organisation and configuration of network's physical components, as well as data formats used.

Both Wi-Fi and cellular technologies rely on standardised network architectures when transmitting information across their networks. The most general standard in use is the Open Systems Interconnection (OSI) model[30]. It prescribes how software and hardware components interact with each other in network communication. This grants interoperability on a global scale regardless of the underlying internal structures and technologies.

The architecture of the OSI model, published in 1984, is part of the International Organization for Standardization (ISO) project to to define a unifying standard for the architecture of all networking systems. The model defines seven layers of functional elements, from the physical layer up to the application layer. Communication is regulated in such way that the decisions concerning layers on the top of hierarchy (e.g. encryption of data) do not affect the ones at the bottom (e.g. establishing a physical link), and the other way around. Between two nodes, layers communicate directly with the layer of the same level (see Figure 4.2). This is interesting in network traffic analysis, as one can get access to the the number of packets transmitted between the nodes (Data Link layer), without gaining full access to the network traffic. Such a technique was applied in counting traffic for the first interactive installations produced in the scope of this research, described in chapter 7.

30) In contemporary networking, OSI and TCP/IP models are used when describing protocols. TCP/IP model is similar to OSI but much less general. It consists of four layers and is commonly used for Internet traffic.

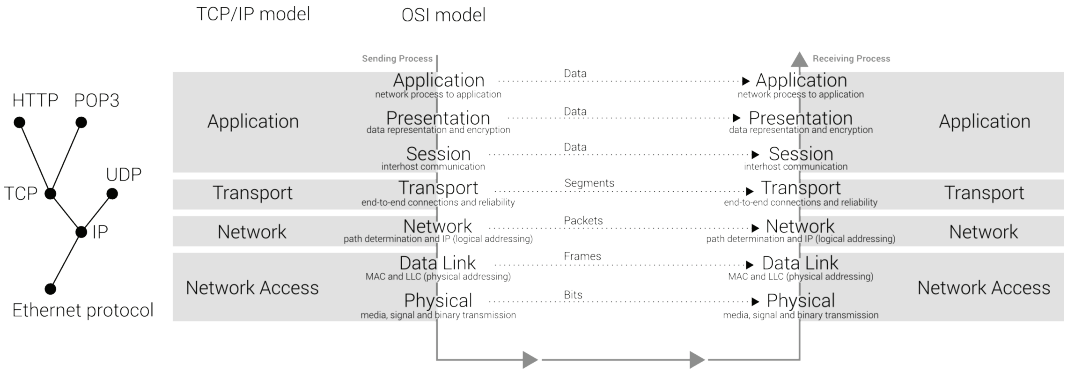

Figure 4.2 The two most important network architectures used in wireless communication. TCP/IP model is older and specific to the Internet traffic. OSI model is more general but rarely applied in its entirety.

Essentially, protocols, models and standardisation in general is about compatibility – it assumes participation of diverse entities in communication (different equipment manufacturers, different types of devices, different services involved when travelling, etc.) and tries to account for their differences[31] . This allows for continuous optimisation of network capabilities and technologies. At the same time, it makes reforms in the way systems operate much more difficult to negotiate and implement[32] .

Although useful for guiding discussion and evaluation, OSI is rarely fully implemented. Network products or standard tools often ignore certain specifications and regulations on functions that belong together in a layer, as defined in the model.

4.1.3. Future Trends

How will wireless infrastructure develop from here? What protocols and bandwidths will it use? Finally, who will be the users of this future infrastructure?

The debate in engineering circles on the future of wireless network infrastructures is centred around efficiency and rationale of providing us with more speed, bandwidth and using as much as possible of the existing infrastructure. On one hand, the preferred infrastructure model is under consideration: *carpet coverage* or *mesh networks*? Will we need more high-power base station repeaters or will the infrastructure rely on a combination of portable and static antennas? These questions address the future of the physical infrastructure that will be embedded in our environment.

31) Mishra, *Fundamentals of Cellular Network Planning and Optimisation*.

32) Barbara Van Schewick, *Internet Architecture and Innovation* (Cambridge, MA: The MIT Press, 2010).

On the other hand, network engineers are exploring bandwidth limitations. Can the current capacities in bandwidth and range be even more optimised? What new frequency bands will be licensed for use in wireless network traffic?

Lehr and McKnight found in 2003 that there was an economical advantage to a centralised, cellular coverage infrastructure approach over the distributed mesh network model[33]. Because every single byte could be charged to each user, this model was more interesting to commercial companies. On the other hand, the comfort of using Wi-Fi technology that depends only on hardware compatibility, is not reflected in the current cellular service that depends on users location (in roaming or not). In 2004, Bar and Galperin discussed the possibility for dynamic, peer-to-peer Wi-Fi networks to replace wired network infrastructures[34]. Without consideration for the financial model of charging for traffic, Bar and Galperin described the possibilities for a bottom-up infrastructure of Wi-Fi clients that at the same time act as Wi-Fi access points: "all Wi-Fi devices can be programmed to detect other devices within their range and create ad-hoc connections". *Mesh networks* could spontaneously emerge when enough Wi-Fi devices were present in an area.

One prominent research focus today is the capacity of infrastructures to offload traffic by getting multiple wireless technologies to work together[35]. In this scenario, every device will be expected to negotiate between the different network services. For example, as most traffic occurs in buildings, a local call would make use of Wi-Fi infrastructure to talk to people in the same space instead of a remote call. Then there were proposals to subvert existing Wi-Fi infrastructure as 3G picocells[36]. This idea was further developed in proposals for the LTE Direct communication standard, which promises network propagation across a mesh of devices, without a centralised base station network[37]. LTE direct functions like a mesh network but uses the spectrum of mobile operators, integrating with their already available services. The forthcoming fifth generation of wireless communications technology (5G, expected to be deployed by 2020), will use cognitive radio technologies to adapt bandwidth to different users. It is supposed to handle about 1000 times more mobile data than today's cellular systems.

33) Lehr and McKnight, 'Wireless Internet Access.'

34) François Bar and Hernan Galperin, 'Building the Wireless Internet Infrastructure: From Cordless Ethernet Archipelagos to Wireless Grids', *COMMUNICATIONS & STRATEGIES* 2nd quarter 2004, no. no. 54 (2004): 45–68.

35) Josh Romero and Stephen Cass, 'CES 2014 Trends: Wireless Networks Need to Learn to Cooperate - IEEE Spectrum', 8 January 2014, http://spectrum.ieee.org/podcast/telecom/wireless/ces-2014-trends-wireless-networks-need-to-learn-to-cooperate.

36) Lucky, 'Wi-Fi and Cellular: Who's the Boss? - IEEE Spectrum.'

37) Lei Lei et al., 'Operator Controlled Device-to-Device Communications in LTE-Advanced Networks', *IEEE Wireless Communications* 19, no. 3 (June 2012): 96–104, doi:10.1109/MWC.2012.6231164; Shahid Mumtaz, Kazi Mohammed Saidul Huq, and Jonathan Rodriguez, 'Direct Mobile-to-Mobile Communication: Paradigm for 5G', *IEEE Wireless Communications* 21, no. 5 (October 2014): 14–23, doi:10.1109/MWC.2014.6940429.

Others still propose completely new protocols and bandwidths (smaller antennas[38], more powerful microchips[39] or switching to millimetre waves[40]). For example, some researchers explore visual transmission of data, under the common name of Urban Optical Wireless Communication (UOWC). Notably, UOWC facilitates rapidly deployable, lightweight, high-capacity communication without licensing fees and tariffs[41]. Nevertheless, optical wireless communication suffers from weather changes and is still not a reliable way to get messages across distances.

In the future, we might also consider the climate impact on waves propagation. British Secretary for Environment report on the impact of climate change on our infrastructures concluded that higher temperature, as well as the risk of more intense precipitation, could have implications on the functioning of wireless networks[42]. As I have previously mentioned, hot air, rain and fog change the way waves diffuse. The report sees opportunities for the ICT industry to develop new technologies to aid climate resilience, e.g. providing networks of sensors and other data points to provide information on weather events.

This brings up the question of the future users of wireless networks. Will the majority of them still be humans or are robots and sensors going to become the main bandwidth consumers? The current trends support a proliferation of connectivity and networks based on the Internet of Things (IoT) and Automated Road Transport System (ARTS). IoT is a name used for the vision of networked objects that are connected and structured in a similar way to the information on the Internet. Unlike the first wave of IoT development that relied on unique RFID tags and readers, the second wave of interest brought a shift towards universal standards like Bluetooth and Wi-Fi connections. This means that all sensors and processors of this large network of devices increasingly communicate through the same channels we use for phone calls and browsing, significantly increasing bandwidth consumption.

38) A new antenna technology described in the article "New Theory Leads to Gigahertz Antenna on a Chip " by Alexander Hellemans in IEEE Spectrum, April 2015 http://spectrum.ieee.org/tech-talk/telecom/wireless/gigahertz-antenna-on-a-chip

39) "Chip Could Double Wireless Data Capacity by Charles Q. Choi" in IEEE Spectrum, March 2015, http://spectrum.ieee.org/tech-talk/telecom/wireless/circuit-transmits-and-receives-simultaneously-on-same-freqency

40) "Millimeter Waves May Be the Future of 5G Phones" by Ariel Bleicher in IEEE Spectrum, June 2013 http://spectrum.ieee.org/telecom/wireless/millimeter-waves-may-be-the-future-of-5g-phones

41) D. Kedar and S. Arnon, 'Urban Optical Wireless Communication Networks: The Main Challenges and Possible Solutions', *IEEE Communications Magazine* 42, no. 5 (May 2004): S2–7, doi:10.1109/MCOM.2004.1299334.

42) Caroline Spelman, *Climate Resilient Infrastructure: Preparing for a Changing Climate*, Cm 8065 (Norwich: The Stationery Office (TSO), 2011).

Autonomous vehicles or self-driving cars were pioneered on the streets of European and American cities in the past two to three years, slowly gaining access to public roads[43]. The public discussion around these transport systems, popularly called the Internet of Vehicles, mostly revolves around safety and acceptance by the general audience, sometimes also about the cost. Yet, autonomous vehicles will become major consumers of wireless network bandwidth, having to negotiate GPS information and user instructions over the same network infrastructure already used by smarthpones, laptops, printers and home media serves.

Or will they? Scholars and designers mostly focused in their discussions on the human user's perspective of the way wireless infrastructure can develop in future: how will we be charged for the data, will we have faster connections on our smartphones, will we be able to extend the network ourselves? Nevertheless, given the previously mentioned, the question on the direction future development will take probably depends more on the non-human users such as self-driving cars, environmental and medical sensors than on our average smartphone user.

4.2. Does the Wireless Environment Reflect the Physical in Which it is Contained?

The wireless environment is a combination of ideal signal propagation and different obstacles it encounters, including people, buildings, atmospheric changes etc. I will introduce five research projects in this discussion, seeking to demonstrate their different approaches and similar findings. These studies examined the relationship between wireless networks and the physical space in which they were contained, focusing on network coverage, its dynamics and use. They all date from the time when Wi-Fi technology became massively adopted and deployed across public spaces and buildings, university campuses and even cities. The first three used techniques of spatial analysis to map and interpret WiFi presence. The later two are ethnographic studies of network users who frequented public space searching for connectivity.

The first two studies analysed university campus networks, which granted researchers access to log files and network monitoring capacities. They treated university campuses as an approximation of complex urban conditions - test environments or miniature versions of an urban neighbourhood where a complex set of activities, including living and working, take place. The third example is a dynamic representation of a city-wide presence of public and private wireless networks.

43) Adriano Alessandrini et al., 'CityMobil2: Challenges and Opportunities of Fully Automated Mobility', in *Road Vehicle Automation*, ed. Gereon Meyer and Sven Beiker (Cham: Springer International Publishing, 2014), 169–84; Mario Gerla et al., 'Internet of Vehicles: From Intelligent Grid to Autonomous Cars and Vehicular Clouds' (IEEE, 2014), 241–46, doi:10.1109/WF-IoT.2014.6803166.

4.2.1. Mapping the MIT Campus in Real Time using Wi-Fi

Between 2005 and 2008, researchers at the SENSE-able City Laboratory, MIT, Boston, conducted an overall mapping on the Wi-Fi usage at MIT campus. They looked at the intersection of Wi-Fi locations and activity (the amount of wireless devices connected to the network access points at different locations) using a tool developed by the project team, iSPOTS. The team could then analyse log files from the campus Internet Service Provider (ISP) and produce spatial visualizations of the observed activity in real time[44]. The research examined the impact of the wireless communication networks "from the point of view of an urban planner or architect". The scope of this study was whether and how the daily working and living patterns of the MIT academic community changed due to the emergence of Wi-Fi.

Besides findings on the possible uses for the iSPOTS tool, the paper stays relatively inconclusive about the extent to which Wi-Fi influences people's spatial preferences. After all, "visualizing aggregate people's movement trough secondary sources such as WiFi, is [...] not the same as understanding the movements and the causes behind them"[45]. The authors open new questions, such as the need to revise the existing classification of space according to their actual use, Wi-Fi connectivity included in the evaluation, or whether Wi-Fi is becoming one of the expected architectural qualities of a space.

4.2.2. Synchronizing Spatial Information in Complex Environments: a Crossover of Space Syntax and Spatial Information Visualization; IST, Lisbon

Researchers at the Instituto Superior Técnico (IST), Lisbon, conducted a related study, starting from January 2006. With the background in Space Syntax and the interest in building a Space-use analysis model, the focus of this research was on knowledge sharing scenarios and its spatial patterns. To be able to correlate the extension of AP signals with the physical space, they proposed a space-use analysis model (SUAm) that explored relationships between "the virtual web space (user communication in a more or less ubiquitous field) and the physical space (users movements in a more or less permeable system)". In their paper *Synchronizing Spatial Information In Complex Environments*, the authors drew a parallel between the permeability of the virtual space of the Internet and ubiquity in the physical space[46]. Starting from the theoretical signal propagation model, the team analysed signal coverage distorted by obstacles such as buildings and electronic

44) Sevtsuk et al., 'Mapping the MIT Campus in Real Time Using WiFi.'

45) Ibid., 336.

46) Heitor et al., 'Synchronizing Spatial Information In Complex Environments: A Crossover of Space Syntax and Spatial Information Visualization.'

equipment in rooms. The Space-use analysis model was developed using activity categorisation tagging of access points (Communicating, Creating, Decision making, Delivering, Applying) in order to analyse the capacity of Wi-Fi networks to serve as a tool for analysing use of space.

Through an aggregation of traces (location queries) and flows (mobility queries), researchers produced heat maps of signal availability intersected with user activity, exploring probability of users movement across APs or permeability at local (connectivity to the system) and global level (integration). The main findings reveal a correlation between the form of a space and connectivity, as "more dynamic and permanent wireless activity located at more permeable levels and confined spaces"[47]. Wi-Fi networks demonstrated the capacity to function as an ad-hoc position tracking system, revealing some regularities in patterns of knowledge-sharing.

4.2.3. City-wide Wi-Fi Geographies

City-wide Wi-Fi geographies research[48] is at the intersection of mapping Wi-Fi infrastructure, its coverage and the analysis of its use. Torrens and his team developed a technique based on wardriving[49] to capture data on location, coverage and traffic provided by APs throughout Salt Lake City, Utah, US. They captured beacon frames[50] from all access points broadcasting in the Wi-Fi spectrum. They then mapped out a continuum of overlapping *lilypads* of network access coming from the access points and produced 3D visualisations of their density, activity, coverage, signal strength, data rates and security types. Availability and use of commercial hotspots was compared to the public ones. Based on the density of access points and network activity, the study concluded that Wi-Fi distribution in space usually "strengthens existing urban geography."[51]. This research was partially motivated by plans for installing city-wide cable or wireless network. The author found decentralised Wi-Fi coverage to be more resilient to network and physical problems, and at the same time significantly cheaper than a centralised cable infrastructure would be, confirming the conclusions of Bar and Galperin[52] discussed earlier in this chapter.

47) Ibid., 098–13.

48) Torrens, 'Wi-Fi Geographies.'

49) Wardriving is a technique for recording locations of wireless network access points, combining a Wifi-equipped device with a GPS device; commonly used in building up alternative positioning systems to GPS http://wardriving.com

50) Beacon frames are sent in regular time intervals to communicate basic information regarding the communications process with a wireless network access point Jim Geier, '802.11 Beacons Revealed', 31 October 2002, http://www.wi-fiplanet.com/tutorials/article.php/1492071/80211-Beacons-Revealed.htm..

51) Torrens, 'Wi-Fi Geographies.'

52) Bar and Galperin, 'Building the Wireless Internet Infrastructure: From Cordless Ethernet Archipelagos to Wireless Grids.'

4.2.4. Codespaces and the Social Life of Wireless Urban Spaces

Laura Forlano extensively explored the co-production of place by what she calls *urban technologies* or location–based social media applications[53]. Her research in Wi-Fi geographies[54] recognized the material and spatial relevance of wireless networks, from the perspective of the resulting lived experience. Similarly, Keith Hampton's investigations of the social life of wireless spaces[55] focused on interactions within these overlapping environments (the wireless and the built) and the emergence of private spaces within public space due to connectivity. He too acknowledged the relevance of actual physical space for the interaction.

Forlano applied network ethnography in her studies – a hybrid approach that combines ethnography, participant observation, comparative research, survey research, and in-depth qualitative interviews. Hampton's study drew upon the observation methods developed by W.H. Whyte for his study of The Social Life of Small Urban Spaces[56]. It combined direct observation, capturing of video and photographic material and interviews[57].

The main contribution of Forlano's study is the definition of *codespace*, which is a combination of software and physical architecture[58]. In *codespace*, code is intertwined with space in such a way that "new qualities of both come into being, reorganizing people, places and information"[59]. The study in Wi-Fi geographies interpreted Wi-Fi hotspots in public space as places of informal interaction, social support, collaboration, and innovation. Not everyone using the network would be necessarily present within the geographic boundaries of the space[60]. Nevertheless, people are attracted to space by the availability of the network. This conclusion is justified by the fact that over 70% of the respondents were attracted to the location by Wi-Fi, and a speculative interpretation of the role wireless networks have in public space (e.g. "WiFi networks are ways of regulating access to digital information through encryption and pricing").

53) Forlano, 'Making Waves.'

54) Forlano, 'WiFi Geographies.'

55) Hampton et al., 'The Social Life of Wireless Urban Spaces'; K. N. Hampton and N. Gupta, 'Community and Social Interaction in the Wireless City: Wi-Fi Use in Public And Semi-Public Spaces', *New Media & Society* 10, no. 6 (1 December 2008): 831–50, doi:10.1177/1461444808096247.

56) William H Whyte, *The Social Life of Small Urban Spaces*, ed. A M Orum Z P and Neal (Project for Public Spaces Inc, 1980).

57) Hampton et al., 'The Social Life of Wireless Urban Spaces.'

58) Forlano, 'Codespaces: Community Wireless Networks and the Reconfiguration of Cities.'

59) Forlano, 'WiFi Geographies', 351.

60) Forlano, 'Codespaces: Community Wireless Networks and the Reconfiguration of Cities.'

Hampton's study similarly found that the availability of W-Fi was attracting people to the space of a park or a square[61]. He and his team observed particularities in the behaviour of network users in these settings: people preferred niches, less attentive to their surrounding and generally somewhere between the public space and private domain of a living room. Interestingly, Hampton concluded that the availability of Internet communication in public space subverted the usual feature of public space to provide exposure to diversity. Instead, it was cocooning people in their chosen discussion networks and decreasing the diversity of messages they are exposed to. Hampton also found that Wi-Fi availability had a "silencing" effect: people who wanted to engage with others felt the social pressure not to do so because everyone was quietly browsing[62]. Finally, Hampton's study confirmed Whyte's finding from 40 years ago: what attracts people the most is other people.

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Some overarching conclusions are put forward by the research projects presented above. The questions these studies asked are nearly the same – whether or not and in which way does the wireless environment reflect the physical? Hampton's and Forlano's studies relied on hybrid methodologies that involve qualitative assessment. Sevtsuk, Heitor, Torrens and colleagues relied on quantitative analysis.

Despite the intelligently designed efforts to measure and map signal availability, wireless environments stay highly unstable and impossible to accurately represent in a static way. Even dynamic representations suffer from biases when connected devices are taken as equal for activity and people[63]. The findings from these studies showed the impact of Wi-Fi availability on people's spatial preferences, which was seen in the realm of a modest influence rather than a radical driver of mobility. Even when high attraction to connectivity is revealed in measurements, it is not clear which other properties of space are playing an important role in spatial preferences. Interviewing or participant observation might be able to shed more light on this question.

Contrary to the reserved tone of these quantitative studies, Forlano and Hampton were significantly more specific in their findings, or at least their communication was more direct[64]. Forlano observed how instead of mapping onto existing architectural boundaries, W-Fi "reconfigures them in a number of ways by permeating walls, bleeding into public spaces, and

61) Hampton et al., 'The Social Life of Wireless Urban Spaces.'

62) Ibid.

63) Sevtsuk et al., 'Mapping the MIT Campus in Real Time Using WiFi.'

64) Forlano, 'WiFi Geographies'; Hampton et al., 'The Social Life of Wireless Urban Spaces.'

breaking down some traditional notions of privacy and property while reinforcing others"[65]. Hampton identified wireless urban spaces (spaces equipped with wireless network access) as somewhere in between public and private in terms of intimacy and diversity. They are less intimate than a family dinner by less public than the disconnected experience of public space. This illustrates the ways in which Wi-Fi networks could reconfigure the experience of space and reorganise people.

4.3. Affordance and Experience of Connectivity

The notion of *affordance* describes the offerings or furnishing of an environment. In his reflections on visual perception, James J. Gibson introduced this notion to describe a property that is at the same time objective and subjective[66]. The main function of vision was, for Gibson, to help the observer cope with the environment[67]. Thus, it is essential that the observer perceives the environment's or object's affordances. His circular argument might look like a logical fallacy at first: the environment affords an animal, the animals afford the environment. This is because affordance is equally dependent on the environment and on the behaviour of this animal. Gibson proposed measuring affordance relatively and uniquely to the user of the environment as opposed to its objective physical properties. A chair is something that affords sitting.

I have previously discussed the basic physical properties of wireless communication in relation to the environment in which it propagates. I will now introduce the concept of affordance to the perception of wireless communication. Wireless communication is made of signals that create zones of connectivity - this can be a whole building, university, hospital campus or a city. Like the city itself, wireless topography can be more or less diverse and more or less dense – a network of access points can be covering the area with one network. Conversely, each apartment in a residential block can be sending out a unique ESSID. While the signal from different wireless communication infrastructures (WiFi, 3G, Bluetooth) penetrates space irrespectively of its property structure, the access to information is limited by service providers. A wireless network is something that affords, not grants connectivity. The affordance and experience of connectivity are determined by a combination of signal availability and information accessibility. Different aspects of network affordance were explored, for example, by Soon and Samson in their reflection

65) Forlano, 'WiFi Geographies', 350.

66) James J. Gibson, *The Ecological Approach to Visual Perception* (Boston: Houghton Mifflin, 1979).

67) James J. Gibson, 'The Ecological Approach to the Visual Perception of Pictures', *Leonardo* 11, no. 3 (1978): pp. 227–35, http://www.jstor.org/stable/1574154.

on the Speed Show 2.0 network art exhibition in Hong Kong[68]. Building on Gibson's concept, they describe network affordance the way the network performs in terms of speed and processing power, specificities of hardware and the overlaid software. Connectivity in turn shapes the flow of activities, objects and people.

Figure 4.3 XKCD, Feedback. Wrongly assuming reception is linked to holding a pineaple on a chair, the character demonstrates the sometimes misleading development of a feeling for connectivity. From http://xkcd.com/1457/

The feeling of connectivity can be best described as some form of (mis)interpretation of feedback. A character in an XKCD comic[69] humorously demonstrates this, holding a pineapple while standing on a chair to get a better signal. Are we not developing a particular sensibility to the presence of wireless signals? There are people who claim to suffer from electromagnetic hypersensitivity (EHS). For example, a former telecommunications engineer Per Segerbäck reports severe physical reactions to the electromagnetic radiation, such as breathing problems, heart palpitations and loss of consciousness. However, EHS is not officially recognised as a medical condition. In their playful experimentation with cultural effects of electronic objects, Dunne and Raby addressed this sensitivity with their Placebo furniture prototypes that supposedly protect

68) Audrey Samson and Winnie Soon, 'Network Affordances: The Unpredictable Parameters of a Hong Kong SPEED SHOW', *Fibreculture Journal*, no. 24 (2015).

69) XKCD, Feedback, The erratic feedback from a randomly varying wireless signal can make you crazy: "Why are you standing on a chair holding a pineapple?" " I wasn't getting a good signal but now I am" https://xkcd.com/1457/

users from EM radiation[70]. The users of the furniture, claiming themselves a sensitivity to EM radiation, found the Placebo furniture to be helpful.

Feelings of *wirelessness* are site-specific, wrote Mackenzie[71]. "Ultimately, however, anyone using gadgets like laptop computers or mobile phones also has some degree of awareness of chipsets"[72]. Mackenzie's wave-like worlds, "far removed from human agency, subjectivity, volition or consciousness"[73] comprise products, projects and politics of wireless networks, as well as urban, economic and everyday life forms. In his empiricist account of wireless networking, Mackenzie[74] makes an unusual intellectual stretch, bridging worlds that rarely *hand together*[75] - the mess of technical knowledge and empiricist philosophy. He establishes a certain intertextuality between philosophical and technical discourse on networking technology. As *wirelessness* bridges computer industry with the telecommunications industry, Mackenzie dives into the realm of wireless outfits – routers, hotspots, chips and signal processing. The book investigates connectivity as an impersonal experience of these outfits and people.

According to Mackenzie, *wirelessness* is (1) "a sensibility attuned to a proliferating ethos of gadgets, services, opportunities, and enterprises that transmit and receive information via radio waves using Internet-style network protocols"; (2) "a strong tendency to make network connections in many different places and times using such devices, products, and services"; (3) "a more or less heightened awareness of ongoing change and movement associated with networks, infrastructures, location, and information"[76].

It is impossible to understand *wirelessness* apart from networks. Mackenzie speaks of limitations of Wi-Fi technology, the often failing Wi-Fi connections that "act as a kind of patch or infill at the edges and gaps in telecommunications and network infrastructures"[77]. He sees *wirelessness* as often interstitial (acting as infill between devices) rather than infrastructural.

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70) Anthony Dunne and Fiona Raby, *Design Noir: The Secret Life of Electronic Objects*, vol. 1 (Birkhäuser, 2001).

71) *Wirelessness: Radical Empiricism in Network Cultures*.

72) Ibid., 60.

73) Zitouni, 'Into More-than-Human Worlds: Feeling Wireless Environments on the Fringes of Our Perception : Computational Culture.'

74) *Wirelessness: Radical Empiricism in Network Cultures*.

75) *In his seminal essay* "The Thing and Its Relations", William James used the compound *hang together* or *hang-together* to discuss the relationships between things. Mackenzie used James' *Radical Empiricism* framework as a base for his discussion on *Wirelessness*

76) *Wirelessness: Radical Empiricism in Network Cultures*, 29.

77) Ibid., 4.

Urban and nonurban *wirelessness* are inseparable. Wireless cities produce the possibility of ongoing substitution and emphasize the sense of transition, of running through networks[78]. Mackenzie tries to attend to ways in which "*wirelessness* alters how transitions between places occur"[79]. The key to reading connectivity in Mackenzie's framework is the fact that it lies in the expression of devices and infrastructure involved.

4.4. Political Aspects of Connectivity

New technologies evolve within an existing institutional context that moulds them to established social and market practices[80]. Modern service providers often resort to distribution strategies that are "no less informed by monopolization strategies than in the past"[81]. The development of radio technology that was informed by the old Victorian attempt to create an institutional framework for its internationalization[82]. It was inspired by the model on which the undersea cable had been based and monopolised.

Belgian sociologist and communication network analyst Armand Mattelart investigated the relationship between communication infrastructure, political and social implications of networking on the world[83]. Covering multiple aspects, from ideological, political, commercial to technical, Mattelart de-constructed the history of communication, from road building through telegraph cables to contemporary telecommunications. He put special weight on social values of communication and the ideologies that were directing this development – from *Universalization* in 19th century Europe, through Geopolitics of the post WWII period to *Transnationalization* and finally Globalization of the end of 20th century.

Mattelart strips down the notion of communication onto its different aspects: channels, language, meaning. Internationalization of communication, for example, relied on unification of language (as happened in France after the Bourgeois revolution) and standardization of measures (general adoption of the metric system). This led to the conception of large engineering projects

78) Zitouni, 'Into More-than-Human Worlds: Feeling Wireless Environments on the Fringes of Our Perception : Computational Culture.'

79) *Wirelessness: Radical Empiricism in Network Cultures*, 19.

80) Bar and Galperin, 'Building the Wireless Internet Infrastructure: From Cordless Ethernet Archipelagos to Wireless Grids.'

81) R. Mansell, 'New Media Competition and Access: The Scarcity-Abundance Dialectic', *New Media & Society* 1, no. 2 (1 August 1999): 3, doi:10.1177/14614449922225546.

82) Mattelart, *Networking the World, 1794-2000*.

83) Ibid.

for construction of roads and bridges, and undersea communication cables. The influence of press and the information market "conceptualized on a global scale and based on geopolitical interests"[84].

Mattelart's perspective is primarily political. He observed a correlation between "the rapid growth of communication technologies and the armed conflicts that broke out during the second half of the nineteenth century"[85]. From the Crimean War (1853-1856) and the first Black sea telegraph line, through The American Civil War (1861-1865), Anglo-Boer War (1899-1902) and the Russo-Japanese War (1904-1905), which demonstrated the decisive impact of communication technologies like the train and the telegraph, to the rise of pan-Germanic movement, the control of geo-communicational complexes provoked national and international tensions.

The utopian dream of "cyber-revolution", enacted through unconstrained connectivity in the spirit of Barlow's Declaration of the Independence of Cyberspace[86] might well never come true in contemporary Internet infrastructure. The backbone of this infrastructure is a brainchild of governments (ARPANET), and property of large-scale national companies since its commercialisation (AT&T, Level3 Communications, Verizon, Global Crossing, TATA Indicom, etc). Next to this, the Internet backbone is subject to strategic political negotiations, trades and espionage - prioritising installation of certain lines and tapping into strategic undersea fibre-optic cables. Increased connectivity in the past decades also gave rise to increased surveillance, as we learned from the 2013 whistle-blowing controversy[87].

The association of political expectations with the way we spread information has not evaporated. Some thinkers believe that independent or alternative modes of accessibility will evoke different modes of social organisation. For example, in the wake of 2014-15 Greek elections and the subsequent political changes, an alternative mesh network created in 2002 by a group of citizens was instrumental in information exchange. The association known as the *Athens Wireless Metropolitan Network* (AWMN)[88] allowed citizens to exchange data quickly, both online and offline.

84) Ibid., 24.

85) Ibid., 13.

86) John Perry Barlow, 'A Declaration of the Independence of Cyberspace', 8 February 1996, https://projects.eff.org/~barlow/Declaration-Final.html.

87) In June 2013, an employee of the National Security Agency (NSA) Edward Snowden revealed the ongoing massive scale surveillance operations that were performed on civilians communication by the agency in the name of the PATRIOT ACT since 2001. These global surveillance disclosures triggered a fierce discussion on privacy, citizens rights, and legality of such actions on one side, and national security and protection from terrorism on the other.

88) Athens Wireless Metropolitan Network (AWMN) is http://www.awmn.net/

Similarly, *Occupy.here*[89] was a mesh of extendible points that provided local, offline information and/or access to the Internet. Alternative Internet services that cost little and protect against government surveillance are increasingly set up by digital activists with avid technical knowledge and creativity. Spanish network *Guifi*[90], *Kanzas City Freedom Network*[91] or *Commotion*[92] are some of the existing alternative services.

Benefits of meshed networks are cultural as well as practical. Mesh Wi-Fi network projects are operating on Wi-Fi technology similar to the amateur radio movement that could act on independent infrastructure in emergency situations, in case of conflicts or natural hazards. Licensed radio amateurs (*hams*) were instrumental in testing new communication techniques and spectra, on their way to a wider adoption[93]. Similarly, grass-root Wi-Fi installations are sometimes referred to as the "Pirate Radio Internet".

In her influential text on ethnographic research of infrastructures, Susan Leigh Star discussed all the underlying structures and patterns that support existing systems to function, from the obscurity of the background. "In information infrastructure, every conceivable form of variation in practice, culture and norm is inscribed at the deepest level of design"[94]. Star explored whether and how values are inscribed in technical systems. She proposed thinking about computers as symbolic sewers and not as information highways. Infrastructure is invisible, backgrounded by another kind of work. "The relationship between e-mail and the larger sphere of lived activity cannot be presumed, but must be investigated"[95]. However, "one person's infrastructure is another's topic or difficulty"[96]. Water pipelines are infrastructural to apartment dwellers but problematic to planners and plumbers; stairs are infrastructural to building users but problematic

89) Occupy.here is a project developed in parallel with the Occupy movement, offering a network of virtual spaces to share collective network infrastructure using customized router firmware. Occupy.here has been active since October 2011, http://occupyhere.org/ (current release November 2013)

90) Guifi.net is a telecommunications network built through a peer to peer agreement of its users who extend the network and grant connectivity to all. https://guifi.net/en Guifi is released under Wireless Commons Licence (WCL) and is in operation since 2006

91) Kanzas City Freedom Network or "Kansas City's Wireless Internet CO-OP" http://www.kcfreedom.net/ is an nonprofit wireless internet service specifically designed for low-income households. Kanzas city is the first place in the world to get the Google's experimental, ultra-high-speed broadband internet service — Google Fiber and was thus an interesting for affordable-internet advocates. KCFN is operating since November 2012

92) Commotion is a free, open-source communication tool that uses wireless devices to create decentralized *mesh networks* https://commotionwireless.net

93) E. Laport, E. Tilton, and R. Rowe, 'Amateur Radio', *IEEE Communications Magazine* 19, no. 4 (July 1981): 16–24, doi:10.1109/MCOM.1981.1090543.

94) Star, 'The Ethnography of Infrastructure', 389.

95) Ibid., 388.

96) Star, 'The Ethnography of Infrastructure.'

to people in wheelchairs; wireless signals are infrastructural to people and networked devices but can be problematic for wildlife[97]. Opposing this apparent invisibility, Star suggested an investigation into the relationships between hidden infrastructure of work organisations, communication systems, routines.

4.5. Discussion

The questions addressed by this thesis pointed towards the need to construct a complex view of wireless connectivity. Such view needs to be able to traverse the different aspects of the experience of wireless communication. In this chapter I discussed four concrete perspectives on wireless networking that are central to its understanding: the technical, the spatial, the perceptual and the political.

Through a brief summary of technical aspects that determine waves propagation, I pointed to its main attributes in relation to space: the wavelength and the way it behaves with obstacles (buildings for example), the different environmental conditions that facilitate or hinder signal propagation. Furthermore, I discussed the distribution of infrastructure needed to transmit wireless network traffic: cellular base station grids, wireless access points, mesh networks, combinations of those. I also considered future directions the development of these infrastructures might take. This will be important when designing environments for better signal propagation.

Two seemingly unrelated types of studies explored the way wireless network signal propagates in space: spatial analysis of university networks and ethnographic studies in public space. The former focused on measuring signal availability and strength in space, while the latter explored people's behaviour in space relative to network availability. All of these studies, however, found that there is a correlation between network propagation and the use and experience of space. Nevertheless, their findings differ on the amount of influence they attribute to Wi-Fi's presence.

Perception of wireless connectivity is essential to the design of interaction with network artefacts (mobile devices, routers, antennas, signals). I examined it through Gibson's notion of *affordance*, which stresses the perceived uniqueness of connectivity as opposed to an objective technical account of network propagation and bandwidth. Mackenzie's concept of *wirelessness* points in this direction: he explored the experience of all that is involved in wireless networking, chipsets and feelings of connectivity included[98].

97) Alfonso Balmori, 'Electrosmog and Species Conservation', *Science of The Total Environment* 496 (October 2014): 314–16, doi:10.1016/j.scitotenv.2014.07.061.

98) Mackenzie, *Wirelessness: Radical Empiricism in Network Cultures*.

Finally, political aspects of wireless networking are an introduction into imagining alternative organisation of infrastructures. Peer-to-peer exchange in mesh networks installed and managed by users themselves is a contemporary example that tells about possibilities of equipment that may be explored further.

The structure of this chapter not only reflected the complexity of wireless connectivity but also of all technical systems which operate in the background and which are designed with optimisation as the main goal. By understanding how wireless networking works, we can understand more about the consequences of such optimisation attuned thinking, and the ensuing decisions that often concern our immediate environment. Thus, the discussion about the technical and the political aspects of wireless communication infrastructure helps build mental tools for thinking about interaction with wireless network infrastructure, within the scope of its utilitarian purpose and beyond.

5. Ruptures in Seamless Infrastructure

In Chapter 3. *Connectivity in Action / Form*, I introduced the notion of *architecturality* of wireless communication signals, particularly their capacity to affect the experience of space. In Chapter 4. *Infrastructure at Hand / in Space*, I described the different technical, perceptual and political aspects of wireless communication, all of which contribute to an objective perspective on this infrastructure. I discussed the technical development of wireless networking, the different network services and their models of infrastructure distribution. I also examined how existing literature addresses the relationship between the availability of wireless networks and people's use of space and traffic.

In this chapter, I explore the relationship between built structures and wireless infrastructures in the context of infrastructure consistency. The consistency of wireless communication infrastructure is reflected in what communication engineers call seamless connectivity. Parallel to the optimisation of communication technology and protocols, user awareness and control of these systems has been increasingly pushed in the background. On one hand, this approach to the design of infrastructures is probably the reason for the ease and high rate of adoption of

wireless technologies. On the other hand, it entails a loss of agency on the side of both users[1] and designers. Seamless connectivity is harder to grasp and critically engage with; it supports the myth of immateriality that hides its social and other effects[2]. The overly pragmatic attitude towards technology disregards the different ways it can be structured and developed. This results in decisions that favour the profit of the most powerful actors (e.g. network providers) over the majority of users[3].

Against the seamless design principle, I posit the idea of *seamfulness.* Matthew Chalmers introduced *seamful* design approach to the ubiquitous computing research of connectivity in the early 2000s[4]. *Seamfulness* in design is also a form of resistance to the invisible forms of control inherent in our devices. Through a revisit of de Certeau's notion of *tactics*, a way of calmly and quietly subverting the use of time, facilities and infrastructures[5], I will discuss the ways for re-engaging with wireless communication.

5.1. Always Seamlessly Connected

The development and deployment of wireless infrastructures was always attuned at seamless connectivity across technology and territory. Why do we want seamless so much? For obvious reasons of the ease of access while on the move; to enable users to focus on information rather than on the availability of connection. It is also important in terms of reliability it affords to real-time applications such as Voice over IP (VoIP) or self-driving cars. Reliability here is critical because "the network interface cards available on the market have been mainly conceived to provide a best effort service, without any guarantees on packet delay"[6]. The unreliable behaviour of wireless network interfaces and the interferences in the radio channel are inherent to the design of wireless communication infrastructures.

Research in seamless connectivity was fuelled by the proliferation of mobile devices such as laptops that could be connected wirelessly to a network (e.g. the Internet). In a paper published

1) Arnall, 'No to NoUI.'

2) Raven, 'An Introduction to Infrastructure Fiction — Improving Reality 2013 | Infrastructure Futures | Futurismic.'

3) Barbara Van Schewick, *Internet Architecture and Innovation* (Cambridge, MA: The MIT Press, 2010).

4) Chalmers, 'Seamful Design and Ubicomp Infrastructure'; Matthew Chalmers et al., 'Social Navigation and Seamful Design', *Cognitive Studies* 11, no. 3 (September 2004): 171–81; Rudström, Höök, and Svensson, 'Social Positioning: Designing the Seams between Social, Physical and Digital Space.'

5) de Certeau, *The Practice of Everyday Life*.

6) Gennaro Boggia et al., 'A Real-Time Wireless Communication System Based on 802.11 MAC', in *Factory Automation*, ed. Javier Silvestre-Blanes (InTech, 2010), http://www.intechopen.com/books/factory-automation/a-real-time-wireless-communication-system-based-on-802-11-mac.

in 1996, two Carnegie Mellon researchers speculated about future mobile working conditions and the need to access multiple networks seamlessly[7]. Based at the University that is known for its pioneering work in (wired) networking[8], they explored the capacities of the two infrastructures - wireless local area network (WLAN) and cellular digital packet data (CDPD)[9] as well as different protocols for seamless packet switching. They defined seamless connectivity as an "automatic connection to the most appropriate network and *handoff* to another network when appropriate"[10]. They worked towards a quick enough *handoff* between Wi-Fi and cellular as well as within one infrastructure, so that the gap in data (or voice) stream stays imperceptible to the user.

The development of this *handoff* discourse continued throughout the first decade of the new millennium, yielding a number of solutions to the gap problem in micro mobility (switching from one access point to another) and macro mobility (switching from one wireless network to another). Ericsson Research proposed the Always Best Connected (ABC) concept, which they depicted through a working day of an imaginary character, Hubert. Hubert is always *online* – wired DSL[11] connection at home, 3G in the subway, Wi-Fi in the office[12]. Switching between different access technologies is done seamlessly and transparently through the Ericsson's ABC solution.

The word "transparency" is used across communication engineering literature to describe the imperceptible *handoff* or the lack of opacity in connectivity. Similarly, the use of the word transparency in software engineering tends to imply backgrounding of information[13]. In her account on the power of software, Inke Arns observed this interpretation of transparency as opposed to its use in everyday language. Transparency implies the possibility to see through.

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7) A. Hills and D.B. Johnson, 'Seamless Access to Multiple Wireless Data Networks. A Wireless Data Network Infrastructure at Carnegie Mellon University', *IEEE Personal Communications* 3, no. 1 (February 1996): 56–63, doi:10.1109/98.486976.

8) Carnegie Mellon worked with IBM in the 1980s to develop Andrew – a wired computer network that linked thousands of personal computers and work stations across the campus. In 1990s, Carnegie Mellon continued the networking research with a campus-wide and city-wide wireless network project, Wireless Andrew D.B. Johnson and D.A. Maltz, 'Truly Seamless Wireless and Mobile Host Networking. Protocols for Adaptive Wireless and Mobile Networking', *IEEE Personal Communications* 3, no. 1 (February 1996): 34–42, doi:10.1109/98.486974; Hills and Johnson, 'Seamless Access to Multiple Wireless Data Networks. A Wireless Data Network Infrastructure at Carnegie Mellon University.'

9) Hills and Johnson, 'Seamless Access to Multiple Wireless Data Networks. A Wireless Data Network Infrastructure at Carnegie Mellon University.'

10) Hills and Johnson, 'Seamless Access to Multiple Wireless Data Networks. A Wireless Data Network Infrastructure at Carnegie Mellon University', 62.

11) One of the currently most commonly used wide-area technology for Internet access that transmits digital data over telephone lines

12) E. Gustafsson and A. Jonsson, 'Always Best Connected', *IEEE Wireless Communications* 10, no. 1 (February 2003): 49–55, doi:10.1109/MWC.2003.1182111.

13) Arns, 'Read_me, Run_me, Execute_me: Software and Its Discontents: Or It's the Performativity of Code, Stupid!'

Arns saw the design of user interfaces, hiding the source code and the operations that are running in the background, attuned at information hiding. The user of the interface does not notice the software working in the background. Transparency in seamless connectivity operates in the same manner – the transfer from one access point to the other is invisible to the user. What network engineering envisages instead is a user that "sees through" the connection into the actual information. Thus, connectivity is transparent and information is foregrounded.

5.2. Seamful Design and Interaction with the Messiness of Waves

The concept of *seamful* design came out of early ubiquitous computing discourse, drawing upon Mark Weiser's ideas about the integration of digital tools. Weiser insisted that the design of interfaces should preserve the agency of users while the technology disappears in the background of attention. This can be done by intentionally revealing the seams in interaction and interface, such as in a *seamful* integration of a paint tool with a text editor. For Weiser, Natalie Jeremijenko's "Dangling String" ("Live Wire") was a prime example of how hardware can be used to expose computational activity[14] while staying at the periphery of attention. We should not here that periphery of attention is not an equivalent to invisibility or transparency as previously described .

The basic principles of *seamful* design were first articulated by Matthew Chalmers who was inspired by Weiser's vision of *seamful* integration. For Chalmers, *seamful* design is also an opportunity to turn a failure of the infrastructure into a feature of the system. He advocated making individual tools features "literally visible, effectively invisible"[15] . Working with a system that enabled a shared visit to a museum mediated by the network[16] , Chalmers and his colleagues were inspired by the impossibility to accurately track users position and focused instead on how to "help users accommodate imprecision"[17] . This lead to a series of projects that aimed to work creatively with these seams, such as the *Seamful map* and the *Seamful* game, arguing for design that

14) Mark Weiser and John Seely Brown, 'Designing Calm Technology', 21 December 1995, http://www.ubiq.com/weiser/calmtech/calmtech.htm.

15) Chalmers, 'Seamful Design and Ubicomp Infrastructure.'

16) A prototype interactive system supporting shared experience by physical and digital visitors to an exhibition were part of *the City* research project and used the EQUIP platform developed in its scope. The experiments involved three visitors, connected by the network, experiencing the exhibition "together". One person would be really in the museum, wearing a portable computer with a camera, another would be online, and a third person would be experiencing the exhibition in Virtual Reality. They could talk over a shared audio channel, share location and interact around 'hybrid' museum exhibits Ian MacColl et al., 'Shared Visiting in EQUATOR City' (ACM Press, 2002), 88–94, doi:10.1145/571878.571892..

17) Matthew Chalmers, Ian MacColl, and Marek Bell, 'Seamful Design: Showing the Seams in Wearable Computing', vol. 2003 (IEE, 2003), 11–16, doi:10.1049/ic:20030140.

allowed user appropriation[18]. The *Seamful game* is an interesting example because it exploited the seams in wireless connectivity as part of the play, users having to go into "offline spots" to pick up virtual bricks. It also allowed users to manipulate the seams, by extending the area of network coverage with their device as a bridge between fixed access points. Finally, it played with tools specific to networking, such as traffic flooding[19], when users would make wrong moves (picking up "fake" virtual bricks). In sum, these *seamful* experiments explored and promoted user's ability to adopt and adapt to ubiquitous computing tools for their own goals and purposes.

In the early 2000s Chalmers' Swedish colleagues at the Royal Institute of Technology (KTH) proposed to work with the seams that appear within and between space, people and infrastructures - such as the establishing of connections, loss of signal, overlays and mismatches of information. They classified these seams as *intra*- (existing within the digital medium, network coverage and positioning), and *inter*-media seams (between digital information and the physical or social contexts)[20]. Aimed at understanding the developing relationship between the physical, digital and social, this "careful and aesthetically pleasing design of seams" worked against what the authors identified as the goal of telecommunications industry: to be seamlessly connected anywhere at any time. Questioning the desire to disconnect or be aware of connectivity, researchers designed an application, *MobiTip*, for SonyEricsson P900[21]. *MobiTip* rendered connectivity observable to the user through notifications and gamification of social and location proximity[22]. They tested the system in the publicly accessible space of a shopping mall where users could leave virtual *tips* to each other using a network of Bluetooth servers. In this way, the application made users active co-constructors of the hybrid space – they created the content and meaning of virtual tips and organised them in space. The important conclusion from these experiments is that computing systems can be made observable while staying peripheral to the user's attention[23].

Rudström, Höök and Svensson's work did not change the fact that we do want to be connected most of the time. It did, however, point to the area of design that would benefit from more attention and understanding: when do we want to be reminded of (dis)connectivity?

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18) Chalmers, 'Seamful Design and Ubicomp Infrastructure.'

19) Network flooding is a Denial of Service (DoS) attack that can be initiated by sending a large number of packets to random (or all) ports on a remote host. As a result, the host will be forced into responding, eventually leading it to be unreachable by other clients.

20) Rudström, Höök, and Svensson, 'Social Positioning: Designing the Seams between Social, Physical and Digital Space.'

21) SonyEricsson P900 was a model of a cell phone combined with a personal data assistant (PDA), a precursor of today's smartphone.

22) Åsa Rudström, Kristina Höök, and Martin Svensson, 'Where Mobile Services Live: Making Users Active Co-Constructors of Hybrid Space', 2005.

23) Ibid.

5.2.1. Embodied Seamfulness Against Disappearing Technology

Another line of critique of seamless integration of tools, computers, interfaces and connections came from Paul Dourish in his first book on embodied interaction[24] and his subsequent collaborative writing with Genevieve Bell[25]. Dourish and Bell questioned the dominance Mark Weiser's vision of ubiquitous computing had within HCI circles. They argued that this vision, as unfounded in reality as *ubicomp*[26] visions have been in general, is also long out-passed by actual real world implementations (such as in Singapore or South Korea, two examples analysed in their essay *Yesterday's Tomorrow*).

Dourish articulated the basic principles for design of embodied interaction, which is about integrating our experience of computing into our experience of the physical world. For him, this is where the seams are coming from. Embodied interaction is based on the idea of embodiment, as discussed in phenomenological philosophy of Husserl, Heidegger, Schutze and Merleau-Ponty. Dourish found Merleau-Ponty's treatment of perception as an activity that brings the environment and the body together, had an important value for HCI. Embodiment also worked towards a deeper connection between social and tangible computing, which are two foundational directions in explorations of our experience of computing.

Coming back to the *ubicomp* vision, Dourish and Bell introduced *messiness* as a way to look at infrastructures, particularly at systems we have been living with for decades or centuries (such as railway, airports – highly controlled, never fully predictable). They proposed dealing with this messiness instead of trying to filter it out of our experience. This is not necessarily far from Weiser's vision in itself (think *seamful* integration of tools) but it is distant from the way this vision has been often applied in interaction design. Dourish and Bell stressed: "Infrastructures, then, be they networks of car mechanics, medical categories, or power sources, are never seamless in the ways in which they are put to work"[27]. Looking at infrastructure as universally available is clearly problematic if we consider fibre-optic cable coverage or even just the availability of drinkable water.

Central to Dourish's argument about embodied interaction design is the intentional design of seams. He located seams at the edges of connections and territories. Embodied interaction design

24) Dourish, *Where the Action Is: The Foundations of Embodied Interaction*.

25) Genevieve Bell and Paul Dourish, 'Yesterday's Tomorrows: Notes on Ubiquitous Computing's Dominant Vision', *Personal and Ubiquitous Computing* 11, no. 2 (22 November 2006): 133–43, doi:10.1007/s00779-006-0071-x; Paul Dourish and Genevieve Bell, *Divining a Digital Future. Mess and Mythology in Ubiquitous Computing* (Cambridge, Mass.: MIT Press, 2011).

26) *ubicomp* is an abbreviation for ubiquitous computing, often used in the HCI discourse

27) Bell and Dourish, 'Yesterday's Tomorrows.'

should, thus, encourage user engagement, as it is "hard to be actively engaged with something that isn't there"[28]. Just as an invisible pen would be a hard thing to use, interfaces are not supposed to disappear but have to be designed in such a way that they can also be mastered[29]. According to Dourish, the notion of the invisible interface confuses coupling[30] with visibility.

5.2.2. The Seamless and Smart Everything

The vision of the ubiquitous or invisible computer[31] has come to life with a twist. Computers are everywhere and they are really small, but they are certainly not out of our way – they are more than ever in the centre of our attention[32]. Two clearly disparate visions characterized early discussions on ubiquitous computing and how it will be implemented. On one side, we have Norman's and Weiser's anticipation of specialised single-function networked appliances, computers embedded everywhere in the environment. Computers would be so pervasive that there would be no need to actually own one, or be personally associated with any of them. On the other side, we have the endeavours to popularise personal computing and portable devices capable of enacting the entire office on the move. Interestingly enough, we live in a world where both are developing in parallel, relying on each other for much of their purpose. On one hand, we have sensors and *smart* functionalities embedded into our products, homes and buildings. On the other, we have the *messy* multifunctional phone (labelled *smart*) that centralises computing in the palm of our hand[33].

We are currently experiencing a second wave of interest in the Internet of Things (IoT)[34] that is again promising to deliver *smart* functionalities to a number of networked, single-purpose devices such as the fridge, the vacuum cleaner, the garbage bin, and many more. As opposed

28) Paul Dourish, 'Embodied Interaction: Exploring the Foundations of a New Approach to HCI', *Unpublished*, 1999.

29) Dourish, *Where the Action Is: The Foundations of Embodied Interaction*.

30) Ibid. Dourish defines coupling as an integration between our body and tools in the act of using the tool for a task during which the tool "disappears" in the background of our attention. He relies on Heidegger's notion of ready-to-hand and "withdrawal" of the tool in our hands. He also stresses that it is users, and not designers that manage this coupling

31) Donald A. Norman, *The Invisible Computer* (MIT Press, 1999); Mark Weiser, 'The Computer for the 21st Century', *Scientific American*, 1991, 94–104.

32) Louise Barkhuus and Valerie E. Polichar, 'Empowerment through Seamfulness: Smart Phones in Everyday Life', *Personal and Ubiquitous Computing* 15, no. 6 (August 2011): 629–39, doi:10.1007/s00779-010-0342-4.

33) Ibid.

34) Internet of Things (IoT) is a name used for a vision of networked objects that are connected and structured in a similar way to the information on the Internet. IoT can also be seen as an attempt to engage the physical world with digital networks. Coined in 1999 by British entrepreneur Kevin Ashton the name refered at first to networking of physical objects using RFID tags and readers in shops and supermarkets, while it now holds for a more general connectivity across objects and devices using Bluetooth or Wi-Fi connections

to the first IoT wave that gained momentum in the middle of 2000s and relied on RFID tags and readers (technology specific to these objects) to connect the *things*, the second wave makes use of smartphones and Wi-Fi connectivity, which are already integral parts of our daily life. Home and building automation is thus achieved through the use of personal, customised devices to control the network of sensors and computers embedded in our environment. I already mentioned the increased network demand these objects create. The discussion on the actual *smartness* of these implementations is beyond the scope of this text. I will contend to observe that both the *seamless* and the *smart* visions became driving trends in technological developments and that they both fail to account for the complexity of the interaction with our environment. Smartphones and sensors are ubicomp devices of the ever approaching future, where everything is seamless and perfectly connected. They are at the same time everyday devices in the world where "networks go down, hard disks fail, sensors fail to sense, processors overheat and batteries die"[35], protocols wear out, bookmarks disappear, and technology sometimes simply does not work.

5.2.3. Redefining the Seams

The preceding discussion on seamlessness has pointed out a more complex problem. There seems to be a conceptual divide on what the seams actually are. Is it the spotty network coverage, addressed by Chalmers in his "*Seamful* map"? Or is it the attention-demanding devices with large interfaces, criticised by contextual technologies enthusiasts, who endorse digital eyewear like Google Glass? Weiser and Chalmers, along with some other HCI researchers, saw the seams in the integration of different tools and devices. In this respect, a smartphone is a perfectly seamless device[36]. On the other hand, this same smartphone is a device that exposes seams in the infrastructure of wireless communication networks or the Internet of Things. These seams have not been intentionally designed (as argued repeatedly by Chalmers[37], Höök and Rudström[38]) but have been largely explored in HCI experiments[39].

Some of the results of these experiments are questionably useful – do we really need to rely on unavailability of networks to justify disconnecting, as suggested by the *Seamful Map* experiment[40]?

35) Arnall, 'No to NoUI.'

36) Barkhuus and Polichar, 'Empowerment through Seamfulness.'

37) 'Seamful Design and Ubicomp Infrastructure.'

38) Rudström, Höök, and Svensson, 'Social Positioning: Designing the Seams between Social, Physical and Digital Space.'

39) Ibid.; Rudström, Höök, and Svensson, 'Where Mobile Services Live: Making Users Active Co-Constructors of Hybrid Space'; Chalmers, 'Seamful Design and Ubicomp Infrastructure'; Chalmers et al., 'Social Navigation and Seamful Design'; Chalmers, MacColl, and Bell, 'Seamful Design.'

40) Chalmers, 'Seamful Design and Ubicomp Infrastructure.'

Is it not more natural and practical to purposefully disconnect wherever and whenever we like to, instead of having to walk to a particular corner of the University Avenue in Glasgow to hide from connectivity? Regardless such hyperbole, *seamful* design outlines a useful path for thinking about interaction with ubiquitous computers, be it a network of appliances or our complicated smartphone. *Seamful* design also points to a way of thinking about the design of technology in general. *Seamfulness* in this context should be understood as a general resistance to information hiding, obscuring interactions and concealing infrastructure work.

5.3. Talking About Infrastructure

Now that I have established a more critical perspective on design of interactions and integration of technology, I will turn to the contemporary discussion on infrastructures. In the past few years, infrastructures became a fashionable topic in media studies, critical design and ethnographic circles. Suzan Leigh Star's observation about the importance of the "study of boring things" was picked up by designers, writers, and critical thinkers, who recognized the same essential value of the underlying structure to the functioning of our world. Intentionally or not, Paul Graham Raven[41] drew on Star's *Standards and their stories*[42] when he proposed *Infrastructure Fiction*[43]. Not only does the title match, but the approach is very much in line – Star proposed the study of boring things; Raven talked about infrastructure as something that is not pleasant to be reminded of.

Visibility, or the lack thereof, is a common theme in infrastructural research. Adam Rothstein wrote about the privilege to experience our infrastructure in first person[44]. Infrastructure, for him, implied anything from container shipment lines, refrigerated food sites map, worker's body in the eyes of the employer, and finally the fiber-optic cables that transmit 99% of our Internet and other telecommunication traffic (the remaining 1% being the wireless portion). All these infrastructures were designed to be visible only to the ones who are supposed to install and maintain them. Rothstein argued for more visibility in order to "re-humanize" this enormous network of objects, cables, people and vehicles[45].

41) Paul Graham Ravan is a freelance writer and a researcher associated with the University of Sheffield's Pennine Water Group. He is often quoted as the originator of *Infrastructure fiction*

42) Martha Lampland and Susan Leigh Star, eds., *Standards and Their Stories: How Quantifying, Classifying, and Formalizing Practices Shape Everyday Life* (Ithaca: Cornell University Press, 2009).

43) Raven, 'An Introduction to Infrastructure Fiction — Improving Reality 2013 | Infrastructure Futures | Futurismic.'

44) Adam Rothstein, 'How to See Infrastructure: A Guide for Seven Billion Primates', *Rhizome*, 2 July 2015, http://rhizome.org/editorial/2015/jul/2/how-see-infrastructure-guide-seven-billion-primate/.

45) Ibid.

The Critical Infrastructures project by Jamie Allen and David Gauthier gathered artists around the methodological and conceptual misappropriations of cultural and other infrastructures. Andrea Fraser's 1989 artwork Museum Highlights: A Gallery Tour at the Museum of Philadelphia, which is a performance critique of material infrastructure, museum sponsorship, cultural, economic and political agendas. Allen asked[46] what could be a parallel to such institutional critique[47] in the contemporary so-called post-digital[48] artistic practice? He did not offer an answer but did hint at two telling cases, the speculative Super Flush[49] and the real case of the Television Pickup[50]. These are examples of a correlation between media, behaviour and infrastructure that is rendered visible through massive synchronised action of toilet flushing or boiling water in a kettle.

The perspective of Jussi Parikka on network dysfunctionality is interesting in this scope too. Parikka, who wrote extensively on materialities and anomalies of media, saw this dysfunctionality in software-driven social actions such as infecting and overloading machines with viruses, malware, spyware and spam. At the same time, the computer virus "has played a decisive role in the generation of novel ideas in the new science of networks."[51], such as viral marketing or experimental *vaccine software*[52]. Parikka reminded of one of the most important and embedded properties of networks observed in 1986 by Fred Cohen: information sharing and computer viruses are inseparable. In order to secure communication, one would have to block it entirely.

This way of looking at connectivity – as an unavoidable broadcast – is more in line with the contemporary condition than the old paradigm of flows susceptible to interception. Networks

46) Jamie Allen, 'Critical Infrastructure', ed. Christian Ulrik Andersen, Geoff Cox, and Georgios Papadopoulos, *A Peer-Reviewed Journal About / Post - Digital Research* 3, no. 1 (2014), http://www.aprja.net/?p=1677.

47) Institutional Critique is a practice that emerged from the developments of Minimalist artistic movement in 1980s. It is concerned with the phenomenology of the viewer, as well as formalist art criticism and art history through a systematic inquiry into the workings of art institutions (galleries museums, etc.)

48) Post-digital is an umbrella term for artistic practices that use the Internet as the distribution medium and are inspired by the online culture and social media, more concerned with the extraction of the digital into the physical (exhibiting digital printed or otherwise materialised artefacts in art galleries

49) During a press conference in advance of the 1987 National Football League Super Bowl game, Harvey Schultz supposedly hinted to the public at large that it might be a good idea for football fans to try not to use the toilet all at the same time during the game (such as during a short break) so as to avoid a potentially hydraulically catastrophic "Super Flush."

50) Television Pickup is a significant power load caused by television viewers turning on electronic kettles in a synchronised manner, such as after a massively watched TV show. The largest pickup recorded for the TV drama East Enders happened on April 5th, 2001, when an estimated 22 million viewers caused a post-episode power load of 2290 megawatts

51) Tony D. Sampson and Jussi Parikka, 'Learning from Network Dysfunctionality: Accidents, Enterprise, and Small Worlds of Infection', in *A Companion to New Media Dynamics*, ed. John Hartley, Jean Burgess, and Axel Bruns (Oxford, UK: Wiley-Blackwell, 2013), 455.

52) *Vaccine* is software designed to find and repair problems in a larger number of networked computers, propagating through networks in the same way as viruses do.

give us what we want most of the time; sometimes, however, they infect or fail. Either way, they are a continuous signal transmission across a network of devices (infrastructure) and throughout the environment. One can interfere with the signal transmission by either broadcasting an interfering signal or by disrupting the older, flow-based infrastructure - the power lines.

Mainstream interaction design has largely adopted the *disappearing interface* metaphor for its goal, epitomised in the study of contemporary trends presented in *The Age of Context*[53]. The need for interfaces to disappear as the hammer does in our hand when we are nailing something into a wall is questionable. Some designers have pointed towards the loss of agency that is inherent in such disappearance. Timo Arnall, who's work consistently explored invisible infrastructures (*Immaterial: Light Painting Wi-Fi*, 2010, *Robot readable world* 2012, *The Internet Machine*, 2014) articulates such concerns in his *No to NoUI* manifesto[54]. Arnall opposed the myth of immateriality and the childish mythologies like "the cloud" in favour of design that integrates the actual qualities of the interface and increases our ability to become proficient at using technical systems. He illustrated this discussion with the example of the Nest thermostat interface, which gives out all necessary information to the user while seamlessly "learning" the user's habits. Arnall argues for focusing on legibility and readability instead of seamless invisibility and removal of the interface. Arnall's work is part of a larger context of artistic and design practice working towards rendering connectivity and its seams visible to a greater audience.

5.4. Re-experiencing the Waves: a Tactical Activity

In the vast landscape of network re-appropriation, it is important to recognize the underlying *tactical* quality of these interventions. I will conduct here a thought experiment, using de Certeau's notions of *strategy* and *tactics* as discussed in his influential work *The Practice of Everyday Life*[55]. *Tactics* and *strategy* will help interpret our two-faced relationship with wireless communication infrastructures.

The Practice of Everyday Life is a study of culture on a large scale, which grew out of de Certeau's studies of popular culture and marginal groups, particularly following his theorising of the '68 protests and his seminal article *La prise de parole* published the same year. Nevertheless, *The Practice of Everyday Life* is not a work of popular culture, but a sociological study of culture in general by

53) Robert Scoble and Shel Israel, *Age of Context: Mobile, Sensors, Data and the Future of Privacy*, 1. ed (North Charleston: Brewster, 2013).

54) Arnall, 'No to NoUI.'

55) *The Practice of Everyday Life* attained a cult status in non-academic circles and could even be considered a best seller (according to Ian Buchanan, more than 25000 copies were sold in the United States until 2000 Ian Buchanan, *Michel de Certeau: Cultural Theorist*, Theory, Culture & Society (London ; Thousand Oaks, Calif: SAGE, 2000).)

a scholar with an eclectic background (philosophy and theology, a Freudian with affinity toward anthropological methods). It is a book about world-making and even more about being in the world.

The world is for and about the ordinary man, "the absent figure who provides both their beginning and their necessity"[56]. It exists for and because of him much like a theatre performance actually happens for the audience, and not for its prominent actors. Continuing on that line, de Certeau argued that the process of consumption is at the same time a process of production. It is a cultural activity through which the consumers make sense of the products they consume. Scattered and with no dedicated space to exhibit itself, this secondary production by the "non-producers of culture" is hidden in the process of use.

5.4.1. (Mis)understanding *Tactics* and *Strategy*

The notions of *tactic* and *strategy* are possibly the most important contribution of this work. In his book *Michel de Certeau: Cultural Theorist*, Ian Buchanan[57] argued that the concepts of *tactic* and *strategy* have been often misunderstood. This is largely so because de Certeau himself left enough room for a variety of readings. *Tactics* and *strategy* were most commonly used to describe two sides of power: the powerful, who use strategies, and the powerless, who resort to tactics. A rebellious invitation to do nothing while pretending to work, tactics are a way to fight the system from within. Tactics, when they are realised successfully are victories of the *weak* over the *strong*. However, such interpretation lacks serious consideration of some important qualities of these two ways of being in the world.

The misconception is firstly in considering *tactics* and *strategy* a part of a totalising power theory, where tactics are the disempowered or powerless position. *The Practice of Everyday Life* thus becomes a theory of "little victories" of daily life, somewhat revolutionary but insufficient to achieve a deep cultural change. Rejecting this reading lead by Fiske's interpretation[58] as an overly simplistic deployment of de Certeau's ideas, Buchanan saw *strategies* and *tactics* not so much as modalities of power but as indexes of belief [59].

The notion of belief brings us to an aspect de Certeau's work should always be evaluated against: his deep religious convictions. Tactics are employed because of the lack of belief. "Marketing agencies avidly make use of the remains of beliefs that were formerly violently

56) de Certeau, *The Practice of Everyday Life*, v.

57) *Michel de Certeau*.

58) John Fiske, 'Popular Forces and the Culture of Everyday Life', *Southern Review*, no. 21 (1988): 288–306.

59) Buchanan, *Michel de Certeau*, 87.

opposed as superstitions. Advertising is becoming evangelical"[60]. However, de Certeau reminds that looking out for one's own interests is no substitute for belief.

The other major misunderstanding is the reading of *tactics* and *strategy* as a binary oppositional pair, the logical and thus complementing oppositions of each other. *Strategies* are calculations and manipulations of power relationships. These manipulations delimit a place and manage external relations with targets and treats[61]. *Tactics* are also calculations but un-localisable. They lack exteriority and thus their autonomy is impossible. "The space of the tactic is the space of the other"[62]. Tactics and strategies are not complementary, one is not defined through the mere opposition to the other, but rather through external concepts of space and place and their common determination as calculations.

5.4.2. Walking, Talking and Packet Switching

Space making is a process of qualitative change. In this process, something that was not perceived as space becomes inhabitable. This has less to do with creation and more with the appropriation of existing resources. The steps of pedestrians in a city, as de Certeau observed, actualise the street resources. That space is not an objective entity but a negotiation between structure and use, as is typical for post-modern architectural discourse. Bernard Tschumi, for example, described architecture as a discourse of events and spaces. This brings us again to de Certeau's metaphor of *walking* and *talking*. The obvious linguistic connection in French aside (*sens* as a direction of walking and as a meaning of a word), there is a more practical point of comparison - to articulate thoughts by talking corresponds to the articulation of space by walking.

Here, I would like to take de Certeau's metaphor a step further and argue that we are demarcating space with wireless communication. Packets of wireless information, corresponding to words in a language, and even more to steps on the street of information flow, delimit the imperceivable space of wireless communication infrastructure.

Like dwelling or cooking, wireless communication is an important everyday practice that spawns relationships on different levels. At the opposite ends of the equation, we have the infrastructure on one side, and the users on the other. The infrastructure is placed strategically. It is composed of devices and signals that enable communication. It produces connectivity. The users access the infrastructure, they visit the space of the other. They do it to simply communicate or to make something else out of it. In this case, they do it tactically.

60) de Certeau, *The Practice of Everyday Life*, 180.

61) Ibid., 35–36.

62) Ibid., 37.

What can the users make of connectivity? With wireless communication technology becoming massively accessible, different practices that deal with its non-instrumental use have blossomed. From war-driving[63], diverse subversive practices like occupy.here[64] to peer-to-peer wireless network sharing projects[65], all these practices entail the use of existing infrastructure and readily available technology for own purposes of pleasure or protest.

In the attempt to describe these practice of re-engaging in wireless communication as a tactical activity, I will revisit de Certeau's definitions of *tactics* and *strategy* once more, focusing on the points where his theory applies directly to the wireless networking.

Communication is an everyday activity that takes place in the space of the other. The other here is the space of connectivity, a service offered and administered by telephone and Internet providers: the city infrastructure, the government, in a few words – the subjects of will and power. In contracts we make with them (mobile phone subscriptions, Internet access), we are consumers of communication services. We are consuming the products of wireless communication technology. The product, the signal, is at the same time part of the system's infrastructure. This infrastructure is made of overlapping layers of devices, cables and signals. While this product is invisible, or rather imperceptible, it functions through a large number of devices that have a material presence and requirements. The network coverage is part of a strategic plan, carefully attuned towards optimisation of connectivity and control over its use at the same time.

The infrastructure assumes a place, it occupies space, it is distributed in places. It creates relations between places depending on connectivity. The proper place and coverage of an antenna generates relations with the exterior of that infrastructure. It establishes the serving radius of connectivity, dividing space onto the connected and the disconnected. The approach to providing signal is a calculus of "political, economic, and scientific rationality" strategic model. The force-relationships established by service provider companies predict a particular behaviour and use of their services.

On the other hand, we have the marginal majority of users. They rely on a large network of devices that depend on network providers for connectivity. The place of their connection belongs

63) Wardriving is a technique of scanning for Wi-Fi wireless networks by a person in a moving vehicle, using a portable Wi-Fi enabled device. Unlike the tone of its name, wardriving technique is not necessarily used as an exploit but also a mapping tool that can log positions and information on available access points for research and other purposes.

64) Occupy.here was created in parallel with the Occupy movement to offer a network of virtual spaces where both committed activists and casual supporters can communicate, autonomously of the Internet protocols and therefore surveillance. See also Dan Phiffer, 'Occupy.here / a Tiny Self-Contained Darknet', 2013, http://occupyhere.org/.

65) Meshed peer-to-peer wireless networks (described briefly in chapter 4.4) are constructed and operated by users sharing network access across a multitude of devices. Athens Metropolitan Wireless Network http://www.awmn.net/ and Spanish Guifi https://guifi.net/en are good examples.

to the service provider, to the other. They do not determine the place or quality of the signal they connect to. They only seize the opportunity to connect and make something out if it, whenever possible.

Contrary to Foucault, de Certeau's method was not to analyse the apparatus that exercises power but to focus on the mechanisms that reorganise the functioning of power. The *tactics* are indeed associated with the *weak* state of power, but de Certeau gave them the status of *art*[66] and not of an act of the desperate. There is something incredibly sophisticated and practical about resorting to *tactics*.

The art of reuse of wireless infrastructure results in temporary connection possibilities, such as the peer-to-peer network sharing systems. Even more interestingly, it can deliver an insight into the invisible terrain of WiFi networks in urban spaces through artworks that reveal the presence of networks. "A tactic boldly juxtaposes diverse elements in order suddenly to produce a flash shedding a different light on the language of a place and to strike the hearer"[67].

The *tactical* use of signal availability insinuates itself into the place of the other, it uses connectivity offered by the provider fragmentarily, without taking over or even grasping its entirety. Whatever access it grants to the network, it only does so for a brief moment. This activity combines heterogeneous elements; the location of infrastructure hardware; the intensity of the signal; the data that is actually transmitted by the network. The intellectual synthesis of the obtained connectivity and data does not render it into a discourse but rather action, the manner in which the opportunity is seized.

5.4.3. Taking Tactics Further

Tactics are not recipes for revolution. They are signs of and cure for disbelief, lack of strong feelings. After the protests of '68, political beliefs are put on a shelf, to be expressed once a year by voting, but not by going to the streets to protest. De Certeau asserts, Jews are those who used to go to synagogue while Christians are those who used to go to church[68].

One of the most powerful concepts in de Certeau's theory is the observation of consumption as another mode of production. This opens up numerous possibilities for reading and moves away from the simple judgement of consumption. Instead, it allows for a recognition of its political dimension.

66) de Certeau, *The Practice of Everyday Life*, 37.

67) Ibid.

68) de Certeau, *The Practice of Everyday Life*.

The notions of *tactics* and *strategy* have exceeded the scope of de Certeau's original work. They can be used to better describe phenomena other than the ones de Certeau focuses on (dwelling, speaking, reading, shopping, cooking). When employed as a tool for evaluation of everyday practices that did not exist at the time the book was written, they merge perfectly in the discourse. This is precisely so because their definition is rather open. The phenomenon of connectivity, for example, falls into one of the everyday activities that are composed both of *strategic* and *tactical* material. This afforded an exercise in re-reading de Certeau's definitions in the context of wireless communication. The questions of accessibility, ownership and participation demarcate the meandering path of understanding the impact wireless communication has on our everyday practice.

Although Ian Buchanan claimed we did not properly comprehend what *tactics* and *strategy* were for de Certeau, we should consider the impact this "weak" misunderstanding has back on our culture. The influence this book has made in this misunderstood way is real, and it has attained a certain relevance. The impact of de Certeau's writing is precisely that what is widely understood to be written in his books, however oversimplified or unjust to his concepts it is. *Tactics* and *strategies* thus become part of the discourse on power structures.

5.5. Discussion

This chapter introduced the idea that the design of wireless communication infrastructure and the interaction with it does not need to be completely seamless. I first gave an account of seamless connectivity in the technologically minded discourse. The efforts in this field have yielded concepts like *Always Best Connected* (ABC)[69], which discourage awareness of the act of connecting but also of the materiality and intentionality involved in this act. A critique of seamless connectivity appeared already in early ubicomp discussions, partially inspired by Mark Weiser's vision on seamful integration of tools[70], partially as a reaction to his vision of disappearing technology[71]. The information hiding paradigm has always been present in the design of technology, from user interfaces to infrastructures.

69) Gustafsson and Jonsson, 'Always Best Connected.'

70) Chalmers, 'Seamful Design and Ubicomp Infrastructure.'

71) Dourish and Bell, *Divining a Digital Future. Mess and Mythology in Ubiquitous Computing.*

The discussion on infrastructures intensified lately, as the account of Raven's *Infrastructure fiction* or Allen's *Critical Infrastructure* exhibition illustrate. Following Star's call for "studying boring things"[72], infrastructures have entered the general discourse – be it about road maintenance or cultural infrastructures[73].

At the end of this chapter, the practice of re-reading de Certeau served to offer an example of looking at waves from a perspective that is not purely technologically oriented. This connects with the following chapter on artistic practices, that are partially inspired by de Certeau's concept of re-appropriation. Beyond mere exploit and dysfunctionality, these re-appropriations can be attuned at anything from the awareness of network availability to aestheticising practices that play with network traffic as a material. As I have shown at the beginning of this chapter, since the advent of networking, researchers have been trying to play with their alternative use (Chalmers, Höök and Rudström, Bell and Dourish) as well as alternative cultural meanings (Arnall, Allen, Parikka). These explorations were also present in the art and design circles, perhaps with a slightly different perspective on alternative use of technology.

72) Star, 'The Ethnography of Infrastructure.'

73) Rothstein, 'How to See Infrastructure: A Guide for Seven Billion Primates.'

6. Probing the Network: *Architecturality* of Wireless Infrastructures in Works of Media Art and Design

In the preceding chapters, I covered three major paradigms that contextualise the investigation of wireless communication networks, focusing on their performance, use and diffusion in space. In order to establish a model for evaluating the effect they have on the experience of space, I compared the *performativity* of wireless signals to the *performativity* of architecture. I described connectivity through the physical properties of waves and the logic of their propagation, using the different infrastructures that support it. I discussed *seamfulness* in design, as well as in the experience of connectivity, in the context of interaction design and in everyday life.

In this chapter, I will analyse a set of design and artistic practices that have emerged with the massive adoption of mobile wireless technologies. These practices were attuned to articulating the interplay of the social, digital and physical infrastructures. I will interpret the outputs of these endeavours through three loosely defined categories: aesthetic experiments, playful interventions and subversive designs. I will identify common threads in the way they manipulate the *wireless material* with a focus on the underlying motivation and resulting artefacts. With different levels

of reference to and relevance for architecture, these practices form a kind of distributed, though mostly unintentional, group design research.

Like every new technology, mobile devices and wireless networks have been a subject to inflated expectations. Scholars, writers, artists and architects have explored how this new digital layer could *reconstitute* our experience of the *real* urban world, *reconfigure* space and finally, *recompose* social interactions within it[1]. Although hardly negligible, the effect of Wi-Fi on the use of public space has not been so spectacular. Instead of using research practices that use methods typical for social sciences (surveys, interviews, field observations) and that study everyday situations, I will explore here the interaction with wireless networks through disruptive situations created by works of art and design. I will particularly focus on architectural aspects of wireless signals, their presence in space, and the way to experience them tangibly. Through an overview of contemporary media design and art practice working with wireless technologies, I will discuss how they demonstrate spatial properties of waves it in an insightful way.

6.1. Wireless Technologies, Media Art and Architecture

Wireless technology and building design and engineering are areas of expertise rarely combined when planning and constructing the built environment. From the architect's perspective, wireless network infrastructure is a service installed posteriorly to the architectural treatment of space and thus, entirely "someone else's problem"[2]. On the other hand, elements of this infrastructure are attached to built structures, be it a cellular tower on a rooftop, or a Wi-Fi access point on a corridor ceiling, with the sole purpose to provide best possible signal propagation in the line of sight while avoiding obstacles and interferences.

Media art has repeatedly challenged this utilitarian approach to technology, the separation of design and use of infrastructures. At first, telecommunication technology was seen as a place to explore immaterialisation, subverting institutional channels of art distribution in direct communication with the audience. Contrary to the closed-circuit media installations typical for the 1980s (e.g. Bruce Nauman's *Live-Taped Video Corridor*), but also different to the subsequent technologically deterministic interactive art that focused on human-machine communication (e.g. Jeffrey Shaw's *Legible City*), Internet inspired artists restored the social significance of communication technology[3]. Continuing on Fluxus tradition of open, collectively authored

1) Forlano, 'WiFi Geographies.'

2) Raven, 'An Introduction to Infrastructure Fiction — Improving Reality 2013 | Infrastructure Futures | Futurismic.'

3) Inke Arns, 'Interaction, Participation, Networking: Art and Telecommunication', in *Medien Kunst Netz : Medienkunst Im Uberblick / Media-Art Net 1: Survey of Media Art*, ed. Rudolf Frieling and Dieter Daniels, Medien Kunst Netz 1 (Springer Wien New York, 2004).

artistic process, net.art approached information and communication as a material[4], continuously exploring engagement and access to the technology. Nevertheless, net.art did not actually engage materiality of the Internet, but rather attempted to produce a different, other materiality of the net made of clicks, animated images, pages reloading. Cyberspace is its metaphor.

When the magic of real-time worldwide communication became widely available (early 2000s), it became evident that Cyberspace and information do rely on a rather material infrastructure, as Jeremijenko had already pointed out[5]. This led to an interest, in network-minded artistic circles, for rendering this infrastructure visible.

Usman Haque was one of the prominent actors in these endeavours. In a discussion on the new, dynamic and fluid of architecture[6] we can recognize the idea that first troubled architectural avant-garde from the 1970s. After decades of exercising the Promethean power of architecture to transform the lives of its occupants that fuelled the practice of modernism[7], it became clear that such revolution might well not happen. This realisation triggered a reaction amongst the then young professionals to embrace different *unbuilding* practices and to explore the idea that architecture is not simply about designing buildings. For example, in Tschumi's view architecture had to negate what society expected from it and instead, engage in the design of subjective experience of spaces[8]. Using *paper spaces* as a tool to criticise and reflect upon architectural theory and practice, Tschumi distanced himself both from the functionalist approaches of modernism and the stylistic preoccupations of his post-modern contemporaries. Architecture was seen as a means of communication, defined as much by the movement and event as by the physical walls.

In a practical sense, the experiments with materialising networks engage with an opposite process of Tschumi's. They give materiality to an otherwise hardly perceivable or palpable infrastructure that acts as a meta-architecture within the built environment. However, the motivation behind Tschumi's work and contemporary media design and art practice is similar in some points. Both contribute to a broadening of the meaning and role of architecture. Giving form to something that is fluid, in constant flux and that cannot be experienced with our bodies becomes part of the architects vocabulary.

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4) Joachim Blank, 'What Is Net Art ;-)?', 1996, http://www.irational.org/cern/netart.txt.

5) Jeremijenko, 'Database Politics and Social Simulations.'

6) Usman Haque, 'The Choreography of Sensations: Three Case Studies of Responsive Environment Interfaces', in *VSMM 2004: Proceedings of the Tenth International Conference on Virtual Systems and Multimedia: Hybrid Realities & Digital Partners--Explorations in Art, Heritage, Science & the Human Factor, 17-19 November 2004, Softopia Japan, Ogaki City, Japan*, ed. Hal Thwaites (Amsterdam ; Fairfax, VA: IOS Press, 2004).

7) Lara Schrijver, *Radical Games: Popping the Bubble of 1960s' Architecture* (Rotterdam : New York, NY: NAi Publishers ; Available in North, South and Central America through D.A.P, 2009).

8) Bernard Tschumi, 'The Pleasure of Architecture', *Architectural Design*, March 1977.

6.1.1. Describing the Hertzian Space of Wireless Communication

Wireless communication infrastructure comprises base stations, access points and other networked devices, connected by high-frequency waves transmitting data through air. The waves are at the same time the message and the infrastructure for communication. Artistic exploration of materiality of this imperceptible phenomenon focuses the attention on its social and political aspects, such as in Paul Graham Raven's *Infrastructure Fiction,* as well as aesthetic and interaction concerns, demonstrated most clearly in visualisations of RFID, Wi-Fi and GSM signals. Nikolay Lamm's artworks *What if you could see...* (Wi-Fi, cellular networks) are classic examples of this.

Ever since Anthony Dunne published his doctoral thesis[9] and subsequently the influential *Design Noir* with Fiona Raby[10], the term *Hertzian space* become widely used by designers and artists to refer to the vague terrain of wireless communications, electromagnetic radiations and their spatial, social, cultural and political representations.

From the perspective on materiality, *Hertzian space* is a direct inverse of Cyberspace – while the last is a metaphor of what happens within computers, "radio space is actual and physical"[11]. Referring to waves oscillating on frequencies expressed in Hz (SI unit of frequency named after Heinrich Rudolf Hertz), Dunne defines *Hertzian space* as "a holistic view of the electronic device and its cultural interactions"[12].

The problem when working with these invisible or otherwise un-sensible materials is that there is immediately an expectation of some kind of translation (e.g. mapping values of signal strength onto perceptible values of light or sound). Dunne tried to explain the difference between visualisation and the work that "does not discuss making the invisible visible [...] but explores the links between the material and immaterial that lead to new aesthetic possibilities for life in an electromagnetic environment"[13]. Many artists have dealt with it since and some of this work has contributed to a better understanding of how *Hertzian space* can be experienced.

9) Anthony Dunne, *Hertzian Tales: Electronic Products, Aesthetic Experience and Critical Design* (London: RCA CRD Research Publications, 1999).

10) Dunne and Raby, *Design Noir: The Secret Life of Electronic Objects*.

11) Anthony Dunne, *Hertzian Tales*, vol. Rev. (MIT Press, 2005).

12) Ibid.

13) Ibid.

6.2. Wireless Media in Design and Artistic Practice

Media art exhibitions and festivals like the Berlin's Transmediale and Ars Electronica in Linz have repeatedly explored wireless media in artistic practice. More specifically, the Art+Communication festival in Riga[14], Radiator in Nottingham[15] Sentient City project[16], Invisible Fields Exhibition, Brighton[17] and Sensing places, Basel[18] made focused efforts to demonstrate the ways to "take control of the very principles and materiality of the *network waves*"[19]. Several artists and designers have been prominent across these events, giving them a representative role in the discussion on spatiality and tangibility of the wireless network layer. In their unsystematic explorations of interaction with wireless signals, their design and artworks question the interaction between people, technology and space. Because of the way they deal with network and platform politics, we could say they are "extending network politics into a hands-on approach to basics of network communication"[20], manipulating networks for different artistic purposes.

I will describe some of these works in order to bring out the distinct motivations as well as technologies involved in their production. Before discussing the artworks in detail, I will introduce three general categories that should help analyse their scope and contribution to the question of *architecturality* of wireless infrastructures. *Architecturality* was defined in Chapter 3. *Connectivity in action / form* as the capacity of something to affect the experience of space in a significant way. The categories introduced here serve to group works around the way they engage with the experience of space, and not to separate them into distinct classes. *Architecturality* of the artworks will be evaluated after they have all been briefly discussed. A chronological diagram (Figure 6.1) and a comparative table (Table 6.1) with basic information on all artworks that are considered relevant for this research can be found at the end of this chapter.

14) RIXC, 'Art + Communication : WAVES', *Center for New Media Culture, Riga*, August 2006, http://rixc.lv/waves/en/home.html; RIXC, 'Art + Communication : SPECTROPIA', *Center for New Media Culture, Riga*, 16 October 2008, http://www.rixc.lv/08/en/festival/index.html.

15) Trampoline, 'Radiator', 2009, http://www.radiator-festival.org/radiator-2009.

16) Mark Shepard, 'Toward the Sentient City', September 2009, http://www.sentientcity.net/exhibit/.

17) Lighthouse, 'Invisible Fields Exhibition', 14 October 2011, http://www.lighthouse.org.uk/programme/invisible-fields.

18) HeK, 'Sensing Place. Mediatizing the Urban Landscape', *Haus Für Elektronische Künste, Basel*, August 2012, http://archive.hek.ch/en/node/350?loc=EX.

19) Rob van Kranenburg, 'When Wireless Dreams Come True', *Mute Magazine*, 5 October 2006, http://www.metamute.org/editorial/articles/when-wireless-dreams-come-true.

20) Jussi Parikka, 'Critically Engineered Wireless Politics', *Culture Machine*, Platform Politics, 14 (2013).

6.2.1. Artistic Approaches to Wireless Networking

Aesthetic Translation

The translation involves relatively direct mapping of wireless signals onto visual, sonic or other media. A measurement of a network value (most commonly signal strength) is assigned a value in the physical system - position on the screen, colour, height, depth, pitch, or speed. These works are most often static, in the sense that they do not respond to the networks in real-time, but are rather displayed as renderings, images or sculptures of value sets that were given form after collecting data.

Playful Interventions

Playfulness is understood here as the use of signal availability and/or data traffic as a dynamic value in creating tangible experiences. It includes a dimension that is controlled by the artist, be it the manipulation of location as in distributed sound pieces, light painting walk, senses or another material like light or video. They are not independent of wireless infrastructure as an input, but they incorporate additional material. These works tend to interpret both physical properties of wireless networks and their impact on people. They engage with controlled network traffic to generate interactions between people, environment and information. Playful interventions are real-time oriented, reacting to quantities of wireless signals (strength, ESSID, encryption type) dynamically.

Subversive Design

Critical reflection and subversive intention are aimed at directly affecting the propagation of signals or another usability aspect of the infrastructure. They make it unavailable or interfere significantly with its functionality. Subversive design requires high technical literacy and understanding of how a technology works.

6.2.2. The Artistic and Design Practice

In the era before *wirelessness*, the "Portrait Of Rebecca With Power Line Fluctuations" by the San Francisco based artist Jim Campbell examined the dynamics of a normalised infrastructure, electricity. Campbells playful intervention rendered fluctuations of the power line visible through an interaction between a portrait and a light bulb on a TV screen[21)]. Electricity, which is normally taken for granted and hidden in walls, is used here as a material in the interplay with artistic artefacts such as a video image and the TV object.

21) Jim Campbell, *Portrait Of Rebecca With Power Line Fluctuations, 1992*, Video monitor, Custom electronics, 1992, http://www.jimcampbell.tv/portfolio/objects/portrait_of_rebecca/.

The issue of normalisation gives art and design an important role when dealing with the aspects of an infrastructure beyond the technical or utilitarian. We can observe the normalisation process of wireless networking from the introduction of wireless communication infrastructure as a *superstructure* - a fascinating technology available to only few and used for specific applications; to a *cultural infrastructure*[22] that is so deeply socially embedded that it becomes unnoticeable. As wireless connectivity is available almost anywhere at any time to anyone with a laptop or another network enabled device, connectivity is not anymore in the centre of attention. Although Campbell's work does not play directly with wireless signals, he sets the stage for artistic and design practices that examine cultural peripherality of infrastructures.

Continuing along the "wired" line, the work *Live Wire*[23] by artist and engineer Natalie Jeremijenko brings attention to wired network infrastructure. The intensity of traffic within a local area network is rendered tangible through the "dangling" of a plastic wire suspended from the ceiling. *Live Wire* is an example of calm technology[24], operating at the periphery of our attention, while delivering information to our senses through a translation of intensity into movement.

One of the first artworks that dealt with intangibility of wireless communications and its *architecturality* was Usman Haque's *Sky Ear*. Conceived as an electromagnetic performance that engages both people and waves as participants, *Sky Ear* is an exploration of activity within the electromagnetic environment. Haque's playful approach acknowledges intangible phenomena that "affect the way we related to space and to each other in much the same way that traditional architectural elements do - they make us move to certain parts of a building, [...] they condition the movements we make and how we make them, [...] they have a direct impact on the way we associate with other people"[25]. By use of mobile phones for sensing and communicating at the same time, the changing colour of LEDs inside a floating structure of helium balloons interprets the interaction between us, the waves and space in between.

Another project by Haque in collaboration with Bengt Sjölén and Adam Somlai-Fischer makes a significant contribution to the exploration of intangible infrastructures. Between 2006 and 2008 the trio developed the *Wifi Camera*, an artistic tool to "reveal the invisible electromagnetic space"

22) Mackenzie, 'Untangling the Unwired.'

23) Natalie Jeremijenko, *Live Wire*, Ethernet transceiver, Local Area Network, Wire, 1995, http://www.nyu.edu/projects/xdesign/mainmenu/archive_livewire.html.

24) Weiser and Brown, 'Designing Calm Technology.'

25) Usman Haque, 'Sky Ear - Concept and Final Design', 2004, http://www.haque.co.uk/skyear/skyearconceptsanddesign.pdf.

and "the shadows that we create within"[26]. The Single Pixel and Panoramic versions expose the information landscapes as "seen" by directional antennas[27]. The camera rotates and takes 'snapshots' storing networks names and signal strengths that it then renders into layered images. The images translate network activities identified in space into a flat surface on the screen. *WiFi Camera* demonstrates physical properties of the waves at 2.4GHz wavelength (12.5cm), their reflections and interference. It uses waves in a similar way the photographic camera uses light. Activity within different wireless network channels coming from laptops, Wi-Fi hotspots, smartphones and even microwave ovens is represented by the intensity of points in the image, through an aesthetic translation.

By 2007, household networks became a standard commodity; more and more of them were coming already encrypted. The project *Constraint City: The Pain of Everyday Life* by Gordan Savičić demonstrates the presence of encrypted private networks "bleeding" into the public space of the street. Performed across numerous cities, this playful work addresses the "paradigm shift in the realms of everyday constraints, therefore, the relation of abstract information layers to our everyday life"[28]. *Constraint City* reveals beacon frames coming from encrypted wireless networks, translating them into the pressure of a corset on the body, causing pain to the person wearing it. The person can in this way "experience access restrictions by walking through the streets", in a more palpable, less mediated way. It is "a pragmatic experiment in constructing ways of sensing relations that cannot be easily shared"[29], relations between pedestrian bodies and nearby wireless networks.

Unlike the practices described so far, which focus on exposing and exploring existing wireless signals, *Hertzian Rain* by Mark Shepard is using wireless communication technology to distribute a participative ambient sound installation and generate interactions between people, environment and information[30]. *Hertzian rain* explores the physical properties of electromagnetic radiation in depth, through playful exploration of the broadcasting range, shielding and filtering and rendering it *experienceable*. Shepard is asking: "to what extent do these *Hertzian* weather systems become as important, possibly more important, than built form in shaping our experience of the

26) Adam Somlai Fischer, 'Panoramic Wifi Camera on Vimeo', 2009, https://vimeo.com/2874874.

27) Bengt Sjölén, Adam Somlai Fischer, and Usman Haque, *Wifi Camera*, 20 WiFi antennas, motors, custom electronics, software, 2009, http://wificamera.propositions.org.uk/.

28) Gordan Savičić, *Constraint City*, Plexiglass, Servo motors, Nintendo DS, Software, 2008, http://www.yugo.at/equilibre/.

29) Mackenzie, *Wirelessness: Radical Empiricism in Network Cultures.*

30) Mark Shepard, *Hertzian Rain*, Wireless transmitters, RF shielding umbrella, Ad-hoc mesh networking transciever, Wireless headphones, Laptop, 2009, http://www.andinc.org/v4/hertzian-rain/.

city?"[31]. Created back in 2009, Shepard's work also tackles the important question of competition for signal dominance, a topic that is gaining importance in a contemporary spectrum and bandwidth saturation.

Light painting technique, when applied to Wi-Fi, visualises the presence of wireless network signals in space. The Touch project team - Timo Arnall, Jørn Knutsen, Einar Sneve Martinussen in 2011 designed a tool with that they performed walks around the Oslo School of Architecture campus. *Immaterials: Wifi Light Painting* is a series of long-exposure photographs of the displayed signal strengths, creating in this way what the authors call "cross sections" of network signal strength. Or, as Arnall put it "a graph in real time. And in real Space"[32]. The work is thus a visualisation of network signal strength, but it adds a playful parameter to the equation - the position of the interactive light rod. While they do simply visualise signal strength of the university network, they choose the place and time to make their walks.

The works by Berlin based artists Julian Oliver and Danja Vasiliev treat wireless networks from a perspective of affordance with a dose of irony. Part of the *Critical Engineering Working Group*[33] these two artists set as one of their goals to expose the underlying technological exchanges that take place within networked systems. In *Newstweek*, they questioned the vulnerability of contemporary media-defined reality revealing the different steps in data traffic[34]. While this is important from the cultural perspective of news top-down distribution model and its possible subversion, it the reveals the materiality of data transmission from ISPs, servers and wireless access points to laptops and mobile devices that receive them. It emphasizes the locality of this traffic – enabling content modification within the physical space of particular network coverage.

Two strikingly similar artefacts complete this list: *No Network* by Julian Oliver[35] and *1:24 Tank, Black* by Addie Wagenknecht[36]. Both feature a scaled model of a military tank with a hidden network jammer, jamming the signal of cellular networks in its proximity (5-15m). Treating wireless communication in a binary manner, these objects create negative space on the map of connectivity.

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31) Ibid.

32) Timo Arnall, Jørn Knutsen, and Einar Sneve Martinussen, *Immaterials: Light Painting WiFi*, WiFi measuring rod, long exposure photographs, 2011, http://www.nearfield.org/2011/02/wifi-light-painting.

33) Julian Oliver, Gordan Savičić, and Daniil Vasiliev, 'The Critical Engineering Manifesto', October 2011, http://criticalengineering.org/.

34) Julian Oliver and Daniil Vasiliev, *Newstweek - Fixing the Facts.*, Atheros based router, Wall plug enclosure, Custom firmware, 2011, http://newstweek.com/.

35) Julian Oliver, *No Network*, scale model of 1966 British Chieftain, WiFi jammer, 14 July 2013, http://julianoliver.com/output/no-network.

36) Addie Wagenknecht, *1:24 Tank, Black*, Remote-controlled model of an M1, Wi-Fi jammer, 2014.

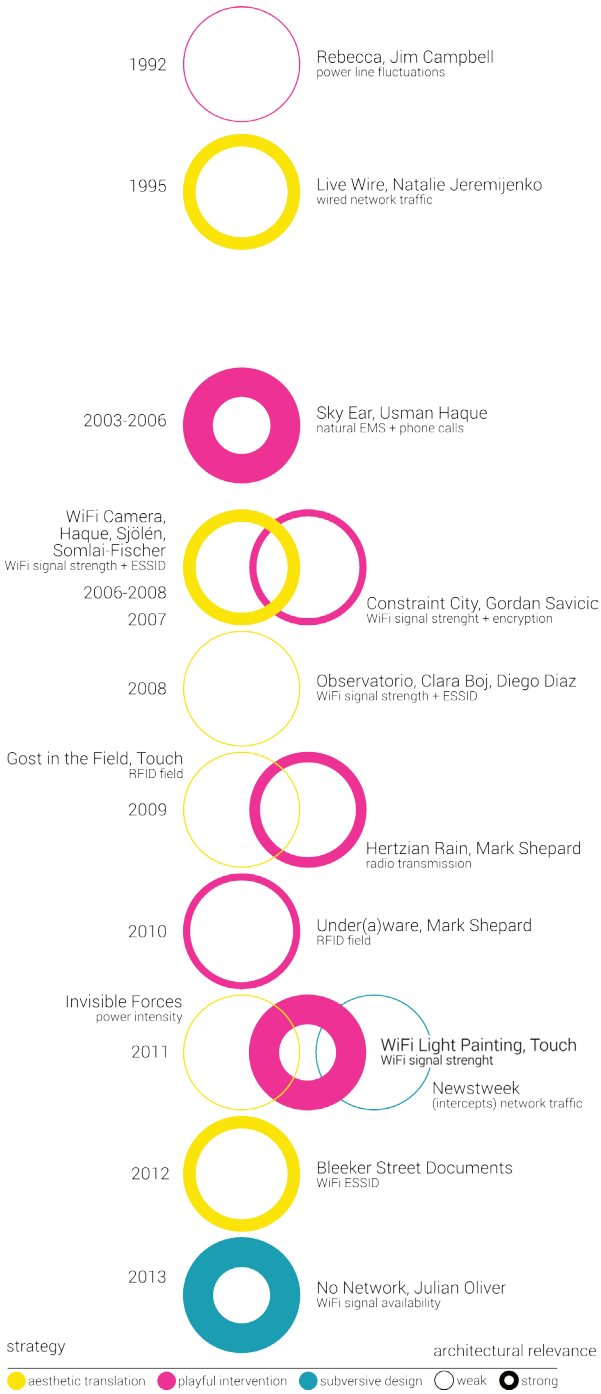

Figure 6.1 Artworks timeline showing the trends in architectural relevance (stroke) and artistic strategies identified in this analysis (colour)

6.2.3. Art, Technology and the Hype

Immaterials: Ghost in the field by the Touch team and *Bleeker Street Documents* by Austrian architect Peter Jellitch are the clearest examples of aesthetic translations. *WiFi Camera*, as well as *Observatorio* by the LaLaLab duo, are dynamic visualisations of the presence of wireless networks. However, because of their objective approach to the signal availability they are closest to aesthetic translation as a strategy.

Constraint City by Gordan Savičić and *Immaterials: WiFi Lights Painting* by the Touch team, although translating wireless network signal strength into pressure (pain) or light, do *spatialise* this information in a manner chosen and performed by the artists. This adds a playful component to the artworks, grouped together with Jim Campbell's *Portrait of Rebecca,* Usman Haque's *Sky Ear* and *Hertzian Rain* by Mark Shepard. These artworks combine wire(less) infrastructure fluctuations with their own medium of expression, be it a video, light or sound.

Oliver and Vasiliev's *Newstweek* intercepts communication between the access point and devices connected to the network through a method called 'Man in the Middle Attack' or ARP Spoofing, which is used by malicious attackers to intercept, modify, or even stop data in-transit, but also as a way to implement redundancy of network services[37]. Such approach makes a rather subversive intervention.

When we put these works in a chronological order, some patterns in the interest and the way to analyse electromagnetic environments emerge. Although not applicable to all, we could find a certain dose of romanticism in the early attempts to play with wireless network infrastructure. Revealing the information landscape[38] or affecting the way we relate to space with wireless communications[39] is a very ambitious task for an artwork. Whether or not floating balloons or images on the screen are able to really address these questions will be discussed later.

Furthermore, certain topical trends peak at certain times. For example, most of the artworks that were produced around 2008 measure Wi-Fi signal strength and react to it. *Immaterials: Ghost in the Field* and the *Under(a)ware* from the *Sentient City Survival Kit*, created around 2009, respond to RFID field. The more critical works that relied upon stronger technical skills from the artists are of a later date[40]. However, throughout this survey, playful interventions take the central role and have the longest presence.

37) Fergal Glynn, 'Cyber Attacks: What Is ARP Spoofing?', accessed 16 June 2014, http://www.veracode.com/security/arp-spoofing.

38) Sjölén, Somlai Fischer, and Haque, *Wifi Camera.*

39) Haque, 'Sky Ear - Concept and Final Design.'

40) Oliver and Vasiliev, *Newstweek - Fixing the Facts.*

Could we blame these trends on general technical developments of availability of technology? For example, a Linksys router WRT54G was particularly popular amongst tech tinkerers and technically skilled artists. Besides its modest price[41], the firmware for this router was particularly inviting to tinkerers as it was based on Linux components and released under the GPL licence preserving the source code available to the public. Linksys open sourced the firmware for WRT54G in 2003. "In the two years since Linksys originally released the WRT54G firmware, whether by design or not, this affordable, common router has become not just a playground for hobbyists, but an open platform for commercial business as well"[42]. This set the ground for artistic experiments as well. It is around this time that the first artworks that used customized routers appeared (Wi-Fi camera for example).

With the release of 3G and 4G technology (around 2003 and 2010 respectively), faster connections and seamless integration between devices came about. This offsets the attention from connectivity even more. Asserting the issues of connectivity with a critical attitude thus became even more important and the language that developed around this artistic practice spanned across a multitude of communication standards. For example, the artworks produced around 2011 interpreted signals from electrical current, through RFID to wireless network signal strength and traffic.

Another interesting technical aspect of the artistic practice is the size and structure of the production team. While the first artworks involved quite a complex team structure and numerous external actors (the list of 25 people and several companies credited for Sky Ear confirms this[43]). In contrast to this, *Newstweek*, developed in 2011 was almost entirely conceptualised, produced, programmed and documented by artists themselves. This change in structure and organisation of work can be due to the structure of cultural funding (artist with larger budgets have bigger teams, especially in the early media art scene), but it is also possible to relate to the increased availability of technology and proficiency some artists gained in the field during years of practice. What it brings along is a certain change of attitude and character of artworks. While both the narrative and aesthetics were more romantic in earlier artworks the conceptualisation and production are more sober and critical in the most recent artworks.

41) The price for a WRT54G Linksys router was 60$ or about 45E when it came out in December 2002

42) Aaron Weiss, 'The Open Source WRT54G Story', 8 November 2005, http://www.wi-fiplanet.com/tutorials/article.php/3562391.

43) Usman Haque, 'Sky Ear - Credits', 2004, http://www.haque.co.uk/skyear/credits.html.

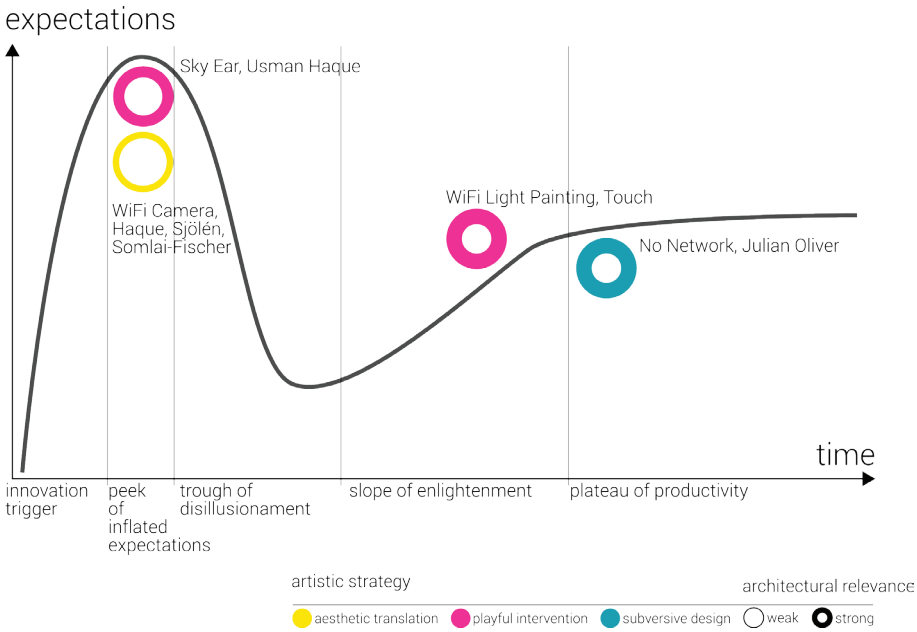

Figure6.2 Gartner's hype cycle applied to artworks' motivation, scope and outcomes

We could compare the development these artworks demonstrate to the Gartner's 2013 *Hype Cycle for Emerging Technologies*[44] . The *peak of inflated expectations* manifested in claims such as to "lead to new aesthetic possibilities for life in an electromagnetic environment"[45] , "give form to this space, to make visible the invisible"[46] or "Expose the invisible information landscape" and "Show how our physical structures are illuminated by this particular electromagnetic phenomenon"[47] . On the other end of our timeline diagram, *Newstweek* serves as "a tactical device for altering reality on a per-network basis" and intervenes in the "top-down distribution model" of news and facts in the vulnerable "strictly media-defined reality"[48] . This goal is not only attainable but also delivered by the artwork.

44) Jackie Fenn and Mark Raskino, 'Gartner's Hype Cycle Special Report for 2013', 15 August 2013, http://www.gartner.com/doc/2574916?ref=sdc.

45) Dunne, *Hertzian Tales*, 2005.

46) Haque, 'Sky Ear - Concept and Final Design.'

47) Sjölén, Somlai Fischer, and Haque, *Wifi Camera*.

48) Oliver and Vasiliev, *Newstweek - Fixing the Facts.*

6.3. *Architecturality* of Wireless Networks in Design and Art Practice

The strategy the artists used to tackle wireless communication – aesthetic or playful or critical – can not be directly mapped to their *architecturality*. Some artworks like *The Portrait of Rebecca* or *Observatorio* engage in no explicit relationship with architecture[49] . They focus instead on their source material – electricity or open Wi-Fi networks and use different image manipulation techniques to render them visible.

Conversely, *Sky Ear*, *Hertzian Rain*, *Wi-Fi Light Painting* and *Wi-Fi Camera* take thinking about space as a starting point for their explorations. They investigate the physical properties of wave propagation in space - wavelength, barriers, surface permeability and try to shape this as a material. *Sky Ear* explored the altering of shape and intensity of the electromagnetic landscape by both human and natural causes. Wavelength and reflections are demonstrated through their different reflection off walls and windows. By the use of EMF shielding fabric on umbrellas in *Hertzian Rain*, Shepard is enabling the audience to actively modify their electromagnetic environment.

Just like the intention, the architectural relevance of the artefacts varies, although it can be somewhat implied from the intention. As for the *Constraint City* and *Under(a)ware* they function on two distinct scales – the urban and the personal. The wearable device is used to experience the overlapping territories of the physical and the digital, the public (street) and the private (body). The reference to architecture is not explicit here. However, these works engage with the complexity of physical networks, which are part of a larger environment defined by architecture, offering a personal wearable experience. Wearable artefacts perform on the body of the person in public space, relative to the invisible conditions in the environment. This body, in turn, performs differently in space, by changing location for example.

Some artworks use architecture as a niche or a background, confirming its existent structure. For example, *Live Wire* with its "dangling" movement confirms the stable and static quality of this corner while its verticality invokes a typical architectural element – a column or a pillar. Furthermore, through a *reinforcing* approach, images rendered using the *Wi-Fi camera* confirm the architectural structure of the interior where they are produced; they visualise wireless network traffic on top of and compared to existing architecture. The reinforcing approach has a lesser impact on the physical, bodily experience of space. Nevertheless, they have a proportionally stronger influence on perception and understanding of signal propagation.

The *Bleeker Street Documents* play with the base as an architectural element, rendering the dynamic change in network availability into a frozen morphology. Its sculptural value is evident

49) This is arguably false, depending on our definition of architecture. The conclusion presented here is derived primarily from artists statements.

but lacking a clear reference to the actual architecture of space under observation, there is not a significant contribution to the question of re-imagining the design of immaterial landscapes. Its main contribution is in the realm of aesthetics as it successfully delivers the feeling of digital while observing the geometry of shapes and shadows it is made of.

Sky Ear exhibits both a visual and structural relevance to architectural experiment. It functions like an interactive "ceiling" or a "roof" made of and for wireless communication and physical objects. It is one of the most architecturally relevant works analysed, although the direct bodily experience is not affected by this distant, floating assembly of balloons. Because it uses the language of architecture and projects it into a soft, dynamic and fluid form, *Sky Ear* achieves a similar effect to *Live Wire* or *Wi-Fi* camera but with a significantly more tangible idea on its consequences for architectural design.

It is interesting to analyse the two works produced by the Touch team from the perspective of their architectural qualities. Both *Ghost in the Field* and *Wi-Fi Light Painting* are using the same visualisation technique – long exposure photograph and both result in images of ephemeral structures. The bubbly representation of RFID field has a somewhat sculptural quality while light paintings of wireless networks have a strong structural relevance to architecture. It resembles a wall, a barrier, a horizontal divider that can be uncovered anywhere the team decided to make their walk. It reveals the connection between the two worlds – exposing, for example, the "holes" in the network caused by nearby building's properties.

The artworks that block network signal, like *No Network* or *1:24 Tank Black* make a structural reference to architecture. It is a metaphor and a manifestation of an empty space created by technology and for technology.

6.4. Discussion

How can the presence of wireless signals be understood and treated architecturally? The artworks are naturally speculative in this respect, as their intention is to raise awareness[50] or demystify and render tangible[51] the presence and activity within the networks. Thus, the relationship with the built environment is highly important, but the methods and outcomes are not subject to rigorous architectural considerations.

The works I discussed here demonstrate the richness of the developing language that talks about intangible, un-sensible things that surround us. The reasons for this are simple: on one

50) Shepard, *Hertzian Rain*.

51) Timo Arnall, 'The Immaterials Project – Timo Arnall', 4 September 2013, http://www.elasticspace.com/2013/09/the-immaterials-project; Savičić, *Constraint City*; Sjölén, Somlai Fischer, and Haque, *Wifi Camera*.

side, wireless communication became an inseparable part of our everyday, embedded in our living space in a multitude of ways. It became more and more relevant while falling deeper in the periphery of attention. Thus, it became interesting for artists, designers and the technologically literate to translate this phenomenon into tangible experiences. On the other side, technology has become more technically and financially accessible due to hardware as well as Open Source developments[52] . This too played a role in the production of network-inspired artworks and designs, affecting the size and configuration of teams, types of collaborations and the resulting complexity of artworks.

Upon further analysis, we can see that some of these works clearly use the language of architecture to expose their "findings", while others do not. How architectural is the intention, and how architectural is the resulting artefact? When thinking about this, one easily falls into the trap of comparing the artefacts to more or less standard architectural elements like walls, columns, ceilings, floors. While this can be useful to quickly illustrate their relevance, it renders both architectural and artistic output banal. Seen from this perspective, it becomes evident that the works discussed here are not able nor supposed to account for the complexity of architecture and experience of space. Attuned at revealing a hidden aspect of our environment, the artworks contribute to a language of hybrid surroundings we are embedding ourselves in. There is clearly a need to become more "fluent" in this language in order to better understand our habitat and its complexities.

Finally, the discussion on the design of *architecturality* of wireless networks, and the awareness of them brings us to the question of production of knowledge. We can regard these efforts of artists and designers as a form of *collective design research*. Their artists statements sound close to research questions and deliver designs and interaction that is clearly capable of building on top of that. The experience of both the authors and the audience resonates strongly with the questions explored. Through the technically challenging process of creating a work of design or art one not only learns more about the operation of these technologies but also about the way they "show" in space and to people – which properties are valuable for interaction, which behaviours could be emphasized, which connections can be made between the physical and the digital. Similarly, the *experiencer* of the artwork is put in a situation where their experience of phenomena begins to explain and reveal relationships between the different actants – space, people and networks. These methods of inquiry into our everyday reveal the potential of direct experience and manipulation to tell about the nature of phenomena observed.

However, it is important to keep in mind that the artistic and design practice discussed in this chapter was not intended as a research endeavour. It is attuned at an aesthetic experience and addressed to an art audience. I have already discussed the thin line between research through

52) Weiss, 'The Open Source WRT54G Story.'

design and design practice that is nevertheless firmly present between these artworks and the actual practice-based research. Besides the fact that their documentation and dissemination is not oriented towards (academic) production of knowledge, the most important to stress here is the intention that should not confuse an artist's motivation statement with a research question.

Table 6.1 Integral list of design and artistic practice exploring wireless media with brief descriptions.

"Portrait Of Rebecca With Power Line Fluctuations"

Jim Campbell, 1992

playful intervention, minimal architectural relevance

Fluctuations of the power line become visible through an interaction between a portrait and a light bulb on a TV screen. Electricity, which is normally taken for granted, is used as a material in the interplay with artistic artefacts such as a video image and the TV object.

Reacts to: electrical power lines

"Live Wire"

Natalie Jeremijenko, 1995

aesthetic translation, reinforcing approach

The use of (wired) network traffic is rendered tangible, while at the same time staying at the periphery of perception

Reacts to: wired Internet (LAN) traffic

"Sky Ear"

Usman Haque, 2003/2006

playful intervention, material approach, structural relevance

By use of mobile phones for sensing and communicating at the same time, the changing colour of LEDs inside a floating structure of helium balloons interprets the interaction between us, the waves and the space in between

Reacts to: natural EMS + phone calls

“Wifi Camera”

Usman Haque, Bengt Sjölén, Adam Somlai-Fischer, 2006/2008

aesthetic translation, reinforcing approach

Artistic tool to reveal the invisible electromagnetic space and the traces we create within. Exposes the information landscapes through layered images of network activity, using waves in a similar way photographic camera uses light.

Reacts to: Wi-Fi signal strength + ESSID

“Constraint City”

Gordan Savicic, 2007

playful intervention, personal wearable experience

A performative tool that reveals the presence of private encrypted wireless networks in the public space of the street. It translates these abstract information layers into pressure of a corset on the body, causing pain to the person wearing it.

Reacts to: Wi-Fi signal strength + encryption type

“Observatorio”

LaLaLab (Clara Boj and Diego Diaz), 2008

aesthetic translation, minimal architectural relevance

A telescope-like observation device that scans the space for Wi-Fi networks. Through a continuous observation, it generates a map of open wireless networks in the city.

Reacts to: Wi-Fi signal strength + ESSID

“Immaterials: Ghost in the Field”

Touch (Timo Arnall, Jørn Knutsen, Einar Sneve Martinussen), 2009

aesthetic translation, minimal architectural relevance

Describes the field within which RFID tag and RFID reader will interact with each other in three dimensions, using long exposure photography.

Reacts to: RFID field

“Hertzian Rain”

Mark Shepard, 2009

playful intervention, material approach

Uses wireless communication technology to distribute a participative ambient sound installation. Explores the physical properties of electromagnetic radiation in depth, playing with the broadcasting range, shielding and filtering and thus rendering it *experienceable*.

Reacts to: custom RF infrastructure

“Under(a)ware” (Sentient City Survival Kit)

Mark Shepard, 2010

playful intervention, personal wearable experience

Explores different modes of coexistence of computing within the built environment. “Under(a)ware” is attuned specifically at alerting to the presence of discrete tagging technologies, rendering RFID readers into a physical vibration using of a motor built into the underwear

Reacts to: RFID field

“Immaterials: Wi-Fi Light Painting”

Timo Arnall, Jørn Knutsen, Einar Sneve Martinussen, 2011

playful intervention, structural reference / relevance

Long-exposure photographs of Wi-Fi signal strengths, displayed by means of a custom made light rod. Their process is similar to building a kind of light mountains with Internet data.

Reacts to: Wi-Fi signal strength

“Newstweek”

Julian Oliver and Danja Vasiliev, 2011

subversive design, minimal architectural relevance

Questions the vulnerability of contemporary media-defined reality revealing the materiality of data transmission. It emphasizes the locality of this traffic - enabling content modification with the space of particular network coverage.

Reacts to: Wi-Fi network traffic

“Bleeker Street Documents”

Peter Jellitsch, 2012

aesthetic translation, sculptural approach

Transforms network availability into a three-dimensional sculpture representing signal strength, ping duration and network speed by height and position of peaks. A sort of romanticisation of a technical infrastructure through a narrative form of a diary.

Reacts to: Wi-Fi signal strength and traffic speed

“No Network”

Julian Oliver, 2013

subversive design, structural reference

A mobile network jammer fit into a model battle tank, it ban access to the cellular (mobile) network creating a kind of negative space of connectivity, which only emphasised connectivity elsewhere and our habit of being online everywhere, all the time.

Reacts to: GSM, 3G, Wi-Fi and other wireless signals

7. Projects and Prototypes

In Chapter 2. *Research through Design, Art and Architecture*, I covered the general notions of research through design methodology, thus setting the ground for a study of design artefacts in the research context. Although there is no general consensus in literature about the precise procedures that are implied or necessary in this research approach, there is a growing body of research that can be extrapolated from. I will restate the basic principles derived from the previous discussion, as an introduction into the process of designing and prototyping presented in this chapter. I will discuss the expectations and findings from these investigations of interaction with seamless wireless network infrastructures in space. I will also discuss the implications of these investigations for understanding the *architecturality* of wireless signals.

7.1. Tangibility of Connectivity

The process of exploring the relationship between built structures and seamless infrastructures is strongly linked to a design practice. This practice aims to render wireless communication signals tangible and *experienceable*. The emphasis I put on the tangibility of wireless communication is meant to work against the normalisation of seamless connectivity. Although both the public and

network engineers regard seamless connectivity as good, it entails a loss of agency both in using (connecting and disconnecting) and in discussing and designing its infrastructure.

I devised a series of experiments to explore the possibilities for alternative interaction with the un-sensible material that results from our use of wireless networks. These experiments emphasised a lived experience and an awareness of network connectivity and traffic. The experiments also contributed to the emancipation of the idea that wireless communication has important architectural qualities and can thus be treated architecturally.

7.1.1. Experience Catalyst

Experience is one of the central topics in *research through design* and the related practice-based research discussions[1)] . It is central to the explorations of human-computer interaction design too[2)] . Experience here has a two-fold meaning: first, there is the experience of designing, of articulating concepts through practice; second, there is the resulting experience of the use or interaction with the design artefacts. Both of these types of experiences lead towards gaining insights into the phenomenon observed: understanding through making, and understanding through experiencing.

In this study, I look at architectural design as essentially the act of designing spatial experience. It is a mediation of spatial experience between buildings, people, and increasingly, information and communication technologies[3)] . In part of my exploration of design possibilities, I revealed the presence of wireless communication signals in space and gave them a tangible form. This practice is closest to the idea of sculpting with wireless connectivity, capturing the fluctuations of wireless signals in a dynamic sculpture.

The experience of space is challenged and explored through *experience catalyst* settings. Creating an *experience catalyst* means stimulating the process of understanding and the inferred-knowledge production through the careful design and manipulation of the aesthetic experience[4)] . The system I used for this manipulation uses the information on network traffic as the input and produces a tangible, observable change as the output. The system gathers information about the

1) Michael Biggs, 'Learning from Experience: Approaches to the Experiential Component of Practice-Based Research', *Forskning, Reflektion, Utveckling, Vetenskapsrådet*, 2004, 6–21; Hannula, Suoranta, and Vadén, *Artistic Research*; Badura, 'Experience Catalyst Research.'

2) Dourish, *Where the Action Is: The Foundations of Embodied Interaction*; Kristina Höök, 'Knowing, Communication and Experiencing through Body and Emotion', *IEEE Transactions on Learning Technologies* 1, no. 4 (October 2008): 248–59, doi:10.1109/TLT.2009.3.

3) McCullough, *Digital Ground: Architecture, Pervasive Computing, and Environmental Knowing*; McCullough, *Ambient Commons*.

4) Badura, 'Experience Catalyst Research.'

fluctuation of wireless signals through a special measurement tool that is related to the users of space and networks. This information is interpreted through changes in space , assigning an aesthetic value to people's interaction with connectivity. We could learn from this not only how much data is passing through the air, and how interesting, or not, this is to the people present. The experiments showcase the changing nature of people's perception and awareness of the act of communicating, and its relevance for the experience of space. It is an experimental way to challenge rational evidence through an aesthetic experience of environments and settings.

7.1.2. Out-bodied Interaction

Paul Dourish introduced the discussion on embodied interaction in the HCI field. He defined embodiment as "the property of being manifest in and as a part of the world" which "constitutes the transition from the realm of ideas to the realm of everyday experience"[5] . Dourish saw interaction as an embodied phenomenon. Interaction is part of the experience of the world "and that world [...] lends form, substance and meaning to the interaction"[6] . Interaction takes place within an unfolding pattern of purposeful activity, it makes this activity meaningful.

Over the course of several years, this view of interactivity gave rise to numerous experiments with tangible interaction. A notable example of this is the research done by the MIT Tangible Media Group, who sought to design new forms of interfaces between humans and digital information[7] . They envisaged different kinds of displays and interfaces that afforded awareness of activities in the surroundings, at the periphery of one's attention. While the information would appear on the ceiling or the wall next to the working desk, people would interact with these systems through bottles, analogue clocks, or hamster wheels. The Tangible Media Group was inspired by Mark Weiser's ideas of ubiquitous computing and a growing number of researchers looking for ways to exploit our physical and tactile skills in computing based on physical interaction[8] .

All these experiments (interactive desks, magic lenses and mutant objects) never became consumer products, whereas smartphones integrated most of these interactions in our daily activities. This is how the notion of *out-bodied* interaction came into being. As most of the

5) Dourish, *Where the Action Is: The Foundations of Embodied Interaction*.

6) Ibid.

7) Hiroshi Ishii et al., 'ambientROOM: Integrating Ambient Media with Architectural Space' (ACM Press, 1998), 173–74, doi:10.1145/286498.286652; Craig Wisneski et al., 'Ambient Displays: Turning Architectural Space into an Interface between People and Digital Information', in *Cooperative Buildings: Integrating Information, Organization, and Architecture*, ed. Norbert A. Streitz, Shin'ichi Konomi, and Heinz-Jürgen Burkhardt, vol. 1370 (Berlin, Heidelberg: Springer Berlin Heidelberg, 1998), 22–32, http://link.springer.com/10.1007/3-540-69706-3_4.

8) Bell and Dourish, 'Yesterday's Tomorrows'; Hiroshi Ishii and B. Ullmer, 'Emerging Frameworks for Tangible User Interfaces', *IBM Systems Journal* 39, no. 3.4 (2000): 915–31, http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5387042.

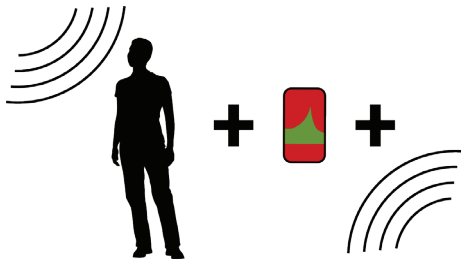

Figure 7.1 Out-bodied interaction. The experience of networks and space is mediated through a mobile device. Networks, people, devices and surrounding space are *interactants* in complex transactions that take place between them.

information we receive is served by our networked devices, we can say that our environment is increasingly interpreted by their processors, external to our body. This is apparent in cases of blindly following GPS navigation instructions, although there is an obvious perceived information of the cliff's edge, a sand pit or a tree in way[9]. We interact with the world through gadgets and sensors next to, and sometimes overriding, our own bodily senses.

An out-bodied interaction is a case of embodied interaction that establishes indirect interaction between information accessible to networked devices, people who use them and the space they occupy. An out-bodied interaction provides an immersive, embodied experience of an interactive installation while using external devices as mediators.

7.2. Probing the Networks: Interactive Design Prototypes

Everyday interaction with wireless networks mostly consists of connecting to an intermediary device (wireless network access point, a base transceiver station, Bluetooth an ad-hoc setup) in order to send or receive data from a remote location. All wireless communication systems, from radio transmission to near field communication, work against distance. Thus, they always act on space, enabling interaction between remote actors in real time.

Wireless network infrastructure can be considered both a technical and a cultural infrastructure. It provides connectivity on a technical level, but also plays a central role in the exchange of information in the contemporary cultural context. My approach to designing the prototypes stemmed from this two-fold relationship: at the intersection of aesthetics and

9) This kind of incident is commonly refered to as the "GPS tracking disaster" with numerous reported examples. A short and comprehensive list can be found for example in this article: Sarah Wolfe, 'Driving into the Ocean and 8 Other Spectacular Fails as GPS Turns 25 | GlobalPost', Global Post, 17 February 2014, http://www.globalpost.com/dispatch/news/business/technology/140217/worst-gps-fails-25th-anniversary.

technological developments, it included both the quantification of network traffic and the qualitative assessment of their experience. The work that followed was an exploration of the means to gather the right kind of data, and the means to represent them in a spatially effective form. It was an exploration of the paths towards a tangible experience of unstable infrastructures and reconfigurable spaces.

This process can be best described as *probing* of networks. Gaver, Dune and Pacenti defined cultural probes as packages "designed to provoke inspirational responses", a part of the strategy of "pursuing experimental design in a responsive way"[10] . The concept of a cultural probe is one particularly strong response to the question on procedures in *research through design*, or design *as* research. Probes afford insights that could not be extracted through observation or interviews; they afford inspiration and evade systematic analysis.

The idea of *probing* is particularly fitting for the exploration of cultural, social and technical aspects of wireless connectivity. Concerning *performativity*, I addressed this question through direct engagement with the phenomenon, constructing ways to interact with and experience network traffic load as a tangible phenomenon in space.

This approach is also close to what Krogh and colleagues identify as *probing*, one of five distinct ways in which research through design *drifts* through experimental activities[11] . The different

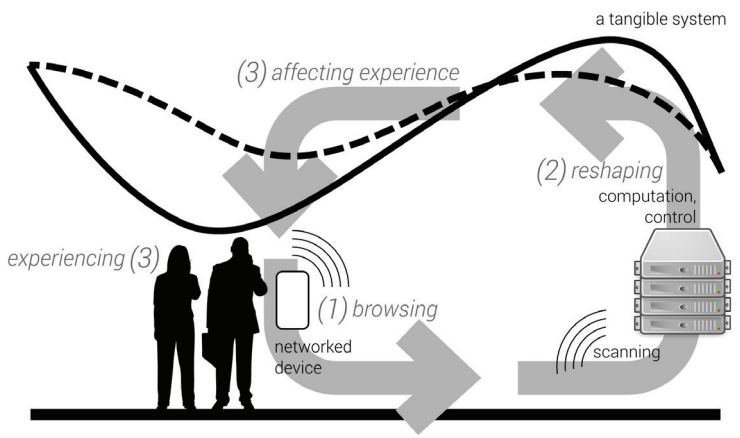

Figure 7.2 General interaction diagram. The use of network traffic (1) browsing activity is scanned by the system which controls the tangible system, by sending it instructions on how to (2)reshape, which in turn (3) affects the experience of space and communication.

10) Bill Gaver, Anthony Dunne, and Elena Pacenti, 'Design: Cultural Probes', *Interactions* 6, no. 1 (January 1999): 21–29, doi:10.1145/291224.291235.

11) Krogh, Markussen, and Bang, 'Ways of Drifting—Five Methods of Experimentation in Research Through Design.'

prototypes that emerged throughout this design process were attuned at tackling an increasing number of questions, raised by the initial research interests but also by previous prototypes.

With the intention to question space occupancy of wireless network signals, I devised a system that enables alternative interaction with wireless networks. This system uses existing traffic as a starting point for interaction between an object that acts on space (interactive architectural skin, light beams), and people who act on both space and traffic. I tested several different behaviours of the system, including deformations on a stretchable fabric, change of colour and position of light beams, or a combination of the two. In a general case, the system tracked network activity (Figure 7.2: (1) browsing), transformed it into a reaction of the interactive object and demonstrated this to the users of the system (Figure 7.2: (2) reshaping) who then reacted by changing their network activity pattern - e.g., created more traffic or stopped using it (Figure 7.2: (3) browsing).

I put the system through numerous tests and improvements throughout its development, at public presentations, exhibitions and research symposia. The different contexts of the presentations were not entirely planned in the function of the research process but consisted mostly of opportunities that appeared along the way. The experiments were framed partially by previous ones. However, they always had to include other variables, such as the changing context and audience of the presentation, as well as the development of data collection techniques (from Wi-Fi data packets to cellular and Wi-Fi traffic counting). I will describe six iterations of the process of prototyping. The prototypes were tested in different settings, in the lab space and in a public setting, at research symposia and with a general audience. I conducted the majority of the work on development within the SINLAB research project.

7.2.1. Gathering Data on Experience: Exhibitions, Symposia and Design Meetings

In the following text, I will discuss six prototypes, grouped into three generations: *RKNFG*, *Quadricone* and *Connect or Not*. I developed them for different testing situations and presented them to the public in different settings. These installations also collected data on users activity and served as a ground for discussion on user experience. By combining a qualitative interpretation of these discussions with network activity analysis of the results of these experiments, I gained insight into the complexity of cohabitation between humans, built structures and wireless infrastructures.

RKNFG

The first *experienceable* structure *RKNFG* was in the form of a cube, that can be entered into. The dimensions were sufficient to accommodate one person who would experience the change in the cube's height. The height of the cube corresponded directly to the activity of an open wireless network available in the gallery space. The movement of the ceiling created more space in the cube when there was more traffic. The cube was, in this way, performing the *conjunctive envelope*[12] , concentrating a person's network activity, Wi-Fi access points behaviour and the resulting movement of the ceiling, in its rectangular shape. This in turn stimulated the person to adapt their network activities (browsing, chatting, watching videos) to the cube's height. They could create more traffic in order to raise the ceiling, or intentionally stop communicating in order to lower it.

The present account is based on direct observations, I did not conduct any interviews or discussions on the spot. *RKNFG* was presented to a general audience at an art exhibition in Kulturhaus Salzamt, Linz, following the residency programme *Expand, Explore, Expose*. It was relatively simple but comparably effective in delivering the idea to visitors. People understood the interaction rules (use the network, create more space) and explored some unintended playful aspects (such as controlling the height externally while another person stands inside). It was not the only interactive artwork in the gallery. It nevertheless demonstrated a special case of interaction that was mediated through a device we sometimes feel internalised to our actions (smartphone).

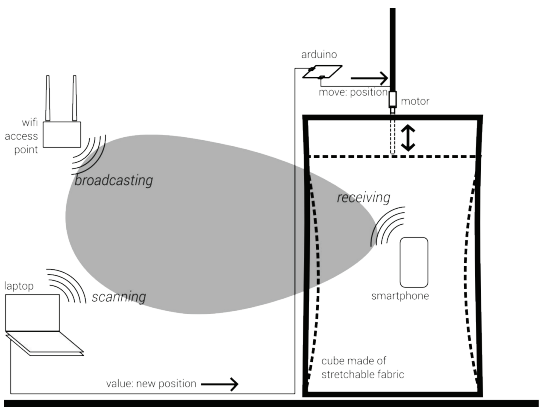

Figure 7.3 RKNFG at the opening of the exhibition 'Expand, Explore, Expose' in Kulturhaus Salzamt, Linz, Austria. The interaction scheme (left) describes the relationship between the main elements: Wi-Fi access point serving the traffic, a laptop scanning and controlling the height of the cube, and the interactive cube with changeable height. People found interesting ways to interact with it (right)

12) *The conjunctive envelope* is a term coined by Mackenzie in *Wirelessness*, used to describe the configuration or concentration of wireless infrastructures, space and data in time.

It emphasised this internalisation through defamiliarisation of an everyday activity much in the way Bell, Blythe and Sengers[13] discussed the *Food Individualizer*, *Viridian's aesthetic electrical meter* and general design against home-and-cocoon. Defamiliarisation of browsing occurred when one's action was attuned at raising the ceiling, no matter which Youtube video they watched; or when an intentional act of communicating resulted in an unexpected movement of the motors behind one's back.

RKNFG also pointed at aspects that I needed to improve or change. It was necessary to make the interaction more natural, through the inclusion of different types of network traffic or at least different wireless networks into the piece. *RKNFG* also showed that the range of the reaction needed to be significantly larger. I envisioned a more complex form for the next prototype, with the intention to more truly represent the complexity of wireless environments.

Quadricone

I further elaborated the idea of the *conjunctive envelope*, through a wavelike form that resembled standard representation of sound or other oscillations. I applied Wi-Fi traffic dependent deformation to the initial, relatively regular waved form. The curious case of Le Corbusier's form-finding methods was partially informing this decision. When looking for inspiration for his *Poème électronique* (Electronic Poem), commissioned by Philips for their 1958 Brussels World Expo pavilion, Le Corbusier was interested in novel ways to generate form[14] . His main collaborator

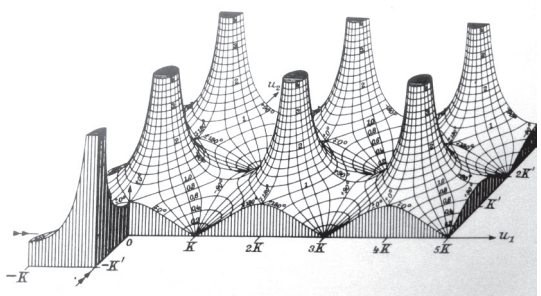

Figure 7.4 Form-finding methods with pure aesthetic consideration: three-dimensional representation of a mathematical function: "Relief on the doubly periodic function cn u for k=0.8", used in Eugen Jahnke and Fritz Emde, Tables of Functions with Formulae and Curves. From Marc Treib, *Space Calculated in Seconds: The Philips Pavilion*, Le Corbusier, Edgard Varese (Princeton, N.J: Princeton University Press, 1996).

13) 'Making by Making Strange: Defamiliarization and the Design of Domestic Technologies', *ACM Transactions on Computer-Human Interaction* 12, no. 2 (1 June 2005): 149–73, doi:10.1145/1067860.1067862.

14) Marc Treib, *Space Calculated in Seconds* (Princeton University Press, 1996).

on the project, Ianis Xenakis pioneered the use of mathematical models in music. Le Corbusier thus searched for mathematical functions that had an interesting volumetric representation. He consulted books on curves generated by different mathematical functions, on example shown in the Figure 7.4.

Le Corbusier's purely aesthetic concerns for mathematical models inspired me to challenge this intentional ignorance when designing the experience of space. Which volumetric form best describes the activity of wireless networks? How does the disposition of the interacting elements maximise their spatial effect and how far can it be from mapping to an actual dataset? Do we expect a surface that describes wireless network activity to be also their map? I addressed these questions with the interactive structure that had four arbitrarily positioned dynamic points on a deformable surface. The disposition of these points was in no relationship with their geographical location so that the experience of interaction would move from the idea of an accurate representation towards interpretation. I expected this to path the way for the *active form*[15] to emerge.

I designed two Quadricone prototypes, intended them for two different presentations. The first one, a scaled model, was part of a presentation at a research symposium, *Stage Digital – A*

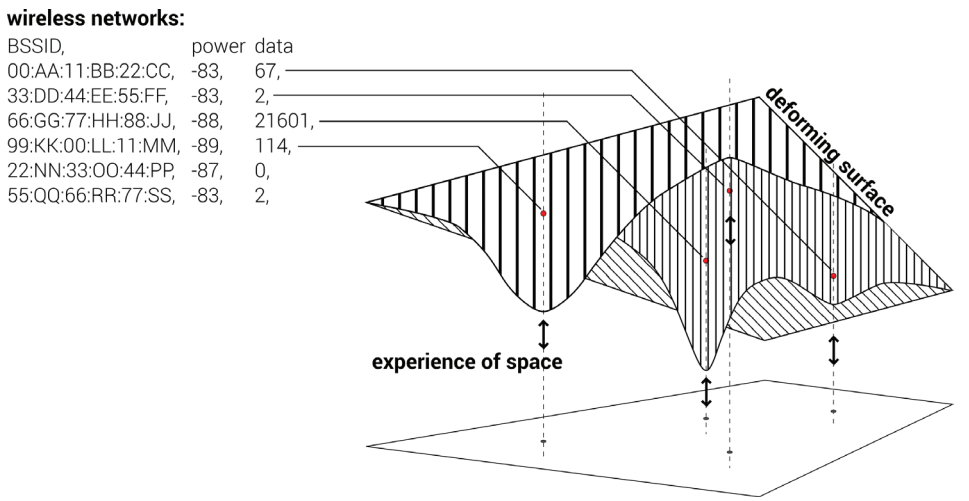

Figure 7.5 The design of active form. Four points distributed over a surface that move according to the amount of data, deforming the surface

15) According to Easterling, whose writing on the active form was discussed in chapter 3: *Connectivity in action / form*, active form is the expression of activity and not its representation.

Scenographic Expedition. It needed to be transportable and easily installed. The large installation of an inhabitable size was part of an exhibition on SINLAB's research prototypes, within the festival on contemporary cultural practices, Les Urbaines.

Both the scaled model and the large installation used stretchable fabric as the deforming element. The changes in the surface were produced by linear movement propelled by motors that picked up the surface at the four designated points. The movement of each point was determined by the activity of a single Wi-Fi access point. I expected that this amount of deformation would create enough room for complex, ineffable form to emerge, while preserving readability of interaction through the limitation to only four networks. Depending on the dynamic quality of the actual traffic and the system's ability to pick it up (access the information on the number of packets), the resulting impact on spatial experience was more or less pertinent and convincing.

Quadricone, Bühne A, Zurich, November 2012

The first *Quadricone* prototype introduced more formal complexity, but on a smaller scale than the first experiment, *RKNFG*. This model, 1m long and 50cm wide, represented activity of four neighbouring access points, by movement of one of four peaks. The distribution of the pick-up points was not mapping the properties of networks neither by intensity nor geographically. I wanted to avoid direct mapping in order to underline character of this structure, which was beyond a visualisation and aimed towards creating an interesting spatial experience. The model offered a bird's eye view on the phenomenon, its scale limiting immersion to imagination capacities of the observers.

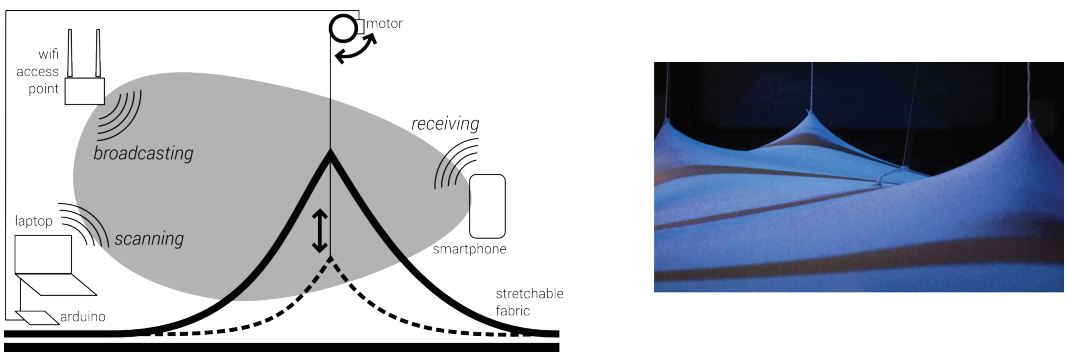

Figure 7.6 Quadricone: the scaled model presented at Stage Digital – A Scenographic Expedition research symposium, Bühne A, Zurich, Switzerland. The interaction diagram (left) shows how the possible states of the stretchable fabric (solid or dashed line) when deformed by the rotation of the motor above it. While a person is using network traffic, a laptop is scanning the amount of traffic that passes through the access point and sending instructions to the motor. The actual form obtained through this system is shown on the right.

When I presented it at the *Stage digital* research symposium, the model allowed for a successful demonstration of the envisioned interaction. The shape was dynamically changing and reacting accurately to the intentional activity of the audience. One could also see when he or she was affecting a particular cone on the surface through their activity. More people could take part in this, adding to the complexity of the shape. This presentation was documented on video and the transcription of the discussion is available in Appendix 2.1 *Quadricone, Bühne A*.

The audience made of researchers in the field of theatre and performance studies, interaction design and architecture quickly took the discussion to the question of representation: whether the model was supposed to represent reality or account for it? Some interpretations such as "the space that wants your attention" were close to my intention. Others focused on the exteriority of the input data, pointing to the arbitrary connection between the nature of the information (wireless network traffic) and its representation (movement of the cones on a stretchable surface). The limited engagement opportunity – through an external device that transmits data packets was seen to obstruct human agency. Besides the obvious lack of opportunity to affect the shape by one's own body, the envisaged interaction in reality quickly exhausted the possible changes to the form.

The discussion was open and profound, with plenty of suggestions how the work could be improved. It centred around design decisions and not on the experience that the system could provide. Interestingly for my experience as a researcher and designer, the reception of this prototype was far more critical than the previous or the following one. This was at least partially due to the scale of the prototype that discouraged the actual physical experience. The direction the discussion took was also influenced by the composition of the audience, made of research professionals attuned at critically assessing the work and its possible outcomes.

An evident flaw in the design was the idea of a *range* of reaction. As it was pointed in the discussion, reality has no range and the limited movement of the motor was indeed incompatible with the design intention. I was going to address this in the following iteration of prototypes, through the use of a looping colour change. Next to the range, the fact that people had to switch from their preferred service (3G to Wi-Fi) in order to engage with the traffic hindered interaction at the entry point. Accounting only for Wi-Fi data packets was insufficient for an image of people's activity within the wireless communication layer.

Quadricone, Les Urbaines, Lausanne, November 2012

The second *Quadricone* prototype engaged a larger piece of space and interacted with users of four wireless networks. The surface of the fabric was stretched over an area of 7 by 2.5m so that visitors could stand directly underneath the reconfiguring surface. Four points of deformation were again not in a relationship with the geographical location or any other property of the analysed wireless networks. They were, rather, established with the intention to facilitate passage under the surface, and at the same time maximise its spatial effect through diversity of shapes that would be achieved in deformations. Because *Quadricone* was not intended as a visualisation of network activity but to facilitate its interpretation, it was important to avoid direct mapping of data onto the surface.

The installation was presented to the general audience at a festival of contemporary culture, *Les Urbaines*, held every year in Lausanne. It was part of an exhibition that showcased a number of SINLAB research projects in a gallery space. The discussion was not specific to the research question and it was not recorded. Observations I present here are the result of direct observations and short conversations with exhibition attendees.

While the scale of the prototype was sufficient to allow physical interaction with the *interactive skin*, the situation with wireless networks was quite the opposite. The scanning system could capture only very little or no traffic and the networks available in the gallery space were all protected with passwords. We had no access to any of them, which made direct interaction practically impossible. Because of this, I attuned the system at scanning for beacon frames instead

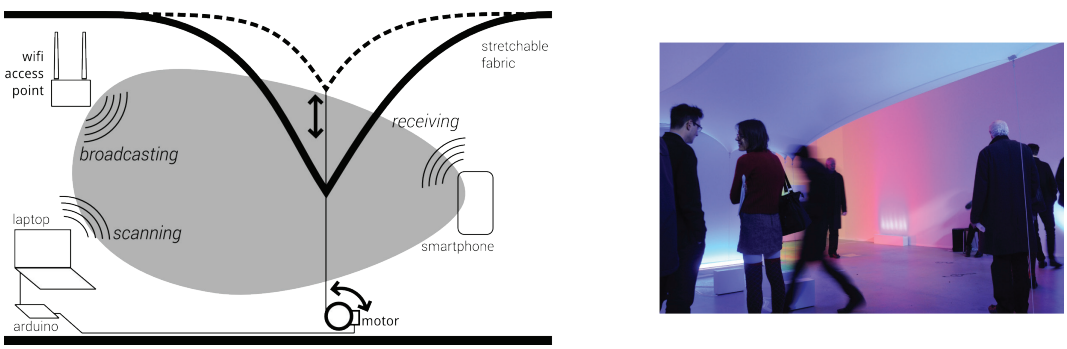

Figure 7.7 Quadricone at Espace Arlaud: Stretchable fabric fixed above the visitors. Les Urbaines festival, Lausanne. The visitors could walk under the structure and be affected by the changing height of the peaks. The mechanism is shown on the interaction diagram (left), the thicker line (solid or dashed) showing possible states of the stretchable fabric, caused by the rotation of the motor on the ground, which is in turn controlled by the amount of traffic passing through an access point – analysed on a laptop.

of data packets[16], in order to keep a dynamic component of the installation. As the time interval between beacons was theoretically affected by distance, the installation was able to capture something of that particular wireless environment.

Having no direct interaction with the installation has actually proved more honest to the work. Wireless network traffic is beyond our control and we do not want to re-engage with it while it serves its primary purpose (browsing or making a phone call). People clearly noticed the surface moving and were trying to make meaning of its movements. Some of them observed the behaviour for a while, trying to identify a pattern. Some tried to generate traffic and see if that would change something in the installation. Others demonstrated the tendency to mystify the movement of the peaks, recognising that it tells about a "secret" knowledge we have no access to (in this case, how often do access points try to communicate to other devices). Regardless the attitude, I can conclude that the experience of the installation was more diverse when people were trying to interpret the relationship between movement and possible cause than when this was made explicit through a presentation (as with the *Quadricone* model). The cultural context of an art exhibition also helped forge engagement and focus on experience.

Connect or Not

The third generation of prototypes, *Connect or Not,* introduced a new way of gathering data. It also introduced a new approach to design. It began with abandoning the physical structure entirely, in favour of atmospheric effects achieved through interactive illumination techniques. Previous experiments have shown how difficult it can be to detach form from (data) representation. Thus, the idea of expressing wireless communication activity through performance of lights emerged. This idea led me to focus on the design of lights behaviour (or as Easterling put it: "what an organisation will be doing"[17]) instead of formal representations of network activity. The light behaviour could, in turn, deliver a more diverse and dynamic outcome than the predetermined linear movement of points deforming a surface. The lights that continuously changed colour and position performed network actions in a fluid way, closer in their character to the ephemeral phenomenon they interpreted. They also permitted to depart from the idea of *range* in the systems reaction, which proved problematic in previous prototypes. The lights, however, required something to be projected on, be it a wall, a screen or artificial fog. This choice was very important for the resulting experience of the installation. For the final version of *Connect or Not*, I combined the interactive system developed for *Quadricone* with programmable lights, in order to concentrate and compare their abilities to influence the experience of space.

16) Beacon frames are sent in regular time intervals to communicate basic information regarding the communications process with a wireless network access point Geier, '802.11 Beacons Revealed.'.

17) Easterling, *The Action Is the Form. Victor Hugo's TED Talk*.

The system for gathering input on network activity was more sophisticated than in the previous prototypes. Instead of listening for data packets or beacon frames sent by Wi-Fi access points, *Connect or Not* used an Android application (*Connect or Not*) that acted as a network traffic counter for multiple services and protocols (cellular – GSM and UMTS, Wi-Fi). Besides this, the system was able to track users (devices) position, introducing spatial relevance into the reaction of the system.

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message ID; user ID (anonymised); timestamp; bytes; minutes (talk); number (sms); position;
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Figure 7.8 Format of the messages sent to the remote server by the Connect or Not app. They contain measurements from all the values that are monitored since the last reading

Connect or Not, Bühne A, Zurich, November 2013

The design of *Connect or Not* rendered the presence and the intensity of traffic into a dynamic change of lights. At the presentation on the Stage Digital II research symposium, the system consisted of two high power LED light spots that were interpreting the type of communication (Wi-Fi or cellular traffic) and its intensity. Following the insight from previous discussions on the *range* of reaction, I designed the light behaviour so that it circulates between two end-states in a *colour loop* (red to purple to red for cellular communication, green to yellow to green for Wi-Fi). The speed of change was proportional to the amount of traffic.

Instead of inviting visitors to interact with the installation, two presenters unfamiliar with the system demonstrated the interaction. They had simple instructions - to generate traffic by watching videos, uploading photos and communicating with each other via phone calls or instant messaging. They also had phones with the Android application pre-installed.

According to the feedback from the presenters, their experience was divided between the atmospheric character of the installation and the lack of outside perspective to observe the changes they were causing. The audience observed the colour of the light bringing data to the skin of the actors. They were interested in its performative possibilities and deeper interpretation. They suggested an even more fluid data input (such as knowing when someone is typing), allowing interaction to be more immediate.

The audience was made mostly of researchers in the field of stage design, performance and theatre. In terms of discussion and feedback, there were much less concrete suggestions on the directions to take and improvements to make. The questions were more attuned to possible interpretations of the work than to design decisions made in the meantime (some of the audience members already participated the presentation of *Quadricone* model at Bühne A the year before). Possible future directions in the stage context were discussed, such as the ratio of “being in”

(immersed) and "being out" (observing) or coupling with other design artefacts (full transcript in the Appendix 3.1)

This presentation made it very clear that interacting with network traffic beyond the purpose of communicating is simply unnatural. It is harder to intentionally produce traffic in order to "serve" an interactive piece than it is to produce the same traffic while communicating. This insight emphasized seamlessness of wireless communication which is broken in this setup.

I decided to push the unnatural quality of interaction even further, in order to emphasize the non-utilitarian character of the prototype. *Connect or Not* was not a visualising machine but a system that interprets wireless communication signals beyond their utilitarian purpose. While the design approach was getting closer to the idea of designing *active form*, interaction with it was as seamful and unintuitive. This necessitated further exploration of the different levels of attention and awareness given to the system's activity.

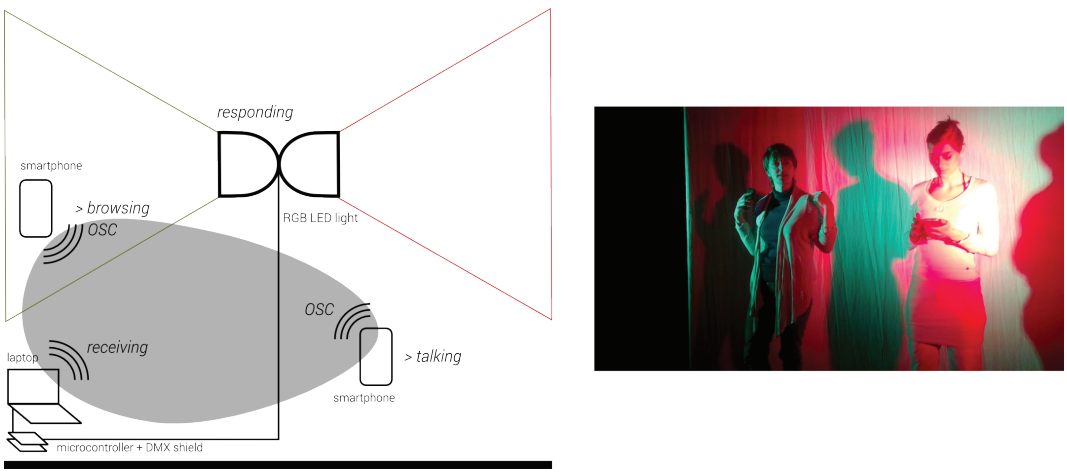

Figure 7.9 Connect or Not presentation at Stage Digital II – The Making of Atmosphere research symposium, Bühne A, Zurich, Switzerland. Two RGB LED lights (left) were used to interpret the type and amount of network traffic, created by the two presenters (right) who were browsing, texting and uploading images on smartphones with Connect or Not application pre-installed. The application would stream data on network traffic back to the laptop running an OSC server and controlling the state of the lights.

Connect or Not, MMC Zavod K6/4, Ljubljana, February 2014

The Ljubljana presentation was a participative version of the previous demonstration. Network activity of the audience determined the system's behaviour, using the *Connect or Not* application. The application was published by the SINLAB in Google Playstore shortly beforehand and thus available to the general audience. The installation used light projectors that had the

ability to change both colour, intensity and position of the light beams. The use of artificial fog reinforced the atmospheric character of the installation. This made the movement of light beams more visible and added to their perceived materiality, allowing them to influence the experience of space in a more tangible way.

Instead of talking to each other, visitors of this event were consumed by their power to affected dynamic change of lights in a closed, dark space. I briefly introduced them into the system and they quickly picked up the interaction principle. Their interaction with each other revolved mostly around interacting with the system together. The isolated space where the installation was presented allowed users to focus on the experience, without external distractions. They observed reshaping of the ambience, and sometimes felt they could take control over the ambience behaviour.

According to an interview conducted with the participants subsequently, the behaviour of the lights was somewhat confusing as they could not tell which ones were related to their actions. Some users were not very familiar with the "language" of the installation and did not know what to look for. Those who participated the workshop I gave earlier, clearly saw the reactions of the system related to specific network activities. They were compelled by both observing their own actions and the activity of others.

Self-identification of the visitors was recognized as an important goal. Feedback from the users clearly stated that people expected to be able to tell when they were affecting the system.

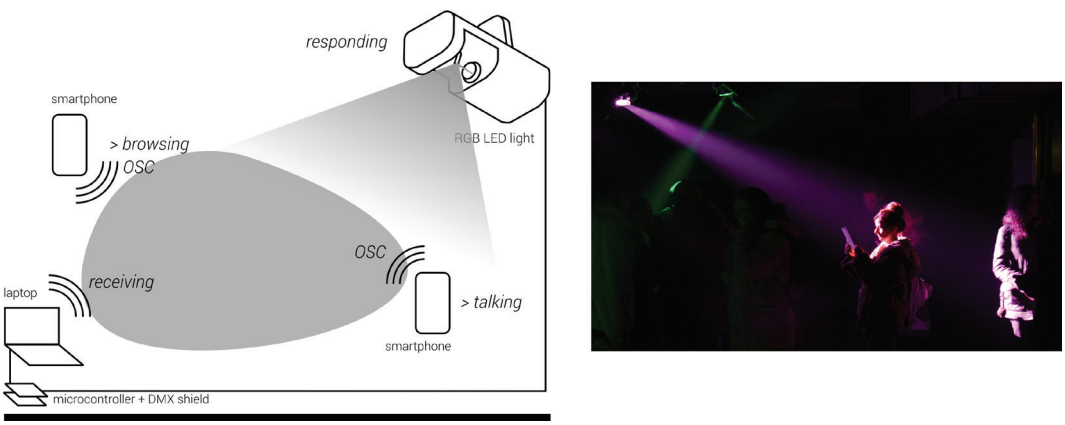

Figure 7.10 Connect or Not in Ljubljana, Zavod K6/4. Light beams and fog interpret wireless network activity. Connect or Not uses the application installed on smartphones that broadcasts information on network traffic using the OSC protocol on a Wi-Fi network; a laptop running an OSC server receives the messages and sends instructions to the lights (left). The visitors are consumed by their ability to affect the system. (right)

For this purpose, and in order to make the system's reactions more spatially relevant, position tracking was added to the list of Android application's functionalities to be developed.

The absence of a fixed form or a tangible object to interact with turned the whole space into an *interactant*. I defined the light behaviour in function of type and intensity of traffic. This contributed to the idea of an active form that expresses activity, the form being at the same time visible and difficult to grasp (light beams moving across space). The visitors did not perceive the language of light changes as specific to the wireless communication as the source of information. This was in contrast with previous observation on the fit between the ephemeral character of light and wireless network signals, both of which propagate like waves. Perhaps the contradiction stems from the different perspective and experience with wireless communication I gained over the course of this research, comparing physical structure, light beams and ephemeral signals. Thus, I decided to include both a physical interface – the stretchable fabric – and light changes in the following prototype in order to test their combined ability to influence the spatial experience of visitors.

Connect or Not, IST, Pavilhao CIVIL, Lisbon, September 2014

The Lisbon installation combined tangible surface deformations and ephemeral light effects. It included an interactive tent structure used previously in the *Quadricone* installation, connected with custom designed LED lamps whose reaction was coupled with that of the motors. This version of the installation also made use of Estimote location beacons to provide low resolution position tracking and user self-identification based on positioning. The result was an interactive architectural skin attached to the ceiling, whose form and colour changed based on the input from data on the use of wireless network traffic. Starting from a regular arcade as one of the basic architectural forms, the skin would deform with the use of cellular and Wi-Fi traffic.

The installation was set up in the atrium of the Pavilhao Civil building on the IST Alameda Campus. Students of architecture and computer science, doctoral researchers and faculty staff attended the presentation on Connect or Not as an experience catalyst, after which it was open to general public. I collected feedback from all visitors who tested the installation.

They perceived it as a novelty, something they had not seen before. A number of respondents installed the application and performed basic interaction with the system (browse; look up; recognize the peak lowering; repeating those actions). Contrary to my expectations, they did not try to do it in groups or pairs, each interacting with the system individually.

Self-identification was related to position tracking. I expected that once the users see the part of the installation closest to them move, they will know it was their actions that provoked it. However, the tracking system was not quick enough to create this connection, often indicating the reaction came from a place the user was standing a few seconds ago.

The respondents saw the scale and position of the installation in the big space as inadequate; the atrium was too big and the activity in it too distracting to allow for a focused experience of the piece. It was hard to affect the experience of space that measures 30m in length by a 6 by 2m installation. Nevertheless, once in its proximity, the reactions of the system were observable and logical.

This presentation opened more threads than it closed. Perhaps due to the decision to mix two previous developments, perhaps due to the character of the respondents (e.g. doctoral students in architecture) the reception was very critical and centring again on design decisions and possible improvements to design. They made a number of constructive propositions on possible directions to take. These include installing the piece in a more intimate, smaller space where it cannot be observed from a side; using other outputs such as sound; using less abstract shapes and trying to embed the meaning into the way data is represented; working on an smoother self-identification through assigning colours to individuals, for example. These suggestions could be implemented in the future development of the work, should there be one. Although they came at the end instead of the beginning of the design process, they make a significant contribution to its understanding. Having a clear reference space – be it a cube (*RKNF*) or a room (*Connect or Not*, MMC Zavod K6/4, Ljubljana) was important for engagement with the installation. When the reference space was too big, more expressive behaviour of the system had less of an effect. Even the tangibility of the

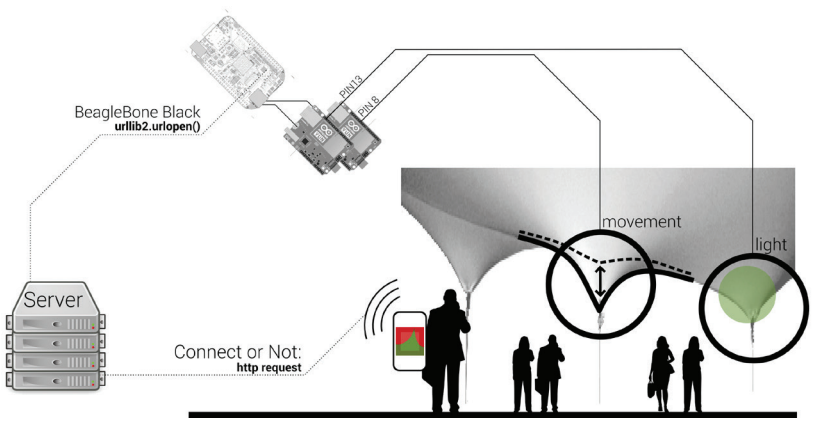

Figure 7.11 Connect or Not, Lisbon, Pavilhao Civil. Stretchable fabric acting as an interactive architectural skin. Information on network traffic is collected per user, through the Connect or Not application. The system reacts by the movement of stretchable fabric and change in colour and intensity of lights. While in the area of the structure, visitors are affected by these changes. The position of the smartphone is estimated using a set of Bluetooth beacons, and the changes in fabric and lights are calculated according to this estimation, working towards self-identification of the visitors.

experience is linked to the scale in a similar way. While one could feel the movement of motors and touch the stretchable fabric, the possibility to make a distance from it resulted in a less immersive experience.

7.2.2. Connect or Not – Collecting Data on Network Traffic

Interaction with wireless network traffic would not be possible without the ability to measure that traffic in some way. In order to quantify the relationship between the use of data and space where it occurs, I opted for a per-device measurement strategy, using *Connect or Not* Android application. The application gathers usually unrelated quantities: data consumption by smartphones and their location. It is an attempt to bridge the gap between the intangible world of digital communications and their physical representations.

I developed the *Connect or Not* Android application in collaboration with the master student Louis David Jean Magarshack. In its first version, the application was counting network activity and broadcasting it over OSC (Open Sound Control) protocol. We introduced a position tracking system later, together with remote server communication. Position tracking is based on two technologies that work together, but are not mutually dependent. One is a set of Bluetooth light energy beacons produced by Estimote, which allow for low-resolution positioning within a previously tagged space. The other is a system based on Wi-Fi fingerprints, which uses Redpin indoor positioning system as a base for triangulating position with a precision of about 1 - 2 meters.

The development process centred around structural and design choices that would demand minimal engagement from the user while providing data on traffic and movement of the device. Throughout the work, public demonstrations I described previously in this chapter offered the possibility to test and improve the application. A significant part of the development was guided by findings from these demonstrations. I will describe these steps chronologically: gathering data, making it interactive, adding localization.

Gathering Data

Wireless signals spread within buildings and in the surroundings in a way that is an approximation between the ideal signal propagation and the actual permeability of buildings. To study the relationship between built structures and seamless infrastructures, we put our focus on the distribution of wireless signals in space and their load (the amount of traffic). Options here were the following: universal traffic sniffers or smartphones. We decided on the latter because of their ubiquity and because sniffers are largely viewed as intrusive and illegal

in Europe[18]. Additionally, smartphones now represent a large part of the global internet traffic and their intrinsic mobility offered interesting further developments[19]. We thus evaluated signal traffic load per device, through the use of a traffic counter Android application that tracked calls duration, the number of text messages and bytes of Internet traffic. We gave the application the same name as the prototype it worked with, *Connect Or Not*. It is available in Google Play Store[20] since January 2014.

The first step towards implementing the system was to efficiently evaluate network traffic. The main existing application that caught our attention for this step is called *NetCounter*[21]. It was written by Cyril Jaquier and released in the Google Play Store in 2010. Its goal was to facilitate tracking of data usage for its users (for example to avoid going over a monthly data cap). It is open-source, well written, easy to understand and published under the GPLv3[22] license, all of which were key to building an application from a solid base.

The key difference from the original *NetCounter* application is that we wanted to gather information from multiple phones, therefore we needed a way to make our application communicate with a central server in charge of aggregating the data. The server would communicate with a system that was actuating lights, sounds or other appropriate effects.

The first approach that we implemented was using Open Sound Control (OSC)[23] protocol. It allowed the phones to broadcast messages through a Wi-Fi network, which we could then gather using a laptop connected to the same network. OSC uses the User Datagram Protocol (UDP) for communication. UDP is a connectionless transmission model that transfers messages (datagrams[24]) through the Transport Layer in a time-sensitive way, thus favouring prompt transmission over guaranteed delivery. This was important for the proof of concept of our application, as the transmission interval was short and real-time was preferable to delayed information.

18) Directive 2002/58/EC grants European citizens a right to privacy of communications and discourages packet sniffing techniques required to gather information on network traffic http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002L0058:en:HTML

19) Teltscher et al., 'Measuring the Information Society Report 2014.'

20) https://play.google.com/store/apps/details?id=net.lmag.connectornot, http://connectornot.emperors.kucjica.org

21) https://play.google.com/store/apps/details?id=net.jaqpot.netcounter&hl=en

22) https://www.gnu.org/licenses/quick-guide-gplv3.html

23) http://opensoundcontrol.org/introduction-osc

24) According to RFC1594 from March 1994, datagrams are "self-contained, independent entity of data carrying sufficient information to be routed from the source to the destination computer without reliance on earlier exchanges between this source and destination computer and the transporting network."

With the design of the back-end, came the first distinctive User Interface (UI) for our application: a single button that would allow the user to start or stop capturing and sending data.

The biggest issue we faced in the first demonstrations of the application as the data gathering system was setting up the environment. We had to either bring phones with the application pre-installed or install it on participants' phones through "USB debugging", which required plugging the phones into a laptop one by one. We solved this by publishing the application in the Google Play Store for the first time. This made it extremely easy to distribute for later experiments.

A second setup inconvenience was that due to the nature of OSC. The OSC server gathering data had to be on the same Wi-Fi network as the smartphones sending it. The smartphone users would in turn have to make sure they are connected to a Wi-Fi network, even if they relied on Mobile data transmission for their access to the Internet. We addressed this issue by reworking our communications to use HTTP and JSON that allowed the phones to send all information anonymously to a remote server using an HTTP request.

Position Tracking

To make our system more relevant for studies of space and its use, we decided to tie location information to our previously available data on network traffic. The challenge here was to get sufficient precision to allow us to identify different areas in a single room.

Bluetooth Beacons

Bluetooth Low Energy (BLE) was introduced in smartphones and tables as part of the Bluetooth 4.0 specification in 2010[25]. One of its goals was to allow easy indoor positioning through small, battery powered and, as the name implies, low-energy consuming Bluetooth devices.

Since then multiple companies and start-ups started manufacturing devices capable of emitting beacons at regular intervals using Bluetooth. We got to test two different products while working on a different project called Pocket Campus[26]. The goal there was to count people and estimate queuing time on the EPFL campus. We first tried working with devices from StickNFind, sadly those were unreliable and we turned to another company called Estimote[27]. We were now able to map a room by placing beacon emitting devices in it. The phones could receive those beacons and associate them with their data on the use of network traffic before sending a message to our remote server.

25) http://www.bluetooth.com/Pages/Bluetooth-Smart.aspx

26) http://www.pocketcampus.org

27) http://estimote.com

The benefit of this method is that once the beacons are in place, space is mapped with a precision depending on beacons settings (their broadcast range can be between 1.5 and 20 meters). The main issue with this method is that BLE capable smartphones were still not widely spread at the time of implementation (July 2014), limiting the reach of our efforts in this domain. Secondly, the mapping of space was limited to the number of beacons we had – three.

For these two reasons, we chose to use an additional indoor positioning system that could rely on existing infrastructure.

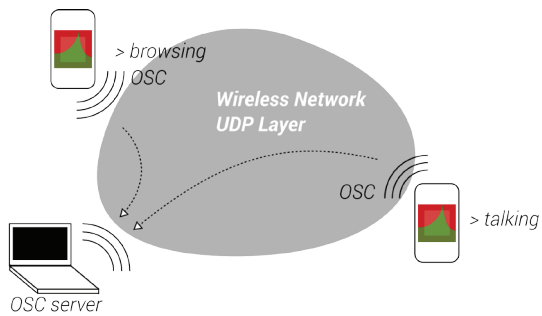

Figure 7.12 Information centralisation through OSC in v1.1. Two smartphones sending messages with data on their use of network traffic over a wireless network. Messages are received on a laptop running an OSC server.

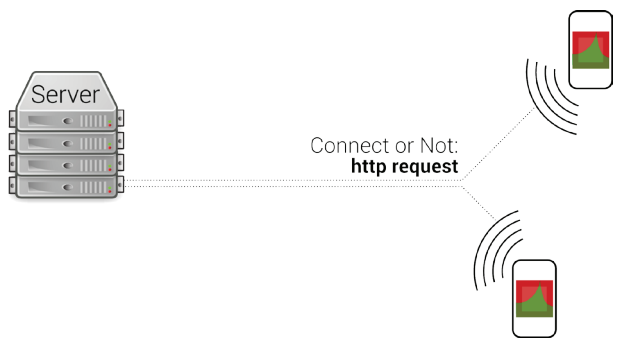

Figure 7.13 Communication scheme since version v2.1. Two smartphones are sending messages with data on their use of network traffic using the HTTP request method which updates a database on a remote server.

Indoor Positioning using Wi-Fi Fingerprints

We looked at various possible solutions here: Indoor Maps by Google[28], Wifi Compass[29], Loc Lizard[30], Foot Path[31], iDocent[32], Redpin[33]. After setting up and testing the aforementioned solutions, we decided on Redpin because of its clean code and the research papers attached to it that helped us understand the system. It comprises two parts: firstly the app on the phone that will scan neighbouring Wi-Fi networks and their strength, creating a database of fingerprints. Secondly, the server that will make use of a Support Vector Machine (SVM)[34] to classify readings into predefined regions. We thank Chih-Chung Chang and Chih-Jen Lin for their implementation of SVM[35].

To get localized by the Redpin system, some setup is needed:

- Upload a picture of the place of interest to the server.
- Fingerprint as many areas as you would like.
- Press "Locate me" button in the app.

Fingerprinting consists of scanning for surrounding Wi-Fi networks and Bluetooth devices while standing still. The key idea is that the set of networks in a given spot is enough to identify it uniquely[36]. Pressing the *Locate me* button on the phone will trigger a scan of the environment that will produce a reading that can be sorted by the server into a predefined fingerprint.

This required a lot of interaction from the user, which we wanted to avoid. So we decided to do the scannings in the background and to leave the option to upload and fingerprint a new map in the menu.

One thing we noticed after the initial testing is that the sorter would have trouble finding the right location because of fluctuations in network strength. We addressed this by offering the

28) http://www.google.com/maps/about/partners/indoormaps/

29) https://code.google.com/p/wificompass/source/checkout

30) https://github.com/metmuseum-medialab/indoor-positioning/tree/master/loclizard/loclizardapi-alpha-4.02

31) https://github.com/COMSYS/FootPath

32) https://code.google.com/p/ece480team2/source/browse/?r=11

33) http://redpin.org

34) http://www.support-vector-machines.org

35) Chih-Chung Chang and Chih-Jen Lin, 'LIBSVM: A Library for Support Vector Machines', *ACM Transactions on Intelligent Systems and Technology* 2, no. 3 (1 April 2011): 1–27, doi:10.1145/1961189.1961199.

36) Philipp Bolliger, 'Redpin - Adaptive, Zero-Configuration Indoor Localization through User Collaboration' (ACM Press, 2008), 55, doi:10.1145/1410012.1410025.

possibility to consolidate fingerprints with more readings. This offers the user the possibility to confirm our localization attempt; if they choose to do so we then add the reading to an existing class, thus making SVM more precise. For this improvement to be useful, we must spend some time teaching the algorithm: getting locating multiple times and associating the readings with correct fingerprints. Other improvements could be made by using information from other sensors of the phone (accelerometers, gyroscope)[37].

Application Overhaul

In the final stage of development, we spent some time improving the user interface of the application. The goal was both to improve ease of use and general aesthetics. We followed standard flat design approaches for an improved look and feel.

We also reorganized the buttons to make better use of the screen real estate and to make the most often used functionalities (switching modes, localization, data reset) more accessible. The rest of the options are to be found in the main menu.

Finally, we added an onscreen menu button for phones that do not possess a corresponding physical one. This was done in order to avoid any future inconveniences as the industry moves forward with new guidelines.

Learning from the Connect or Not Application

The Connect or Not app is a tool that actively captures smartphone usage of cell towers and Wi-Fi traffic exchange. It relates this data to a physical location. It is able to periodically gather call duration, the number of text messages and data usage from the phones, associate a location to those values and send this bundle to a remote server. The server stores this information and allows its use for interactive demonstrations, as we have seen in the previously described work.

The communication model (transferring data to a remote server via HTTP instead of OSC transmission) proved to be a good choice, as it allows for simultaneous logging and use of data in the interaction. It also surpasses the divide that exists among smartphone users based on their preferred network service (3G and 4G or Wi-Fi).

We did a series of tests to compare BLE and Wi-Fi positioning as well as to see if we were indeed able to improve the localization offered by the original Redpin. For this purpose, we placed three Estimote devices in our office and defined Wi-Fi fingerprints for the same areas. The advantage of BLE is that it does not require any user interaction at all. The Bluetooth beacons are read and sent

37) Philipp Bolliger et al., 'Improving Location Fingerprinting through Motion Detection and Asynchronous Interval Labeling', in *Location and Context Awareness*, ed. Tanzeem Choudhury et al., vol. 5561 (Berlin, Heidelberg: Springer Berlin Heidelberg, 2009), 37–51, http://link.springer.com/10.1007/978-3-642-01721-6_3.

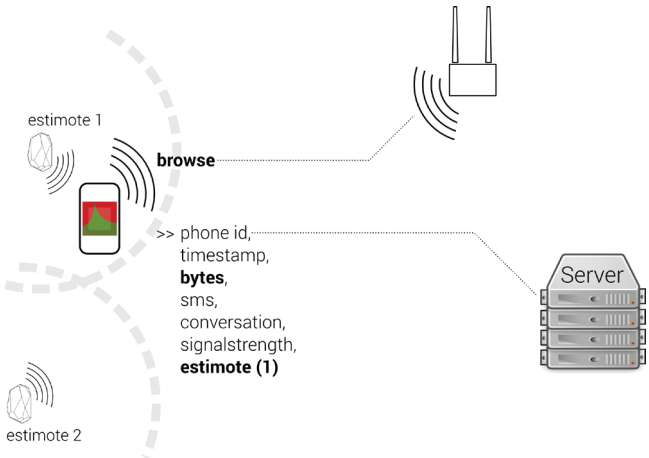

Figure 7.14 Communication diagram of the application. While the smartphone is browsing, it sends messages to a remote server in regular intervals. These messages contain infromation on it's id, timestamp, amount of traffic and nearby Estimote beacons

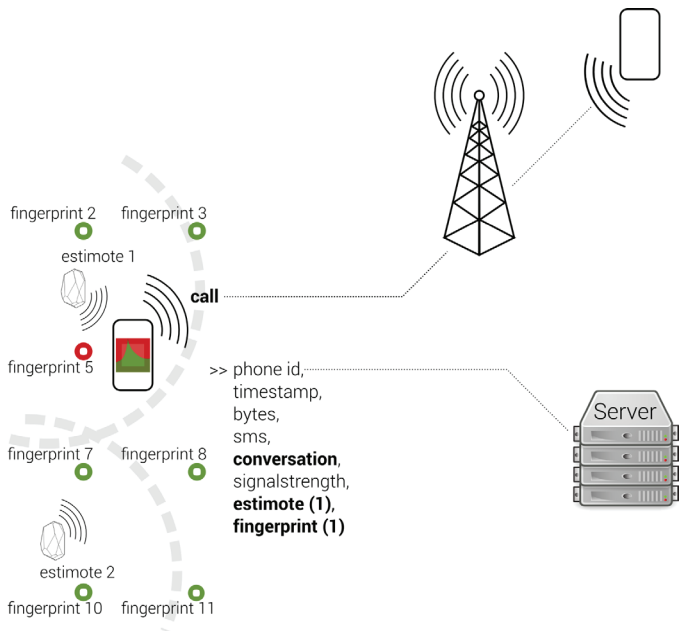

Figure 7.15 Communication diagram of the application with Wi-Fi position tracking added. While the user is making a call, the smarphone sends messages to a remote server in regular intervals. These messages contain information on it's id, timestamp, amount of traffic, nearby Estimote beacons and Wi-Fi fingerprints

by the phone without the user noticing. The advantage of Wi-Fi fingerprints is that they rely on an existing infrastructure and there can be as many as the user likes to make.

We conducted several measurement tests in the lab to track if and how the system was improving. We walked around with a smartphone to see which system would perform better. Consistent with the findings of Zhao and colleagues, BLE did better than Wi-Fi fingerprints in the first set of measurements[38] . It succeeded in following the actual path (marked yellow) in proportion to their limited number (three devices only, indicated in Figure 7.16 in red). Wi-Fi localization (Figure 7.16, indicated in green) did not prove very dynamic in these first tests. The precision we got from the Estimote beacons was in the order of a few meters and the number of areas we could identify was limited by the number of devices we had bought.

Although the study by Zhao and colleagues demonstrated multiple benefits of Bluetooth technology that is designed specifically for indoor localization (different kinds of beacons and tags), Wi-Fi fingerprints have the advantage of using existing infrastructure and allowing for an unlimited number of fingerprints. More importantly, the advantages of BLE, mostly found in their channel hopping mechanism and much higher sampling rate can be outperformed with an addition of fingerpints and measurements per fingerprint. We demonstrated this by repeating the same measurement technique after several 'learning' iterations. Learning outcome is clearly visible in Figure 7.16 where the number of recognized Wi-Fi fingerprints grew from 1 (left) to 6 (right).

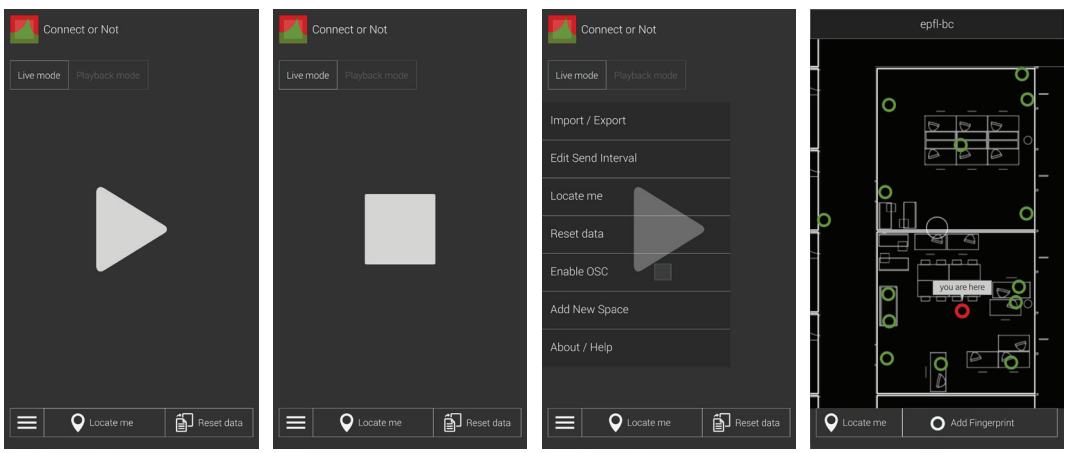

Figure 7.16 Application layout and main functions (from left to right): Play - transmit data on network usage; Stop - strop the transmission; Main menu; Locate the device (requires an existing map and fingerprints)

38) Xiaojie Zhao et al., 'Does BTLE Measure up against WiFi? A Comparison of Indoor Location Performance', in *European Wireless 2014; 20th European Wireless Conference; Proceedings of*, 2014, 1–6.

A number of issues remain: the localization service is not as precise as we would have liked. Both Bluetooth beacons and Wi-Fi fingerprints cannot guarantee a precision under 1.5 – 2 meters. Although the number of Wi-Fi fingerprints and the system's ability to learn through multiple readings promise to improve this, our results (Appendix 4. *Position tracking tests*) show that indoor positioning systems can hardly accurately track a person on the move in real time.

Nevertheless, this project helped to demonstrate what could be accomplished through a smartphone application in terms of data aggregation. It was also a good way to scratch the surface of the possibilities offered when physically interacting with the intangible and rapidly evolving medium of digital communications.

7.3. Discussion

Practice-based research is mostly characterised by a *drifting* path of design or artistic efforts that address the research question from multiple perspectives. Unlike classical research process that follow a predefined, straight line from the hypothesis to the results, *research through design* allows unexpected insights to emerge from the not always consistent or controlled design process. The prototyping process I described in this chapter illustrates a drifting path from the first attempt to render wireless communication tangible through subsequent prototypes that explore the design of *active form* and expression of network activity through movement and lights.

I introduced two main concepts that underlie this design process: *experience catalyst* and *out-bodied* interaction, both of which explore tangibility of connectivity. Rendering network activity tangible is a way to question normalisation of seamless connectivity and our understanding of the way this infrastructure performs. *Out-bodied* interaction works towards this goal by mediating the activity of a wireless communication network through an external device and embodying it at the same time. It involves both intentional human input through usual screen behaviour (browsing, calling, texting, uploading), machine input and output (machine-to-machine communication) and mechanical output (movement of motors and lights). Once the behaviour of the system was acknowledged by the people present in space, they would usually adapt their network activity to it. They would, however, do so only for a limited amount of time and then adopt a more observing role.

The general development of the prototyping process relied on learning along the way. After each iteration, I tried to address issues encountered with the previous one. Sometimes these decisions led to opening new problems, sometimes they did not conform with the intended improvement while at other times they encountered a positive response. For example, the decision to increase the range of the movement from the insignificant tens of centimetres in RKNFG to up to 50cm in Quadricone, while adding more wireless networks into play did not in

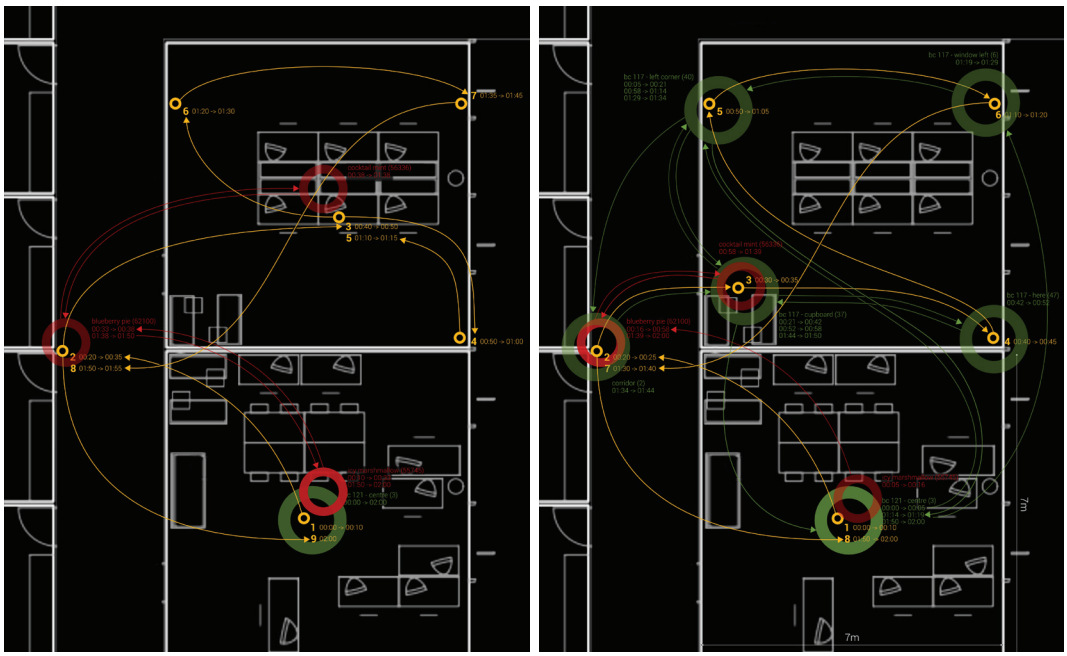

Figure 7.17 Position tracking measurements: first tests, December 2014 (left) and learning results, August 2015 (right). Movement of the smartphone (thin yellow lines) between 9 positions (yellow circles), which correspond to predefined Wi-Fi fingerprints, is tracked by two systems: one is based on Estimote beacons (red circles) the other on Wi-Fi fingerprints (green circles). The learning process consisted of a user repeatedly confirming correct positioning and adding more measurements at pre-existing positions or correcting the system's estimation. We can observe a growing recognition rate of Wi-Fi fingerprints. In the first measurement, Estimote estimations corresponded to the actual position some of the time, while Wi-Fi located the devices constantly in the same position. After the learning process Wi-Fi outperformed the beacons.

fact make the experience more immersive or interaction more natural. Because of other factors such as the scale or placement of the installation that discouraged physical engagement, these improvements went largely unnoticed. At the same time, the range of reaction – significant or not – proved to be a difficult concept to work with, which led to the idea of a circular loop that was much more natural to the phenomenon observed.

While searching for more tangible and physical influence on visitors, I decided to couple deformable surface with lights in the last prototype presented at IST, Lisbon. This still proved insufficient in captivating attention of the audience due to the scale of the surrounding atrium. Such a change in the environment prevented me from observing the impact the system would have in an isolated space. However, it allowed me to gain insight into the relevance of the context of the installation, both in terms of space and audience. While I believed I needed to focus on the design of interaction with the system and its tangibility, it was actually equally important

to consider the relationship to existing structure. The prototypes were the most successful in conveying the idea of active form and interpreting wireless communication when existing structure was engaged in the performance – as in the case of Ljubljana presentation.

After considering all different setups that I tested, I came to the conclusion that the experience of the small cube was more significant in terms of its architecturality than that of the large stretchable fabric sheet. Having to enter the cube, one would concentrate on the changes that occurred and would indeed feel contained in the small rectangular space. With the scale of the installation, the effect of a limited liner movement diminished too. While the range of movement in RKNFG was significantly smaller than in the Quadricone installation, the person inside the cubicle had the cubicle as a referential system and was thus affected by this small change. Contrarily, in an open space where Quadricone was installed, its movement – although more perceptible, had less of an effect on visitors because they had the whole room as a reference, and could observe it from a side. Next to this, the envisaged diversity of form resulting from the movement of certain points on the surface was in reality quickly exhausted and perceived as uniform. Another unexpected insight is that in the absence of a fixed form or a tangible object to interact with, the surrounding space turns into an *interactant*, as was the case in presentation in MMC Zavod K6/4 in Ljubljana.

While the design approach was getting closer to the idea of designing *active form*, interaction with it was as seamful and unintuitive. I decided to acknowledge this by insisting on *out-bodied* interaction and emphasizing the problem of attention switching between the act of communication and the act of interaction with a system influenced by this communication.

The project witnessed strong development in data collection techniques. From listening to the number of packets that pass through a wireless access points it transformed into a much more accurate and spontaneous data collection through the *Connect or Not* Android application. The data on network usage does not tell us much about the experience of the users, particularly not about their spatial experience. It was thus necessary to couple this data with a qualitative assertion of this experience.

Quantitative data does, however, make some of the known network traffic behaviours explicit. Firstly, traffic is constant, as devices communicate to each other at regular intervals to stay connected. This amounts to a regular incremental traffic count, which is clearly distinguishable from human-created traffic (see Appendix 3.1 *Connect or Not, Bühne A* visualisations at the end). Secondly, perceived signal strength is constantly changing, independent to the actual traffic load (same visualisations).

Position tracking based on Wi-Fi fingerprints, although it sometimes gives accurate results, is still rather imprecise and cannot be reliably used for locating the person within a room. The system does provide a relatively accurate log on person's movement as the device tends to be

recognized at correct locations with a delay. This can be used for other applications that do not require direct and immediate interaction.

Finally, presentation context matters and it should be accounted for in the design. For example, people engaged with a much less developed prototype at an art exhibition (*RKNFG*) but refused to do so at a university campus (*Connect or Not* in Lisbon). When presented with an installation at an exhibition, people tend to accept and immerse themselves with what they are given. Contrary to that, at a research symposium, discussing with a professional and critically attuned audience, the discussion focuses on inconsistencies in design intentions and decisions. Such settings tend to produce feedback attuned at improvements, new design ideas and paths to explore, as well as suggestions how the work should have been made. This knowledge can be useful for planning the order of presentations according to the feedback needed – meeting with the research and design community first, presenting the development at symposia with first results, and the general audience at the end.

8. Discussion and Conclusions

Wireless communication signals propagate through the environment, distributing information as far as possible. They are met with resistance in the form of built structures and other obstacles, the movement of bodies and people's communication activities. The actual performance of wireless networks is more complex than can be explained by a singular perspective focused on their propagation or human experience. To capture this complexity, I constructed a conceptual framework that establishes relationships between space, people and networks. This conceptual framework intersects concepts from networking technology, media and communications theory, architecture theory, human-computer interaction, science and technology studies, research through design, and philosophy. I then constructed a practical framework, using different software and hardware to measure and represent the quantities and qualities of wireless network traffic. I used this practical framework in the design and development of interactive prototypes, that describe the relationships explored.

The need for an intersection of all these fields of knowledge is needed is confirmed when we attempt to explain wireless connectivity through the lens of a single field. We soon realise how inadequate the optimisation oriented engineering perspective is in accounting for people's use of wireless networks in public space; or how insufficient it would be to look only at the

interactive qualities of network infrastructure, when considering its distribution throughout the environment. Wireless communication is a *social activity* that involves an exchange of information between humans; it is a *technical activity* that enables the transmission of data packets across signals, cables, and a network of devices. It is a *spatial activity* that involves transmission of information and energy across distances, occupying territory in different ways. None of these lenses accounts sufficiently for the effects of wireless connectivity in the other fields. Latour identified similarly complex topics that cannot be discussed within the "purifyingly modern scientific method that uses a singular disciplinary lens"[1] – the Ozone debate, global warming, deforestation and even the concept of black holes (which is not only explained through physics but also through philosophy). I assert that wireless-communication infrastructure is one of those complex topics, which points to the importance of preserving an *irreductionist* perspective on wireless connectivity.

The discussion in the first three chapters of this thesis alternated between different aspects of wireless networking – the political and infrastructural[2], which is further questioned through posthumanist[3], and flat-ontological views[4], the performative, material-semiotic[5] and the spatial[6]. This serves to demonstrate how complex wireless connectivity really is, and how none of these individual aspects provides a comprehensive view. My intention is to contribute to a perspective on wireless connectivity in space that works across these disciplines.

It is not easy to build an argument that holds independently across the different fields. For example, the agency of wireless signals is hard to assess from a technical perspective of network engineering. Even the performative aspects of signals and space were so differently addressed by the different schools of thought in architecture (as demonstrated in Chapter 3.3 *Performativity of Architecture*). Some universal observations do apply. When talking about the experience of space, one has to recognize that it is influenced by many things, amongst which wireless networks are not the most prominent factor. In spite of this, the presence and affordance of these networks have an effect on people's spatial preferences. Some researchers interpret this as a proof of Wi-Fi's capacity to reconfigure space and social interactions in it[7], which is a slightly inflated expectation.

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1) Latour, *We Have Never Been Modern*.

2) Mattelart, *Networking the World, 1794-2000*; Star, 'The Ethnography of Infrastructure.'

3) Hayles, *How We Became Posthuman*; Barad, 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter.'

4) Latour, *Reassembling the Social*; Levi Bryant, Nick Srnicek, and Graham Harman, eds., *The Speculative Turn: Continental Materialism and Realism*, Anamnesis (Melbourne: Re.Press, 2011).

5) Barad, 'Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter'; Smitheram, 'Spatial Performativity/Spatial Performance.'

6) Easterling, *The Action Is the Form. Victor Hugo's TED Talk*.

7) Forlano, 'WiFi Geographies'; Gordon and de Souza e Silva, *Net Locality*.

The effect of connectivity and reconfiguration of social relationships is nevertheless present in relatively slow changes that occur in our relationship and attention to our surroundings, as McCullough observed in *Ambient Commons*[8].

Narrowing the perspective leads to what I will call the "this is like that" problem. The reduction of the properties of something, in order to compare it to something else, is a common practice in human thinking. Nevertheless, this often results in forcing inexistent similarities and generates misleading generalisations. Later in this chapter, I will describe in more detail what "this is like that" means and how it is situated in this discussion on wireless connectivity.

In Chapter 4. *Infrastructure at Hand / in Space*, I presented five scientific studies that are informed by spatial analysis and by ethnography, and that explore immediate correlations between connectivity, network activity and people's behaviour. In Chapter 6: *Probing the Network,* I analysed different artistic and design projects that engage with wireless communication. Spatial preference is one of the more evident correlations, directly influenced by signal availability. In the analysis of Wi-Fi networks' capacity to act as tools for identifying emerging spatial patterns, researchers found that the probability of users mobility across access points (the flow of data and people) is non-arbitrary and dependent on human factors[9]. Spatial preference is statistically linkable to signal availability but, next to their presence, it is also influenced by other factors[10].

The result of this spatial preference affects the perceived character and qualities of space in return. As Forlano's and Hampton's research in the use of public spaces shows, Wi-Fi availability has an important effect on the experience of space in everyday work and other situations[11]. In the 1970s William H. Whyte, with a team of his students, set out to explore and explain the use of public space. One of the main findings from his observations of New York plazas was that people are attracted to places by the presence of other people[12]. The 2007 study by Keith Hampton and his students "walking in the shoes of William H. Whyte"[13] found again that people are attracted to parks, cafés and other Wi-Fi equipped places, by other people. The role of Wi-Fi availability in this spatial preference depends on the service people prefer to use (Wi-Fi or cellular), general qualities of space (availability of benches, tables, hade, etc.) and other habits. Thus, Wi-Fi availability is not decisive for the movement of people, but it does change the way they use public space.

8) McCullough, *Ambient Commons.*

9) Heitor et al., 'Synchronizing Spatial Information In Complex Environments: A Crossover of Space Syntax and Spatial Information Visualization.'

10) Sevtsuk et al., 'Mapping the MIT Campus in Real Time Using WiFi.'

11) Forlano, 'WiFi Geographies'; Hampton et al., 'The Social Life of Wireless Urban Spaces.'

12) Whyte, *The Social Life of Small Urban Spaces*.

13) Hampton et al., 'The Social Life of Wireless Urban Spaces.'

Awareness of the act and the affordance of connectivity is mostly overlooked in the instrumental design of these systems. As a counterbalance to this, some researchers experiment with rendering the *seams* visible – be it the act of connecting[14], availability of networks[15], their embodiment[16] or interaction with them[17]. Raising awareness is amongst the most common and explicit intentions of artists who work with wireless media. Interactive visualisations, objects, and installations render abstract information on signal availability *experienceable* and embodied. However, the way the awareness of networks influences the experience of space through these works is much less explicit and in some cases even non-existent.

8.1. The "This is Like That" Problem

"Explaining a joke is like dissecting a frog.
You understand it better but the frog dies in the process"
e. b. white

"I call architecture frozen music", said Goethe in a conversation with the German poet, Johann Peter Eckermann[18]. He further explained: "The influence that flows upon us from architecture is like that from music". Goethe was comparing the influence or experience of architecture with the experience of music. This experience frames one's state of mind (to be satisfied or to become slothful), relative to the personal preferences and needs (of an emperor or a writer), as well as his habits (Goethe is used to his little, somewhat disorderly-orderly room). We could imply Goethe's musical preferences from this statement. What often happened in the centuries that followed instead, was an over-interpretation of similarities between architecture and music. Statements such as "Architecture represents the art of design in space; music, the art of design in time"[19] confirm this. Elizabeth Martin edited the Princeton's Pamphlet Architecture Issue 16, in which this statement appears. The pamphlet explores the possibility of breaking down culturally erected barriers that separate the audiences of architecture and music. The results from these

14) Rudström, Höök, and Svensson, 'Social Positioning: Designing the Seams between Social, Physical and Digital Space.'

15) Chalmers, 'Seamful Design and Ubicomp Infrastructure.'

16) Dourish and Bell, *Divining a Digital Future. Mess and Mythology in Ubiquitous Computing.*

17) Arnall, 'No to NoUI.'

18) Johann Peter Eckermann, *Conversations with Goethe in the Last Years of His Life*, trans. Margaret Fuller (Hilliard, Gray and Company, 1839), 282.

19) Elizabeth Martin, ed., *Architecture as a Translation of Music*, Pamphlet Architecture 16 (New York: Princeton Architectural Press, 1994), 8.

explorations and design efforts remain, however, to be consumed in the context of architecture, featuring architectural models that appear as fictional musical instruments.

The list of architecture-is-like metaphors is inexhaustible, and I will only introduce a few notable examples. In her book on the power of infrastructures, Keller Easterling[20] made a reciprocal connection between serial and parallel communication to building types. "Mainframe computing was a serial network that passed information sequentially, while a parallel network might be modelled as a more open mesh with information flowing simultaneously from many points."[21] Although serial communication traffic is similar to the way an elevator in a high-rise building accesses floors one by one, parallel communication is characterised by a road network, similar to buildings with multiple points of accesses (markets, train stations, office buildings, etc.)

As the role of technology in creation and the mediation of space shifted from a tool that represents the virtual environment towards computing that attempts to process the environment, architecture is increasingly compared to interaction design. McCullough observes this similarity in the fact that both architecture and interaction design "address how contexts shape action"[22]. Information technology becomes social infrastructure, says McCullough, a transformation architecture has long undergone.

The connection between architecture and interaction design relates to another analogy, that of computers and theatre, which was instrumental in shaping some of the early human-computer interaction (HCI) theories. In *Computers as Theatre*, Brenda Laurel makes a case for the dramatic metaphor that becomes the guiding principle in the field of interaction design. She finds similarities between interface design and theatre, in the fact that both deal with the representation of action[23]. "In a theatrical view of human-computer activity [...] the technical magic that supports the representation, as in theatre, is behind the scenes. Whether the magic is created by hardware, software or wetware is of no consequence; the representation is all there is"[24]. Interaction design is, thus, about designing (cues for) attention.

It is not their use in thinking that makes analogies problematic. It is their linear application to properties of one thing to the expected properties of the other. When we speak of the "this is like that" problem, there is a potential for misunderstanding both "this" and "that". We choose each determiner for only some of their properties, disregarding all the others in the comparison.

20) Easterling, *Extrastatecraft*.

21) Ibid.

22) McCullough, *Digital Ground: Architecture, Pervasive Computing, and Environmental Knowing*, 47.

23) Brenda Laurel, *Computers as Theatre* (Reading, Mass: Addison-Wesley Pub. Co, 1993).

24) Ibid., 18.

This means that a strong property of "this" in relation to "that" might not be taken into account because it is not relevant to the analogy. Conversely, the actual effect of "this" on "that" will be overlooked if the potential for such effect does not exist in the initial metaphor.

The idea that wireless signals are "like" architecture is at the core of the questions addressed by this research. When I compare the *spatiality* of wireless communication to the *spatiality* of space, I apply the properties of space (which is static, and tangible) on communication (which is dynamic and intangible). The connection here lies in the fact they are both relevant simultaneously to our experience and present.

The analogy between wireless network signals and architecture can also work in terms of shaping. There is a shape to things that surround us, to the built environment that defines our movement and encloses our bodies (furniture, rooms, clothes). There is also a shape to the wireless communications infrastructure, defined by its range and influenced by the same built environment (barriers to propagation, but also air moisture, interferences with other signals, to name a few). There is material for a double analogy here: the built environment affects our experience of space and also the actual state of network propagation, the network propagation affects our experience of space in turn. This means that although wireless signals are "like" architecture, which brings out the spatiality of wireless connectivity, architecture is "like" wireless signals in the sense that it actively shapes our experience of space and is open to interpretations.

8.1.1. Analogical Thinking: When is "this" really like "that"?

"This is like that" is a way humans take an abstract concept and make it concrete. Analogies make meaning - they are a bridge from the familiar to the strange. Psychologist Bryan H. Ross[25] discusses the use of analogies when learning new cognitive skills, more specifically the difference between using an earlier example for *principle-cuing* (cuing of relevant abstract information through example) or for *example-analogy* (when a principle is understood in terms of a concrete example, not a formula). Looking at ways novice learners make use of an earlier problem to solve a current one, Ross offers a comprehensive experimentation report on the structure-mapping process. His team designed different experiments to test the effect of relevant and irrelevant similarities. Ross' research demonstrates an important mechanism in constructing analogies, specifically the fact that similarities in detail (as in *example-analogy*) drive the access to earlier knowledge, rather than similarities in abstract principles (as in *principle-cuing*). Put simply, it implies that the way "this" is "like that" is often closer to formal than structural similarities are. It is possible to connect anything with anything else, once we establish parallels that seem formally convincing.

25) Brian H. Ross, 'This Is like That: The Use of Earlier Problems and the Separation of Similarity Effects.', *Journal of Experimental Psychology: Learning, Memory, and Cognition* 13, no. 4 (1987): 629–39, doi:10.1037/0278-7393.13.4.629.

When scientists reach for analogies to explain their findings to people who do not share the same experience and proficiency in the field, they simplify it for the sake of communication. Psychology professor Brian Hughes[26] amusingly describes such a scenario in the *Babel Fish dilemma*. Babel Fish, as described in the *Hitchhiker's Guide to the Galaxy*, makes a person instantly understand other languages without learning. Comparing the popularisation of scientific findings in mass media to inserting the Babel Fish in one's ear, Hughes lists numerous examples of their misinterpretations, due to the loss of the original scientific context, research methods, complexity and accuracy. The popularisation of science presumes a certain simplification combined with familiarisation of concepts – as in the case of molecules with silly names, aiming at memorability through association (putting forward a property of the molecule's structure or behaviour, however unusual or unexpected, such as Adamante, Bastardane, Moronic Acid, to name a few)[27].

Dedre Gentner, cognitive scientist and expert in analogy, describes the selection problem: When constructing theories of analogical inference, people make a selection of the source's properties that they project on the target[28]. If everything known about the source could be projected onto the target, the analogy would be useless in reasoning. Gentner stresses that making an analogy is not a deductive process. There is no guarantee that the inferences from a given analogy will be true in the target, even if the analogy is carried out perfectly and all of the relevant statements are true in the base. She also stresses the unpredictable side of analogies: "analogy can suggest genuinely new hypotheses, whose truth could not be deduced from current knowledge"

Referring to the spatial analogy between architecture and wireless network signals, the question is how actually important is their similarity? Is this analogy a good way to describe the presence of wireless signals in space? I address these questions through the performative paradigm of architecture and wireless communication. In architectural and engineering literature, *performativity* is not a primary characteristic of either buildings or wireless signals. In spite of this, the *performativity* of these entities is central to the experience and meaning we make of them. The performative paradigm enables me to shift away from a utilitarian, technical, ethnographic or any other singular perspective. It also enables me to take a distance from the initial analogy between space and wireless connectivity towards a more internalised perspective, one that does not compare the two from the outside, but tries to make internal connections.

Laurel's intention, when comparing computers to theatre, was not to construct a consistent metaphor. It was rather to trace a way to conceptualise human-computer interaction. Similarly,

26) Brian Hughes, 'The Babel Fish Dilemma: Talking Science with Non-Scientists', *The Science Bit*, 21 April 2011, http://thesciencebit.net/2011/04/21/the-babel-fish-dilemma-talking-science-with-non-scientists/.

27) Mollecules with Silly or Unusual Names, http://www.chm.bris.ac.uk/sillymolecules/sillymols.htm

28) Dedre Gentner, 'Psychology Of Analogical Reasoning', in *Encyclopedia of Cognitive Science*, ed. L. Nadel, vol. 1 (Nature Publishing Group, 2003), 106–12.

this research conceptualises the *out-bodied* interaction between space, people and networks through, but also beyond analogies.

In the work on the *Connect or Not* application, I collected data on signal strengths, data traffic and devices position in space. This is the base for the visualisation of propagation densities (see Appendices 3.1 and 3.3. *Data visualisations*). These visualisations still do not account for the relationship between signal and space because of two important missing aspects. The first is time, the second is the personal perspective. People using smartphones not only decide to create traffic at a particular location and at a particular time, they also distribute it with their movement. Parallel to quantitative data acquisition, I collected qualitative information about the experience of interaction with wireless networks in the particular *experience catalyst* settings I created (see Appendices 2.1, 3.1, 3.2 and 3.3 *Presentation notes* and *Interviews*). The combination of these two accounts is the source of generalisations I make about the different aspect of wireless communication in space. In general, the analogy between architecture and wireless signals draws a thin line between perceived experience, as demonstrated in interviews and discussions, and quantified interaction – as demonstrated by data obtained through measurements.

8.2. Contributions to Research Methodology

8.2.1. Research Design Artefacts, Their Potential and Limitations

In Chapter 2: *Research through Design*, I covered some general notions of practice-based research, setting the ground for a study of design artefacts in the research context. In Chapter 7. *Projects and prototypes* I documented my own research process, through six iterations of design prototypes and their presentations. There is no overall consensus in the literature about the precise meaning and procedures of practice-based research. There is, however, a growing practice that can be grouped under the name *research through design* and that contributes to the establishment of a more solid understanding and framework.

Design artefacts produced in research context are numerous. We can find such diverse examples ranging from explorations of a Japanese technique for fusing metal[29], mixed-media

29) Ian Ferguson, 'The Development of Solid State Diffusion Bonded Mokume' Gane' (Royal College of Art, 1996), (uk.bl.ethos.267640); Alex Seago and Anthony Dunne, 'New Methodologies in Art and Design Research: The Object as Discourse', *Design Issues* 15, no. 2 (1999): pp. 11–17, http://www.jstor.org/stable/1511838.

cultural probes[30], to interactive visual interfaces[31], tangible interfaces[32] and placebo objects[33]. It is evident from examples on this list that artefacts produced in research context do not necessarily serve a utilitarian purpose. They provide an explicit feedback about their use and the experience they invoke. In terms of design, they are like code with excessive debugging statements. The process of design is rarely linear and is usually characterised by decisions that changed along the way, what Krogh and colleagues call *drifting*. A way for arriving at original research contributions, *drifting* is an adaptive process characteristic of the type of research driven by intermediary findings and open to unanticipated observations[34].

Research through design gives agency to artefacts. Researchers are not the only ones who influence the analysis process; their artefacts point at unexpected directions too. The research process is a negotiation between the research question and the artefact, its development and effects. More examples are needed in order for researchers to be able to compare each other's approaches and results. This is not done with the expectation that results from prior efforts would be replicable, as is the case in natural sciences[35]. Its purpose is rather for establishing a rational basis for the evaluation of knowledge these design artefacts unveiled.

Research through design implies a certain type of transdisciplinarity. The research itself typically takes place at institutions that bring together researchers from different backgrounds. Designers are often part of a team they did not selected themselves[36]. This does not infer that there needs to be a strong 'single-disciplinarity' amongst them. Rather, individuals are likely to possess transdisciplinary skills themselves, bringing their worldviews closer and enabling a collaboration that facilitates mutual inspiration. As organising principle, it is the design initiative that is important in these collaborations. In an interview following the Research through Design 2015 conference held in Cambridge, UK, Frayling recently observed that design and art are often not central to collaborative research projects that also involve engineers or economists

30) Gaver, Dunne, and Pacenti, 'Design: Cultural Probes.'

31) Ava Fatah, Alan Penn, and Eamonn O Neill, 'Mapping, Sensing and Visualising the Digital Co-Presence in the Public Arena', in *Proceedings of the 9th International Conference on Design and Decision Support Systems in Architecture and Urban Planning.*, ed. H. Timmermans and B. de Vries (Eindhoven, The Netherlands: Eindhoven University of Technology, 2008), 38–58; Huang and Waldvogel, 'Interactive Wallpaper'; Sengers et al., 'Art, Design & Entertianment - Culturally Embedded Computing.'

32) Timo Arnall, Jørn Knutsen, and Einar Sneve Martinussen, 'Immaterials: Light Painting WiFi', *Significance* 10, no. 4 (August 2013): 38–39.

33) Dunne and Raby, *Design Noir: The Secret Life of Electronic Objects*.

34) Krogh, Markussen, and Bang, 'Ways of Drifting—Five Methods of Experimentation in Research Through Design.'

35) Zimmerman, Stolterman, and Forlizzi, 'An Analysis and Critique of Research through Design: Towards a Formalization of a Research Approach.'

36) Koskinen et al., *Design Research through Practice*.

or ethnographers[37]. He insisted that in order to produce a valuable contribution to design and *research through design* methodologies, this transdisciplinarity needs to be design-led.

Can research deliver convincing and usable design artefacts? From the examples in this thesis and numerous articles on similar artefacts discussed in research through design literature[38], we could conclude that different aesthetic and usability expectations provide design research artefacts more freedom. With this freedom comes an opposite trend of acceptance by the general audience. Aside from a few notable examples of research design artefacts that blur the results with high quality of their design and production, it is evident that research design artefacts rarely become commercial products. However, commercial viability cannot be used as an argument against validity of research design artefacts, as they offer a unique way of dealing with research questions. The outcome of research through design does not appear as a final product if it ever does before it has been repeatedly demonstrated to different expert audiences. In this sense, it has more opportunities to attain its purpose than a commercially designed product does. The development and production process is also documented and communicated more extensively.

Two distinct research traditions, which seem to exist parallel to each other, question the role of the design artefact in research projects. Design research, incarnated in the Design Research Society, exists through conferences and journals that have discussed design methods since the 1960s. This body of work focuses on knowledge in the area of design problems, methods and processes relevant to the improvement of practice. Whereas, *Research through design* focuses on knowledge that can be attained only through the practice of designing.

Design research has often criticised research *through* design for the lack of reference to the findings and publications in the established field of design research. In the light of this division, Bryan R Lawson criticised the book *Design Research in Architecture* edited by Murray Fraser. Fraser's book[39] is a sum of different points of view on *research through design* with a general aim of grounding this research in the architectural context. Lawson's critique is concerned with what he sees as Fraser trying to simply "generate design work that affords multiple interpretations"[40]. According to Lawson, this would allow Fraser and other authors in the *Design Research* volume to generate theories on the process, outcomes and experience of design, which does not necessarily accommodate the rigour of scientific research. Such criticism seems to dismiss all the work done in the field of *research through design* as scientifically relaxed. The fine but important difference

37) Frayling, RTD 2015 Provocation by Sir Christopher Frayling Part 7: Design-led research - the next chapter on Vimeo.

38) Koskinen et al., *Design Research through Practice*; Krogh, Markussen, and Bang, 'Ways of Drifting—Five Methods of Experimentation in Research Through Design.'

39) Fraser, *Design Research in Architecture*.

40) Lawson, 'Design Research in Architecture', 127.

is that the scope of research through design is not the process of designing – a topic that was comprehensively explored by authors such as Cross, Buchanan, Dorst and Lawson himself.

Research through design is not about studying outstanding designers from an outside perspective: a perspective internal to design but external to the design process. It is more about studying phenomena outside of the immediate design practice - such as the experience of the environment, production of meaning, interaction of human and non-human *actants* etc. This approach is observable in research projects such as Kristina Niedderer's 2004 dissertation *Designing the Performative Object,* which deals with mindful interaction design and performative objects, exceeding the relevance to the process of design alone[41]. Human-computer interaction (HCI) research-projects also gravitate around experience and perception rather than around the process of design, thus extending the scope of theory that can result from *research through design*. Gaver wrote on the kinds of theory that research through design produces, describing it as "provisional, contingent and aspirational"[42]. It is generative theory that describes what *might be* as opposed to what *is*.

The other, even more important difference, is the role design has in the research process. How precisely practice happens within research in *research through design* has still not been clearly defined, and perhaps never will be. What all research through design and arts literature insists on is the central role of *making*. The research outcome is different from the design artefact, but it is more than an exploration of the process of its design. It is also not reducible to this artefact either[43]. This process is embodied in research and inseparable from it.

8.2.2. Layers of Evaluation and Interpretation

Throughout the discussion on research methodologies in this thesis, I have given some ideas about how research design artefacts can be evaluated. However detailed and recurrent this account of possible strategies, it has not given answered the question on the evaluation criteria or procedures. There have been some attempts in the literature to address this issue, but an important fact is often overlooked. Evaluation is made on multiple levels, firstly by the researcher or research team. At formal presentations, there is a broader professional or general audience who experiences the output of the design process and communicates this to the researcher - through an interview, a focused discussion, an informal conversation, or in some other way. Researchers use this feedback for an evaluation of the "ripeness" of the artefact for the research purpose.

41) Kristina Niedderer, 'Designing the Performative Object: A Study in Designing Mindful Interaction through Artefacts' (Falmouth College of Arts, 2004).

42) Gaver, 'What Should We Expect from Research through Design?', 938.

43) Markussen, Krogh, and Bang, 'On What Grounds? An Intra-Disciplinary Account of Evaluation in Research through Design.'

The artefact is part of the communication process of research outputs. Its meaning comes from interpretation by both the researcher and the audience. Although I have already stated that aesthetic, functional or commercial value criteria cannot be a measure of success of a design artefact in research context, a general or a professional audience tends to look for these values in research outputs. This is not an explicit expectation from either the designer or the person experiencing the design but it nevertheless plays a role. In literature, there is very little discussion on these different levels of interpretation.

The multiple evaluation and interpretation processes have both driven and obstructed my research process. I have tried to keep the design of the artefacts open-ended, focusing on what they *do* more than how they *look*. Thus, aesthetically oriented evaluations by the professional audience provided feedback on an aspect that was not central to my inquiry and interest. Presentations in the artistic context yielded much more interesting observations than focused discussions with professionals. Nevertheless, these evaluations were important for understanding the implications of design artefacts, beyond what I have designed them to do. They have provided an invaluable insight into the perception of my design decisions.

Because evaluation criteria are as flexible as I have just shown, it is not always clear what exactly *research through design* contributes to knowledge. Interpretation and evaluation are made on multiple levels and through the experience of the researcher, the experience of the audience, and finally through all the ways outputs are communicated, discursive or not. We could say that there are as many levels of knowledge acquisition as there are levels of interpretation in this process.

One way to centralise these different evaluations would be to think of the multiple reception levels from the beginning of the research design. This implies accounting for different types of input and finding creative uses for these types of feedback. It also implies a more complex organisation of the timing and context of the presentations. Furthermore, making interpretation and evaluation more explicit would improve the documentation and communication of the findings as well as contextualisation of acquired knowledge.

8.3. Contribution to Architecture

The design and use of wireless-communication technologies are related to different aspects of design and research, addressed from a multitude of fields. The research community explores the optimisation of this technology, its social and spatial aspects in different dynamics and with different interests. These interests were driven by a combination of factors.

In the early 2000s, more specifically between 2002 and 2005 in HCI research, the number of papers that dealt with wireless technologies and their alternative rose sharply[44]. This trend was followed by computational spatial analysis that performed sophisticated measurements and mappings of signal availability and use around 2006 and 2007[45]. Artistic and design engagement with the technology expanded significantly around that time as well (Usman Haque's *Sky Ear*, Haques, Sjolen and Somlai-Fischer's *Wi-Fi camera* to name a few). Ethnographic studies which explored the importance of these new technologies for the use and character of public space began appearing in 2007 and 2008[46].

We can thus speculate about the growth in interest triggered by the availability, adoption rate and social relevance of wireless-communication technology. Although HCI researchers and their funding could afford experimenting with PDA computers in the early 2000s, independent media artists only gave a significant contributed once significantly the widely affordable Wi-Fi router became a standard some four or five years later. Tools for mapping were developed hand in hand with wireless technologies, at the time when Wi-Fi became ubiquitous across campuses and cities. Similarly, ethnographic analysis of the use of networks appeared when wireless communication became widely used in everyday situations.

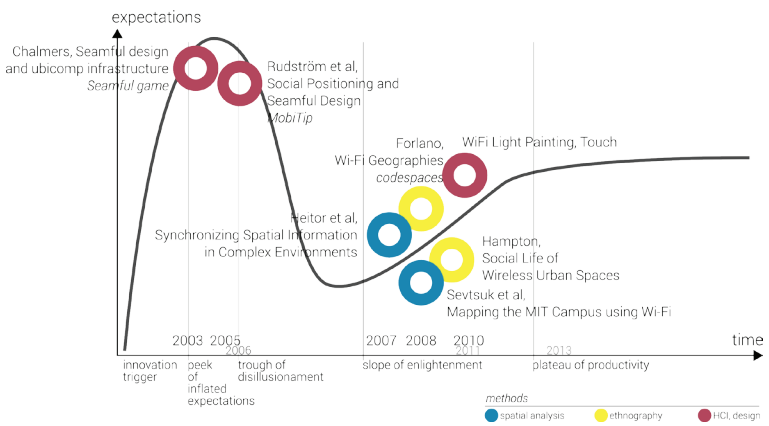

Figure 8.1 Gartner's hype cycle applied to academic research interest in wireless communication

44) Chalmers, 'Seamful Design and Ubicomp Infrastructure'; Rudström, Höök, and Svensson, 'Social Positioning: Designing the Seams between Social, Physical and Digital Space.'

45) Heitor et al., 'Synchronizing Spatial Information In Complex Environments: A Crossover of Space Syntax and Spatial Information Visualization'; Sevtsuk et al., 'Mapping the MIT Campus in Real Time Using WiFi.'

46) Forlano, 'WiFi Geographies'; Hampton et al., 'The Social Life of Wireless Urban Spaces.'

Finally, it is about time that architectural design deals with wireless communication infrastructures more systematically. Architects do not really consider it their job to design for *wirelessness* – the service provided by somebody else and thus "someone else's problem"[47].

8.3.1. Catalysing Experience

I introduced the idea of the *experience catalyst* in Chapter 7, together with the conceptual underpinnings of my approach to projects and prototypes. *Experience catalyst* hints at new types of constellations in the relationship between humans and infrastructures (architecture and wireless communication included) by seeking to catalyse a particular experience that can be discussed in the realm of artistic, design or architecture studies[48]. I investigated the relations between humans and infrastructures through an aesthetic strategy: the development of form-settings arising from the waves and their dynamics. This is not merely about visualising waves, a representation of network activity, but about a sculptural approach oriented towards physically sculpting the electromagnetic environment. Such an approach to wireless communication signals renders their multidimensional character *experienceable*. It is an expression of the *active form,* a form that performs or expresses network activity, rather than representing it.

Three generations of design prototypes came out of these endeavours: *RKNFG*, *Quadricone* and *Connect or Not*. I designed them to gain insight into the intersection of spatial, social and technological frameworks. Realised and presented in different conditions, these prototypes demonstrate different possibilities for interaction with the observed phenomenon. The primary intention of these experiments was to find if and how our experience of space changes when our use of networks triggers a change in the surrounding space.

Deriving from the experience of designing and presenting the prototypes, I made three observations. First, an interaction with a system that is only possible through mediation of an external device, named *out-bodied*, raises awareness of one's action. It makes interaction *seamful* and usually leads to a discussion on the reasons behind design decisions in prototype design or research motivation in general.

The second observation is that the awareness of the materiality of wireless communication does not in fact change the experience of space. It changes the experience of communication. This concept is fundamental to the analysis of the performance of wireless communication signals in space, because it restates the importance of the design of attention and of the effort of shifting this attention from space to the act of communicating and back.

47) Raven, 'An Introduction to Infrastructure Fiction — Improving Reality 2013 | Infrastructure Futures | Futurismic.'

48) Badura, 'Experience Catalyst Research.'

The third observation is that the context of presentation is more important than the level of prototype development. The presentations I gave over the course of this research were opportunities to spatially experience sensitivity to wireless connectivity. I imagined them as open-ended sessions for immersing our senses with digital information that is relative to one's use of networks. In reality, much of the aforementioned immersion depended on the context. When the work was presented to an art audience, perceiving it as a *given* artwork, the experience was much more immersive than when I discussed it with a critically attuned research audience. This means that within a "finished" cultural framework – such as an exhibition – people perceive the installations as something given to interact with. Installations presented at design meetings or research symposia were perceived and criticised from the point of design decisions, rather than their experience.

Changing space is not a trivial task. Relating this change to the networks is an even more ambitious one. Over the course of the design of these interactions, it became more and more evident how challenging it was to sum up the whole complexity of our networked interactions into the simple linear movement of elements or change of colour. This pointed out the complexity of perception and apprehension of space. I was able to observe how these relationships could not be summed up into a deterministic system that accounts only for several carefully chosen elements of these complex systems. To affect one's experience of the whole space, more than a surface or object needs to change. At the same time, the change of light in a dark space affects the experience more than a ceiling that is dropping down, if there is enough room to avoid it.

The timing of experiments and their duration plays an important role in the experience of the visitors. It also determines the way the researchers and designers talk about them. This means that the order and character of presentations needs to be carefully planned to accommodate for the discussion that follows the development of the prototyping work. This planning would offset the risk of contradicting feedback this designing process has often met. For example, after successfully presenting an installation to an art audience at a gallery, the same installation would be met with strong criticism of the research audience, unwilling to engage with it. The researchers feedback would have been more useful at earlier stages of the work, when conceptual changes and improvements could still be made. In the case of research prototypes produced in the scope of this thesis, the order of presentations would imply organising design meetings in the beginning and presenting the development to a research audience when some results were already achieved. Finally, when a prototype satisfies from the perspective of a researcher and their peers, it should be presented to the more general audience who can provide the unique feedback through profound engagement.

8.3.2. Future Work: a Permanent Awareness of *Wirelessness*

With reference to both my prototypes and artworks discussed in Chapter 6. *Probing the Network*, I make one general observation. Jeremijenko's desire to tackle the "consensual hallucination of immateriality" embodied in the concept of Cyberspace[49] and Haque's ambition to "give form to the invisible electromagnetic space" through a cloud of colourful balloons[50] both address quantities of network traffic. These works were realised by taking information on an aspect of wireless connectivity (signals availability, strength, encryption type) and assigning it some aesthetic form. This is an interesting experiment in itself, because it affords thinking about network traffic more tangibly. This also contributes to the development of a language around signal availability and traffic use. But the image that is produced is short lived - whether it is a one-time visualisation of traffic, a dynamic representation of the quantities of data, or a movement of a stretchable fabric. The majority of artworks were presented at galleries or performed on the streets once, and then removed. In order to establish a language of interactions, these interventions would need to be more permanent. The short timespan of their presence prevents us from observing patterns and learning about regularities in the presence of wireless network signals.

One interesting example of long term research in observation is the listening experiment *Phantom Terrains*[51] by Frank Swain and Daniel Jones. Swain, a journalist and Jones, an artist and software engineer augmented Swain's hearing aids to include presence and proximity of wireless networks. In this way, Swain continuously listens to the wireless network "population" and perhaps develops a sensitivity or understanding of patterns that emerge in signal propagation.

There are two levels of awareness designers can adopt towards *wirelessness* through permanent observation. First, the presence and distribution of wireless networks in buildings can be optimised through architectural design. Second, the experience of designing interaction with wireless connectivity can induce a designer's sensitivity towards the way signals perform in space. The experience of designing and presenting the prototypes also show how difficult it can be to detach form from (data) representation. Thus, the most important idea explored in the process is that of expressing wireless communication activity through a performance, as an *active form*.

Architects can account for the use of materials and disposition of routers in a more instrumental manner, resulting in better signal propagation. This would require in-depth studies

49) Jeremijenko, 'Database Politics and Social Simulations.'

50) Haque, 'Sky Ear - Concept and Final Design.'

51) *Frank Swain and Daniel Jones collaborated on a project called Phantom Terrains* (2014) which plays with assistive hearing technology as a prosthetic, extending its function to hearing the wireless network landscape http://www.phantomterrains.com/

of network propagation similar to those currently done with building performance metrics that focus on energy use, but also daylight performance, thermal, visual or aesthetic comfort.

It would also require rethinking the use and qualities of existing materials in order to design signal propagation according to the use of space. In the most basic case, we might want to isolate a sleeping room from signals while providing uninterrupted reception in the office or living room. This can be done by isolating the space applying the principle of the Faraday cage[52] in the first, and using a thin and transparent enclosure in the other. A notable example of this in practice was the isolation of Sistine Chapel during the 2013 Papal conclave. A Faraday cage was set up in the five hundred years old chapel, sub-optimal for keeping a convention secret in terms of wireless communication. This emphasized the discrepancy between architecture as a shelter from the weather and from electromagnetic radiation. The need for information secrecy is probably not going to diminish in the future, but on the contrary, it will demand more elaborate solutions. The use of Faraday cages might become a standard for any kind of business, religion or other convention purposes that seeks to prevent information leaking and hinder intrusive technologies of intelligence organisations.

Conversely, most working environments require fast and reliable signal propagation, yielding to the need for architecture to become nearly transparent to the propagation of wireless networks. In the light of recent discussions on the future of wireless networking, the

Figure 8.2 Faraday cage and network jammers installed in the Sistine Chapel to protect secrecy of the Papal conclave. Vatican, March 2013. Photo by Clayton Tang/Wikimedia Commons

52) Faraday cage, named after Michael Faraday who proved the principle in 1836, blocks electric fields by means of an enclosure made from a conductive material

transparency of architecture to wireless signals might become even more important. One strategy for increasing the current capacity of wireless infrastructures is the reduction of the cell size in cellular communication and the reconfiguration of devices to extend the network across each other. This trend could lead to communication entirely relying on network propagation across a mesh of devices, without a centralised base station network, as recent articles in the networking and communication journals suggest[53]. To be connected, one would need to be in a proximity of other mobile, connected devices. The effect of obstacles, such as buildings and walls would be significantly greater in this case, hence the need to think about materials that do not absorb signal. Visualisations made in the Wi-Fi camera project by Haque, Sjölén and Somlai-Fischer[54], show that windows are not only more transparent to light but also to Wi-Fi. Glass-enclosed spaces better facilitate signal availability. Materials will thus increasingly tested for propagation, while fulfilling other demands such as sound isolation or opacity to light.

The prototypes I produced in this research help to develop a *design sensibility* towards the availability and behaviour of wireless communication signals through awareness. This *design sensibility* is not equal to a recommendation. I am not suggesting that architects begin making interactive ceilings to depict network activity in real time. Rather, by engaging with similar experiments architects and designers might learn to understand propagation of signals and their use by people, devices and rooms. This should open an *agential* perspective on wireless network signals, but also other *actants* in the environment (light, sound, electrical signals, wind, rain, earth movements, etc). Such a perspective on the environment will empower the designer to account for and envision more dynamic environments that are able to accommodate change, as well as information in a completely new way.

53) Lei Lei et al., 'Operator Controlled Device-to-Device Communications in LTE-Advanced Networks'; B. Raghothaman et al., 'Architecture and Protocols for LTE-Based Device to Device Communication' (IEEE, 2013), 895–99, doi:10.1109/ICCNC.2013.6504208; Mumtaz, Saidul Huq, and Rodriguez, 'Direct Mobile-to-Mobile Communication.'

54) *Single Pixel Wifi Camera - Wifi Camera*, WiFi antenna, motor, custom electronics, software, 2006, http://wificamera.propositions.org.uk/Single-Pixel-Wifi-Camera.

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Appendix 1
RKNFG

RKNFG

1

Atelierhaus Salzamt. Linz. Austria:
September 2012

RKNFG was a cube, where one can enter. Its height was controlled by the amount of traffic on an open wireless network available in the gallery space.

THE SETUP

The installation consisted of the interactive cubicle hung from the ceiling, with linear servo actuators attached to its top, controlled by an Arduino Diecimila microcontroller board and a computer (with a WiFi network usb adapter). The top and bottom of the cube were made of wooden plates, while the sides were out of stretchable fabric. This top to moved up and down, increasing or decreasing the height according to the external input.

details on technical development:
http://emperors-wiki.kucjica.org/doku.php?id=rknfg

INTERACTION

The system reacted to the traffic generated by the visitors (or network clients, more precisely) and in turn affected their experience of space and comfort in the cubicle. The range of the reaction was minimal, the vertical movement spanning about 12cm.

The scanning part was done at the laptop side using the aircrack-ng software. The results of the airodump-ng network dump were filtered, capturing only the traffic of an open wireless network that was available in the gallery space. A Python script was accessing this log every 3 seconds and calculating the difference in the number of packets. It would then send the command to the microcontroller with the new position of the motors. If there was a significant increase (more than 50 packets), the script would send the "shrinking" command to microcontroller and the motor would reduce it's length by a third. This would effectively raise the top by about 4cm. When the change in number of packets would be between 8 and 50, and the motors would shrink for about 1cm. If there was no new traffic (packet difference is 0), the command would be to 'go down', increasing the length of the motor and lowering to top of the cubicle by about 2cm.

- hardware

the structure

- 2 plywood boards, base and top, 1x1m
- white stretchable fabric (1.5x3m)
- 2 L12 Firgelli linear servo actuators

the controls

- Arduino Diecimila board
- laptop (Thinkpad X30 running Debian GNU/Linux (wheezy) with orinoco_cs 3.2.0-3-686-pae driver for wireless interface)
- D-Link Wireless USB Adapter GWL-G112

HARDWARE

The cubicle is constructed from two sheets of plywood, 1x1m each, connected by stretchable fabric at a distance of about 1.55cm. Two Firgelli linear servo actuators are attached to two points on the top of the cubicle. The actuators are moving the top up and down, controlled by an Arduino Uno microcontroller, which is receiving values from a laptop fixed on a wall nearby.

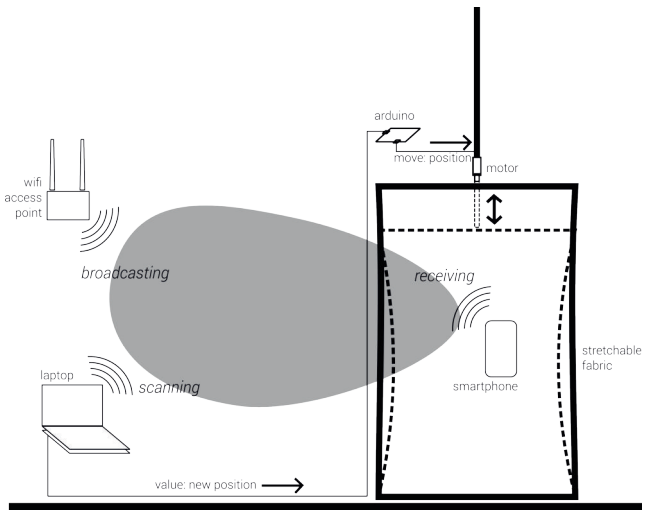
software

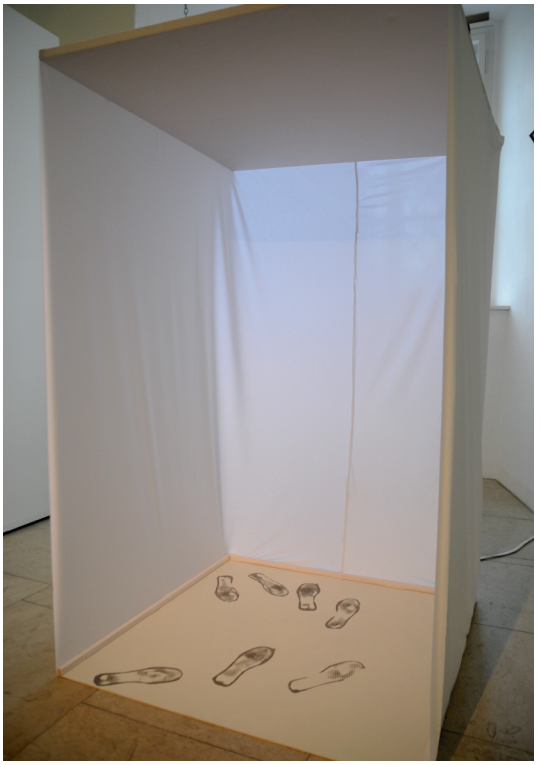
- aidrcrack-ng
- extended-python-arduino API firmware for Arduino, with associated
- arduino.py library
- python script motor-scanner.py

SOFTWARE

RKNFG is using Open-Source software working under a Debian OS. Network scanning is done using Aircrack-ng, a set of tools for auditing wireless networks. Arduino firmware is based on a Python Arduino API. The programme that connects the network traffic data to the microcontroller is written in Python and uses serial communication to control the motors.

RKNFG INTERACTION SCHEME





RKNFG presentation notes

Atelierhaus Salzamt, Linz, Austria
September 2012

PRESENTATION CONTEXT

Group exhibition in an art gallery Kunsthaus Salzamt in Linz. Exhibition featured works produces during a summer artistic residency in the same institution.

AUDIENCE

General audience, mostly younger people who live and work in Linz and have a connection to art

OBSERVATIONS

The exhibition featured several pieces that asked for some kind of engagement of the audience (e.g. edible buildings by Emily Speed). This, along with the title of the exhibition ("Expand, Expose, Explore"), created an explorative atmosphere at the opening.

People were open and receptive. They understood the concept and principle of interaction quickly. One obstacle in the natural interaction was that they would have to switch from the 3G UMTS service to Wi-Fi on their smartphones in order to participate. This however was not a turnoff for participation. Several people spent over a half an hour with the piece and two of them kept coming back to it the whole evening.

Interaction was straightforward and clear. As soon as there was activity on the network, to top would raise and visitors picked this up very quickly. Because the network was open, they could observe the direct relation between them generating traffic and the top of the cubicle raising up.

The basic rules of 'play' were to use Internet traffic to lift the ceiling of the cubicle, thus creating more space within it (depending on the person's height, this also meant they could straighten their back). When the traffic was too calm (only packets of exchange between devices delivered through the network) the cubicle's height would shrink, reducing the space. Some people understood that they can also 'do it for each other', lower or lift the ceiling intentionally while another person was standing inside. This was an unintended and indeed very useful connection discovered by exhibition visitors themselves.

The change in height of only about 15cm was insufficient to produce a wide enough range to express the dynamic od the traffic. The visitors could still perceive the movement as well as a height difference because the space was initially very low (155cm).

Increase the movement range, current 15cm of height change do not demonstrate dramatically enough the traffic activity;

Connect the system to more than one network;

Connect the system to other types of wireless traffic so that people wouldn't have to switch from their preferred service (3G or Wi-Fi)

TO DO

Appendix 2
Quadricone

Quadricone model

"Stage Digital I". Bühne A. ZHdK. Zurich
November 2012

2.1

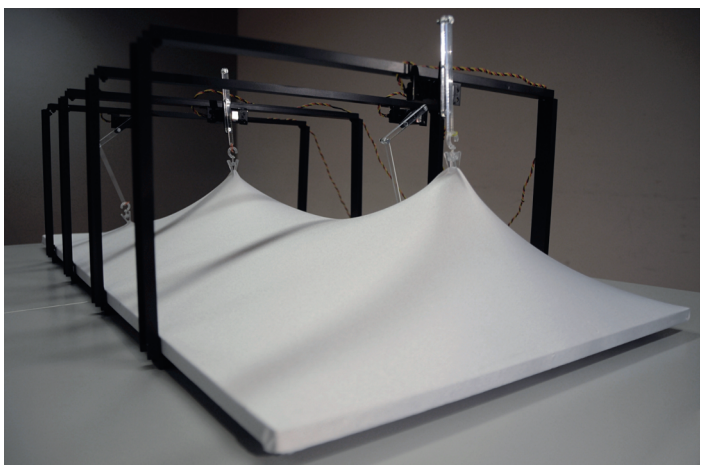
Quadricone is an interactive structure that reacts to the activity of surrounding wireless networks, reshaping the space it entangles. It consist of 'cones' formed by pulling stretchable fabric at certain points. The 'cones' dynamically reshape according to the amount of traffic going through WiFi access points in the surrounding.

Quadricone model was presented at Stage Digital – A Scenographic Expedition, organised jointly by SINLAB, EPFL, Institute for the Performing Arts and Film, ZHdK and Bühne A, Theater der Kunste, ZHdK

THE SETUP

Quadricone model is built on a wooden plate, with a sheet of stretchable fabric stapled on it and four metal frames attached at equal distances on the sides. Servo motors with custom designed handles (translating rotation to linear motion) are picking up the fabric at four randomly chosen points and these are associated with four wireless networks in the space. A laptop is scanning network traffic and an Arduino is controlling the motors.

details on technical development of the model:
http://emperors-wiki.kucjica.org/doku.php?id=quadricone-model



hardware

the structure:

· particle board 1.6mm, 50x100cm

· 4 aluminium frames made from a 10x22mm profile, 50x25cm

· 4 HiTEC ultra torque servo motors, HS-645MG

· rotary to linear translation mechanism, lasercut plexiglass

controls:

· Arduino Mega (ATMEGA1280) board

· laptop (Thinkpad X220 running Linux Mint Lisa, built-in Intel Centrino Advanced-N 6205 wireless interface and iwlwifi 3.11-2-amd64 driver)

software

· aircrack-ng

· Arduino-Python 4-Axis Servo Control firmware by Principialabs

· Principia servo.py library

· python script quadricone.py

QUADRICONE model, presentation notes

"Stage Digital I". Bühne A. ZHdK. Zurich
November 2012

Quadricone was an interactive structure that reacts to the activity of surrounding wireless networks, reshaping the space it entangles. It consisted of ‘cones’ formed by pulling stretchable fabric at certain points. The 'cones' dynamically reshaped according to the amount of traffic going through WiFi access points in the surrounding.

PRESENTATION CONTEXT

Research symposium "Stage Digital – A Scenographic Expedition" organised in collaboration between the following institutions: ZHdK Colorlight Center, ZHdK Stage Design and Scenography departments, SINLAB and Bühne A Technics Team

AUDIENCE

Invited researchers in the field of theatre and performance studies, interaction design and architecture, including colleagues from the SINLAB research laboratory. There were in total 10 people following the presentation and participating in the discussion

OBSERVATIONS

The installation was able to capture and represent traffic through numerous open wireless networks (4 at a time). The disposition of 'peaks' was in discrepancy with the actual position of access points, which was intentional (not a visualisation). Interaction was direct but not spatially significant, due firstly to the installation's size (100x50cm) but also to the existence of a 'range' of possible reaction.

The discussion with the audience turned out very critical of the design decisions, questioning the motivation and possibilities to gain insight into the phenomenon through this approach. Focusing on both design decisions (more activity - more space; clean and white, counting network traffic and not taking network dysfunctionality into account;) and the resulting interaction (lack of human agency, simplicity of the installation's "language") the discussion brought out some very interesting ideas for future development and improvement of the work.

TO DO

Avoid the idea of a 'range' of reaction - reality has no range

Explore different ways of representing Wi-Fi which are more true to the nature of the data

Explore feedback - measure the elasticity of fabric, put people in a more direct relationship with data

Connect the system to other types of wireless network traffic so that people wouldn't have to switch from their preferred service (3G or Wi-Fi)

PRESENTATION

Quadricone is currently the noisiest piece here, but the noise is not its main property. It is a model experiential space that demonstrates how much wireless internet traffic that is travelling in real time around us, traffic in which we are also participating. Traffic is used here to shape a surface. My intention is to deal with something that has transformed from a technical into a social infrastructure (wireless networks); to use it as found material. I would like to give it a direction that is not instrumental. The point is that we are aware of the existence and our dependence of this technology and at the same time there is not much interesting debate in the field of architecture and space about the way this affects or can affect things; not just our bodies or our health but the world. This is one example how it can affect the world: it can give it a shape.

This is why I gave the design direction the name "dynamic parametricism" - there is one parameter that determines the shape of the surface, and it's dynamic - it keeps changing. The way it's changing is simple. I am scanning the networks around us. Some of them are open so you can connect to them and try to affect the shape. We don't know at any time which network is connected to which motor. This is not a visualisation of EM field and also it is not about ethics - but about aesthetics. We too often talk about ethics - for example, this saturation being on the edge of an ecological problem.

When I start the program the motors get assigned a dump of packets that are going through a network; the more packets that go through, the more the motor moves; download something, watch Youtube videos…

I determined a threshold of possible change: I am using four of these elements and what I want as a result is a space that grows and shrinks (I would like you to imagine yourself under this structure actually). The shape comes from the idea of modelling space in the most efficient way: let's stay that a circle defines a certain area, and then we give it a third dimension - a point in the air somewhere. This point moves and this is the parameter that determines a complete space. What I think is important to add is that the future of this project makes sense if it becomes more complex if the resulting shape of space can become more complex.

DISCUSSION

Q[1]: What is more complex?

A: If there is only one line that goes up and down, the complexity of the shape is soon consumed. When people ask questions whether of not this is a visualisation - yes it is representing the traffic. But for it to get a life of its own or an extra meaning, it needs to include more parameters that determine the shape.

Q[2]: What motivated you to use traffic as an input?

A: Participatory possibilities; enabling interaction with it (indirectly). I want to emphasize our involvement with the state of these waves; this is also why I think the ethics is not so important. I am not trying to say "imagine there are these waves and they are getting into our body" it's more about the fact that we are driving this traffic, we produce this equipment, we put it on, we plug it in, we need it and we create these packets. This is why I think traffic is the most important parameter;

Q[2]: In terms of this participant in this field - they are aware that while they are downloading things that they are going to influence the shape of the system? You said you want complexity: why do you pick an outside source of input vs an indigenous data source - meaning the thing itself? The data (source) is coming from the outside, it's like in the ether the wavelength and you can affect it you know… but it has nothing to do - it's exogenous to the system. Indigenous would be something that's part of the system, let's say the relation of the motors and the elasticity of the fabric….

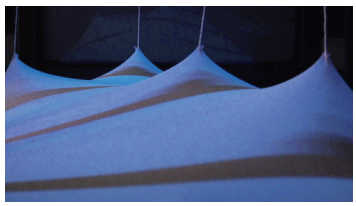
A: I could also measure the stretch of the fabric…

Q[2]: It could be interesting if people were on that surface and there is a lot of activity on that surface, that makes the system more unstable; or perhaps not - depends on how you deal with the data. It seems that the exogenous - this is what Jim Campbell calls "data arbitrary art" - you have an input, you have an output… We can have any input and map it to any output. It might make more sense to try to think about the system as it behaves to itself; because of course you'll have influences from the outside but it would start to understand itself - to respond to its own behaviour. I could substitute your wireless data source to the strength of the sun or whether it's' raining outside, there is traffic going by… the noise floor… all of these have not a lot to do with people's own bodies in the environment.

A: My intention is to really physicalize this external thing.

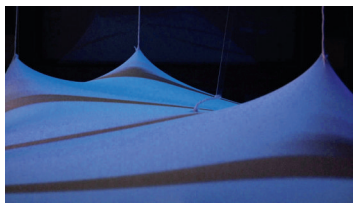
Q[2]: Maybe you have to think about how to internalize the physical thing.

Q[3]: This is then a visualisation or if you want spatialization of data; and for me, one way is to say “feed it anything” (arbitrary data source) but the other way, when you started talking, the non-ethical incentive was actually a weird thing to me because you are using the Internet -which is our playground....

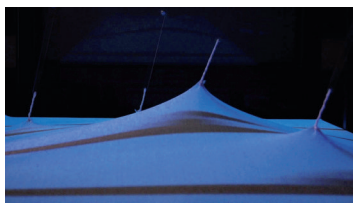


A: But I am not using the actual information...

Q[3]: But you are using the amount of data, so I am imagining myself standing in the space, doing the things on my computer and suddenly I am being squished by the space - I understand there is information in this space; "I want your attention", the space is telling me "stop with this … and play with me!". That is how I read your work. I am not sure if it is just arbitrary or if you should actually go deeper into the idea of this is wireless data (source) - what does it mean?

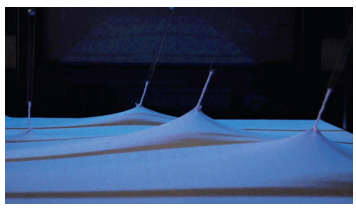


A: Why I say it’s not about ethics is because it’s not about the primary biological influence of waves on our bodies and because it’s also not about saturation and levels of power; there are regulations on how strong the broadcasting power of routers can be - this is an ethical discussion to me, how much do we let this thing take over the physical space



Q[3]: You don’t want to make 'statement art' but I think it’s not about your opinion...

Q[4]: I think this is a question of using this work and relating it to something; the wall ("Moveable wall" project started at SINLAB) at the beginning had a very political question and this is also an ethical dimension.



A: It’s a different ethical question

Q[2]: We spent the last 10 minutes talking about all ethical questions of wireless data and not about the work, about the experience; this is the problem about an arbitrary data source. That’s why you have to think about the environment itself and what does it mean? In terms of experience?

Q[5]: Because it’s real data (source), it’s part of our reality in the world; but reality is not as clean as that and it includes death and war and ships sinking… I see the motor only has this range but the reality has no range! And I think even the internet sometimes collapses! The real reality is different - this seems to be all under control while I think we are out of control. How can that be shown?

A: Well that is a very interesting question. I think it is a little bit hypocrite to say “I am now going to design (for) chaos”

Q[5]: You said when it's more complex, it will be the real thing. If I

am there and I am in reality, I don't know if this thing collapses because something happened in the world or the data goes really mad; I would be in a different situation, I would not say just 'oh, it's beautiful'

Q[2]: I think there is also this abstraction going on here about data. You can't sit home in front of your computer and order a book through Amazon and then complain that there is noise in your village because of trucks going through it.

Q[6]: You totally can because people are doing it!

Q[2]: But that's the problem! It says you have to think about what does the environment do based on people's presence but the fact that people are there may distort it; destroy this cleanliness; send the system into the probation... This thing you made, it abstracts it from people's agency

A: It is obvious this thing is not nature. I think everything we do is super controlled, we are control freaks. Otherwise, we would maybe not do anything. This relates to the discussion on designing organicity; how could you actually define rules for something that would be chaotic enough to allow reality?

Q[2]: Chaos doesn't mean arbitrariness. It means there is actually a pattern. I am trying to figure out why would I spend the 5 minutes of my life in this thing? What would it do to me? What does it tell me? How do I respond to it? What would I get when I leave it?

Q[5]: Since we mentioned Lausanne before, I think it should be connected to the data in CERN! It's the most important research project in the world and it probably has so much data, maybe it would be a visualisation of what is really happening there because nobody outside of this project can imagine.

Q[4]: This is a model of something which should be developed and should create an experience we only can speculate about - there is a second point since it is research project that is just starting - there is a key question you started in the beginning you don't want to make some kind of illustration (visualisation) - it is a big challenge to find a way to create an experience catalyst setting that is more than just an illustration of the waves around. I think this is the main challenge you are going step by step through models.

Q[1]: did you think about having people on the surface (instead of underneath)?

Q[2]: If people are on the surface they are really complicit with what you do.

A: Yes, if the presence would feed back into the behaviour - like people press the point and it lowers the bandwidth...

Q[1]: Where does the idea of being inside come from?

A: When you are inside then you can experience space; when you are on it, your experience of space is mostly related to things that are around you, but not necessarily the things that are under you.

Q[4]: As far as I understood, the idea is also to find new stimuli to shape forms that might appear from the surrounding and the environment we are de facto living, we are not realizing that this could be a shape that is interesting

Q[7]: More activity is more space and less activity is suffocating. That is also a choice, right?

A: Right. We can speculate whether this or that is what would be better for people's experience (upside down, inside, on top...) It is not crucial to my conclusions at the moment that either of them wins. I hope to be able to explore different possibilities.

Quadricone

"Les Urbaines". Espace Arlaud. Lausanne
December 2012

2.2

Quadricone reacts to the activity of surrounding wireless networks. It consists of four 'cones' which dynamically change size according to the amount of traffic going through WiFi access points. The visitors can interact with it indirectly, through devices they use to connect to the Internet.

THE SETUP

Quadricone is formed out of a sheet of stretchable fabric, 7×2.25m, fixed at a height of about 1.80m, spread between two walls. Wire cable are running along the longer sides to keep the fabric in as horizontal position as possible. Four points of the fabric were 'activated' by motors, connected to the fabric with cables rolled up on custom-made wheels. The motors with wheels were fixed to heavy (40kg) bricks which kept them from being pulled up by the fabric. The movement of motors was controlled by a microcontroller which was receiving commands from a computer.

details on technical development:
http://emperors-wiki.kucjica.org/doku.php?id=quadricone-installation

hardware

the ceiling:

· stretchable fabric, 2.25x7m

· 2 wooden bars, 5x5cm, 2.25m long

· 2 wire cables, 7m long

· hooks, screws, staples…

the floor:

· 4 HiTEC ultra torque servo motors, HS-645MG, modified for continuous rotation

· 4 theatre weights to attach motors + 4 wooden boxes around

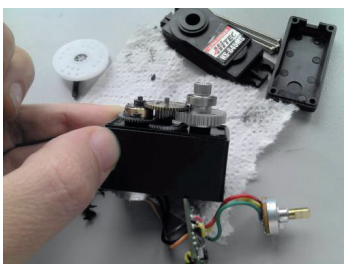
· Arduino Mega (ATMEGA1280) board

· custom shield with connectors for the motors and independent power

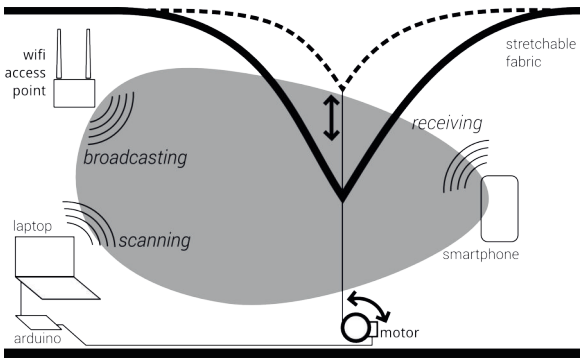
· 24W universal power adapter, 6v

· plexiglass wheels on motors

· laptop (Thinkpad X220 running Linux Mint Lisa) with a built-in wifi card



QUADRICONE INTERACTION SCHEME



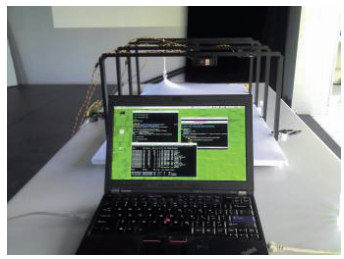
INTERACTION

The following reaction chain connects the elements and participants of the setup: four points on the Quadricone react to the activity of four wireless access points in the surrounding. This activity can be generated by the visitors present in the space or not. Accommodated by high stretchability of the fabric, the shape of the fabric modifies, creating obstacles for movement of visitors under the Quadricone 'skin'. Visitors react by modifying their browsing activity (usually trying to generate more network traffic) to the desired effect they want to have on the 'skin' (making the space more comfortable or claustrophobic).

The overall network traffic in the space is scanned, using the aircrack-ng software. The results of the airodump-ng command are logged and fed to a custom-made programme which is reading the number of packets for each network. The programme takes four most active networks and compares the current number of packets on each network to the previous one, in an interval of 1s. It then makes the decision on the movement of motors accordingly, one of 5 possible cases. The reaction ranges from doing nothing (none or too small change), small movement of about 3cm (rolling the cable down for 0.5s in a lower speed), slightly bigger movements of 5 to 8cm (rolling the cable down for 0.5 to 1.5s in a higher speed) to extreme movement of about 10cm (rolling the cable down for 2s in high speed). Because motors could turn continuously, they could theoretically roll on full length of a rope, pulling the point where it was attached down by 2m. In practice, they were limited by their strength and the overall pressure in the fabric pulled from four sides to lengths of about 30-40cm.

HARDWARE

The shorter sides of the 7m long, 2.25m wide sheet of stretchable fabric are stapled to wooden laths, which are then fixed to two walls, stretching the fabric in between. Two wire cables are running along the longer sides to keep the fabric as flat as possible. Small hooks are attached to four different points on the fabric, with a 2.2m long rope tied to each. The other side of the rope is rolled up on a custom-made wheel out of plexiglass, which is attached to the motor. Four HiTEC HS-645MG ultra torque servo motors were modified for continuous rotation to allow for a greater movement of the fabric.Motors were controlled by an Arduino Mega board, connected to a laptop.



SOFTWARE

Quadricone is using Open-Source software working under a Linux OS. Network scanning is done using Aircrack-ng, a set of tools for auditing wireless networks. Arduino is running Arduino-Python 4-Axis Servo Control firmware by Principialabs, interfaced with the associated servo library for Python. The programme that connects the network traffic data to the microcontroller is written in Python and uses serial communication to control the motors.

software

· aircrack-ng v1.1

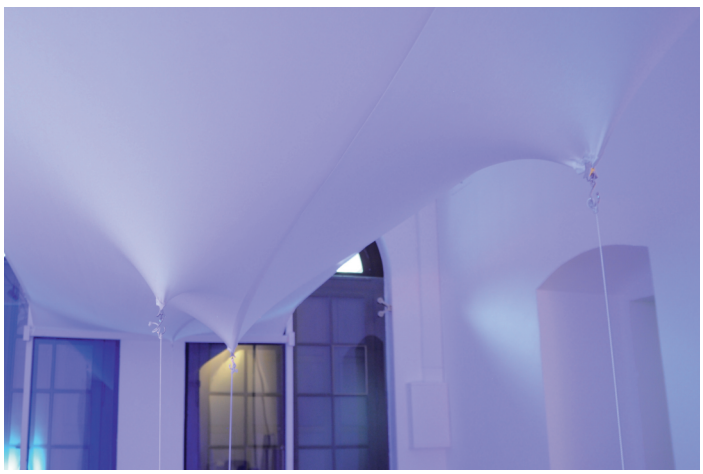
· Arduino-Python 4-Axis Servo Control firmware by Principialabs, with associated

· servo.py library

· python script quadricone.py (Python 2.7)

EXPECTATIONS

– Observe the quality of interaction; do the visitors make the connection between their actions (i.e. watching an online video) and the reaction of the installation; once they understand the principle, do the visitors change their behaviour to achieve a particular impact on the installation (i.e. try to generate more or less traffic)



Quadricone presentation notes

"Les Urbaines". Espace Arlaud. Lausanne
December 2012

PRESENTATION CONTEXT

Group exhibition of SINLAB research projects and developments as part of the lab's present at Les Urbaines festival in Lausanne

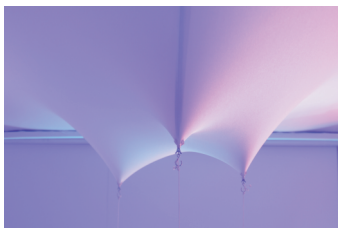
AUDIENCE

General festival audience, including colleagues from the SINLAB research laboratory.

OBSERVATIONS

The installation was very responsive to the presence of wireless networks in the exhibition space, especially when considered that their activity was very low. The 'cones' were moving down and up, their movement clearly visible to the visitors.

The space where the installation was tested with audience proved to have almost no active network traffic. There were numerous access points visible in the scan, but none of them had any active traffic. Furthermore, we had no access to any of the available networks in the space, making direct interaction impossible. Because of this, the system listened to the beacon frames instead of data packets. Beacon interval depends primarily on router settings but its reception depends on signal strength and distance. It was thus used to display the activity and availability of different access points.



Quadricone's purpose was to go further from a visual representation of these data, rendering them physical and thus allowing for an immersive experience. One important aspect of the installation is exactly this openness to inputs from different 'locations.' It does not offer merely a 'scan' of this dynamic environment, but it allows for interaction with the users, therefore becoming a physical interface.

However, in offering a 'flattened' view of wireless network activity, Quadricone might have had mislead the audience into believing the setup was a geographical mapping of networks. One very important questions for future development is therefore: to which extent does it matter who generated these signals and what are the consequences for interaction with them? What is the clarity of interaction in such a system, when the input is translated to a linear mechanical movement of the 'peaks'? What further possibilities of interaction with wireless communication signals exist?

Avoid the idea of a 'range' of reaction - reality has no range

Explore different ways of representing Wi-Fi which are more true to the nature of the data

Explore feedback - measure the elasticity of fabric, put people in a more direct relationship with data

Connect the system to other types of wireless network traffic so that people wouldn't have to switch from their preferred service (3G or Wi-Fi)

TO DO

Appendix 3
Connect or Not

Connect or Not

3.1

"Stage Digital II", Bühne A, ZHdK, Zurich
November 2013

Connect or Not offers an ephemeral aesthetic experience of wireless communication. It renders the presence and the intensity of traffic (GSM and WiFi) into an interactant, manifested in the dynamic change of lights. It uses Connect or Not Android app to quantify network traffic and communicate this information to system that controls lights.

This iteration of Connect or Not was produced as part of a collaboration with the ZHdK department of Performing arts and Film and ICST and was presented at Stage Digital II: The Making of Atmosphere at Buhne A in Zurich. The nature of this collaboration was open, one of the goals being to share our progress with people working in closely related fields (stage design, sound design, performing arts)

details on technical development:
http://emperors-wiki.kucjica.org/doku.php?id=connect-or-not-zurich

hardware

· 2 Wybron Cygnus VN100 RGBW LED spots

· Arduino Uno

· DMX shield by Conceptinetics

· laptop (Debian Wheezy)

· smartphone (Samsung Galaxy S3, Android 4.0.4)

software

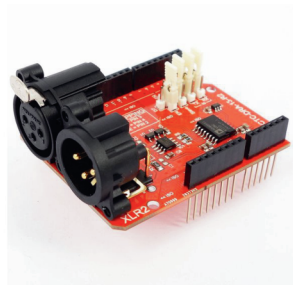
· Connect or Not app, v 1.0

· Arduino DMX Simple library, customized

· arduino.pd

· puredata patch wybron-setup.pd

Wybron 6510 Cygnus 200W Color Wash

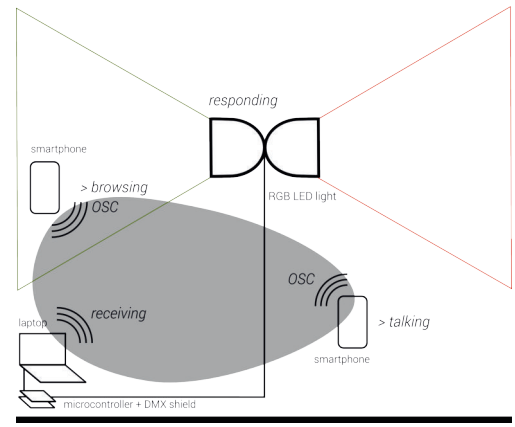


DMX shield by Conceptinetics

THE SETUP

Two RGB theatre LED spots, set in front of a curved white wall defined the space of interaction. Two actors dressed in white and each equipped with a smartphone, interacted with the system. They were talking to each other on the phone, taking pictures of the audience and uploading them to social media websites, sending SMSs to people outside of the presentation space, and browsing websites. The colours and flashing of the projectors were determined respectively by data usage, phone call length and number of text messages. The speed of change was determined by the intensity of the traffic.

CONNECT OR NOT INTERACTION SCHEME

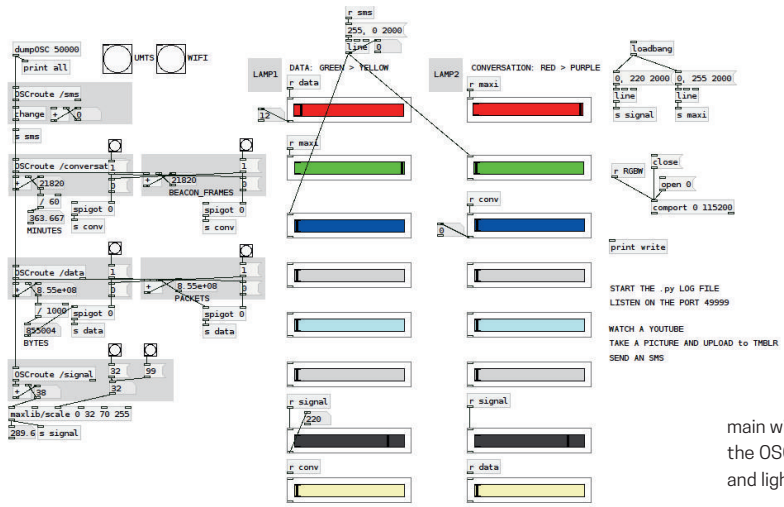


INTERACTION

The presenters used smartphones to make phone calls, send SMS's, browse websites and upload images they took to social media. This traffic would cause a change in the colour of lights, according to the type of traffic (calls, smss, data). The amount of traffic would influence the speed of light change, thus the system would get more dynamic when there was more data passing through networks. The light change would indicate to the presenters what their activity looks like, when interpreted with such a system. This would in turn cause them to try other types of activities and observe the effects.

HARDWARE

Two Wybron 6510 Cygnus 200W Color Wash LED stage lights were used. An Arduino UNO with a DMX shield by Conceptinetics was connected to the laptop. The DMX shield was used for communication with the lights. The data for interaction was collected through the Connect or Not Android app, in its version 1.1. The data was communicated via OSC protocol to a PureData patch listening on the laptop.



main window of the PureData patch with the OSC server (dumpOSC -> OSCroute) and light controls

SOFTWARE

Android app Connect or Not, developed in collaboration with Louis Magarshack within a semester project with SINLAB. The development of this first phase was based on the open source Netcounter application by Cyril Jaquier. OSC comunication and signal strength measurements were implemented on top of it. On the other end, PureData was used for listening (dumpOSC object) and controls (through serial communication with Arduino, using comport object). Arduino was running a customized DMX library.

EXPECTATIONS

- Improve the input into the system - take more types of traffic into account, not just WiFi;

- Consider shareability of data

- Improve the ease and flow of interaction; have the participants use their devices in a natural way;

- Test the idea of Out-bodied interaction

CONNECT OR NOT presentation transcript

"Stage Digital II", Bühne A, ZHdK, Zurich
November 2013

PRESENTATION CONTEXT

Research symposium "Stage Digital II: The Making of Atmosphere" organised in collaboration between ZHdK departments Institute for the Performing Arts and Film (IPF), Institute for Computer Music and Sound Technology (ICST), Interaction Design (IAD), Farb-Licht Zentrum (FLZ) and Scenography, at Bühne A in Zurich.

AUDIENCE

Invited researchers in the field of theatre and performance studies, interaction design and architecture, including colleagues from the SINLAB research laboratory as well as performing arts professionals and students from the different departments involved. There were in total around 15 people following the presentation and participating in the discussion.

OBSERVATIONS

The app took a little bit of explaining in the beginning but the actresses swiftly grasped the principle and started moving in the light while texting, taking and sending pictures. The app counted traffic generated by these actions and broadcast messages over OSC protocol to an OSC server listening on a laptop.

The use of OSC protocol for communication was beneficial for the concept of 'shareability' of data. It allows any device which can be connected to a WiFi to use the UDP layer to receive the stream of data without authentication or any other intermediary step. In this way, it bridges common compatibility gaps both in software (OS, software where OSC server is running etc) and hardware (manufacturers, models, types). However, the requirement for all devices to be on the same network can sometimes prove unproductive, especially when devices seamlessly switch networks.

Although it was relatively easy for the presenters to engage in interaction with the system, it proved quite difficult for them to perceive the feedback. They stated it was rather stressful having to use the phone all the time for different activities, in this somewhat artificial situation. They had very little time to observe and enjoy in light changes, as they had to be constantly busy interacting with the phones.

The idea to develop a 'language' of wireless transactions proved interesting to the audience but needed more development. The colour and intensity linked to different network activities, questions like "What does it mean 'green'?" were raised.

PRESENTATION (summary)

Connect or Not is an interactive installation that offers an aesthetic experience of wireless communication. It renders the presence and the intensity of traffic (both GSM and WiFi) into an "inter-actant", manifested in the dynamic change of lights. It is an experience catalyst for interacting with 'herzian' space. The input in the system is data gathered with an Android app, Connect or Not, which was developed in collaboration with Louis David Jean Magarshack.

Connect or Not establishes a setting where waves are actants, taking an active role in the interaction with the performers. The performers, from their side, try to interact with the change of light through by creating more traffic.

PRESENTERS FEEDBACK

PRESENTER 1: I have to be busy all the time. I can't just enjoy what is happening, my experience is more like “Oh, I have to make more input now!”. It could be interesting to have statistic showing in what way and how much people are active. A house of these letters. The colours. A daily log of activities.

PRESENTER 2: I think it's interesting how light changes... although I am very concentrated on what I'm doing and I don't have the outside view, I sense the lights, they are kind of atmospheric.

DISCUSSION

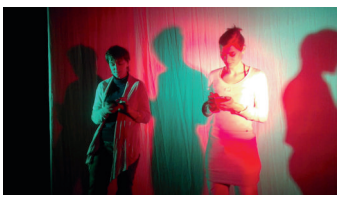
Q[1]: This language - it's a change of colours. It is your choice, right?

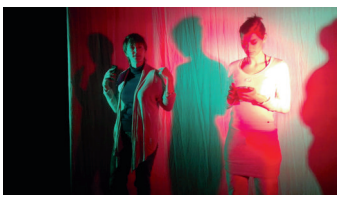
A: Signal strength affects the intensity of the lights; The amount of data - be it through the cellular or the Internet protocol - changes one of these two lamps more or less dynamically into another colour.

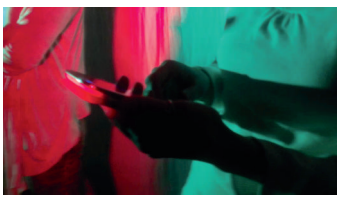
Q[1]: Let’s talk about Normality. What does it mean 'green'?

A: The light circulates through states. In order to open the system to as many inter-actants as possible, I need to be able to somehow demonstrate these changes while including either 10 or 100000000 data. I was trying to scale it down and have a language made of colour ranges, where each colour would represent an activity. But it is hard to perceive the subtlety between a colour representing some sort of value. It is ungrateful to use the colour of the light to indicate quantity. Thus, I opted for a circular 'movement' or 'colour loops'. I thought that gives more of an idea of what's going on with this kind of dynamic change.

Q[1]: That's a way of visualisation? What's your idea of content, of dramaturgy, of aesthetic, of a production?







A: This system is not meant for a (theatre) piece that exists already. I need this experience when people are using it to see what could actually be an interaction that's interesting for somebody to watch, and which is at the same time actually doable by humans. It's quite hard to do all this stuff all the time (the marginal activities like texting, browsing, uploading photos) and not do anything else. So we need to find a ratio between "being in" and "being out" that gives an interesting result.

Q[2]: Does it only (inter)react when I send an SMS or also when I receive?

A: Both. Everything that is served to your phone.

Q[2]: It would be interesting to know while somebody is typing…

A: Yes, it doesn't have to react only to what it does now. This system is in a sense 'mono'. It only reacts to the phone, and yet we are talking about perception. We could have much more data input in it. But it is a prototype of the way it would react with this data, and we can combine it with other data. What I envision at this stage is very a physical system, and I was thinking without the intending to actually build something, of a kind of screen, that would bend... and relax, demarcating smaller areas, connecting them and disconnecting from each other like a dynamic labyrinth. An architectural element that would be displaced easily. But I wanted first to test the system with lights and very slow and atmospheric changes.

Q[3]: How many dimensional is this work? What is the difference from the previous iteration (Quadricone)?

A: Here, you are kind of washed with light, I like this idea. How to actually perceive the change: you have the data come onto your skin! The lights really come to you, you don't have to watch them. I would still like it to be more physical than lights. This only means it shouldn't be a screen or something that needs to be perceived by reading, with your eyes. Eyes are busy with the phone.

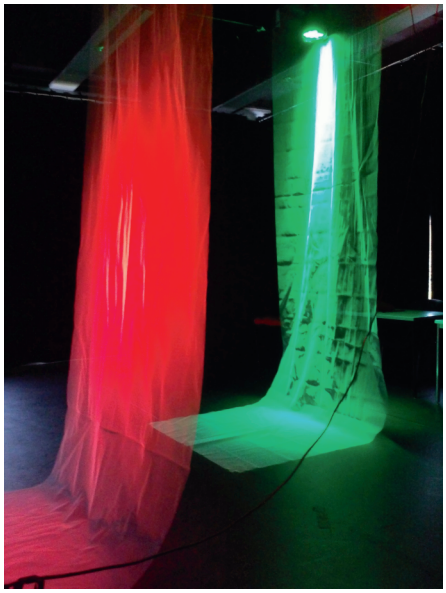
Q[1]: How do you see it on the stage?

A: I see it as a possible element of a theatre piece, not as a piece in itself. Because it uses a very simple language. I see it as a kind of performative tool that can be part of another, larger piece. Perhaps it can work with physical objects that are moving. Something that's actually more dramatic.

Next time we could write the numbers to call.. or set up a free number that you can call which in turn affects the system. Or set up a number that's very expensive to call and then fund the project with it.

EXPERIMENTS WITH COLOUR PROJECTIONS

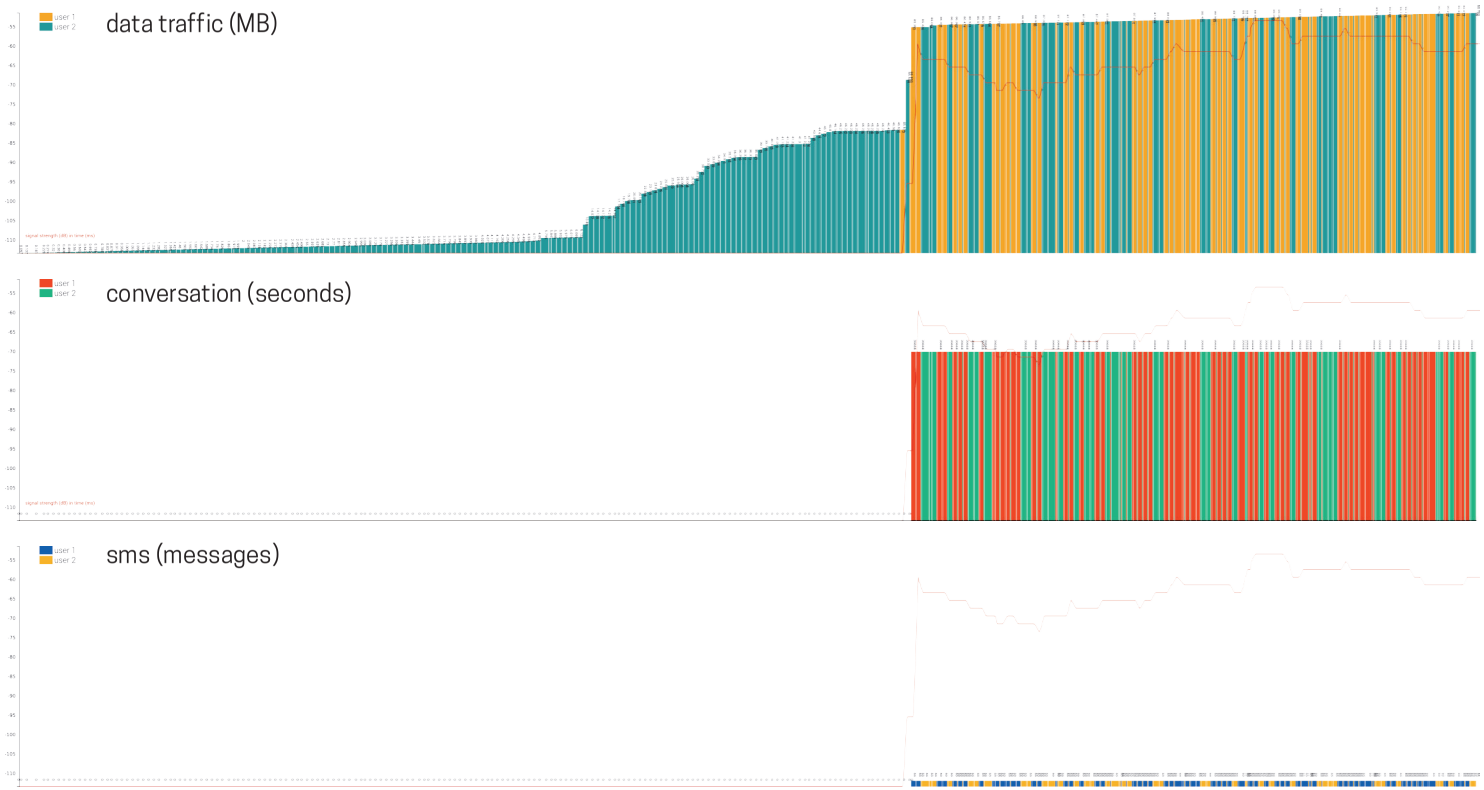
Prior to the Zurich presentation, some basic experiments with the way light would appear in space were conducted. Projecting on the walls and floors, furniture and tulle netting were tested, before deciding to use human bodies as the main receptor for the lights. Below are some images from these experiments, using tulle in different states of the system.

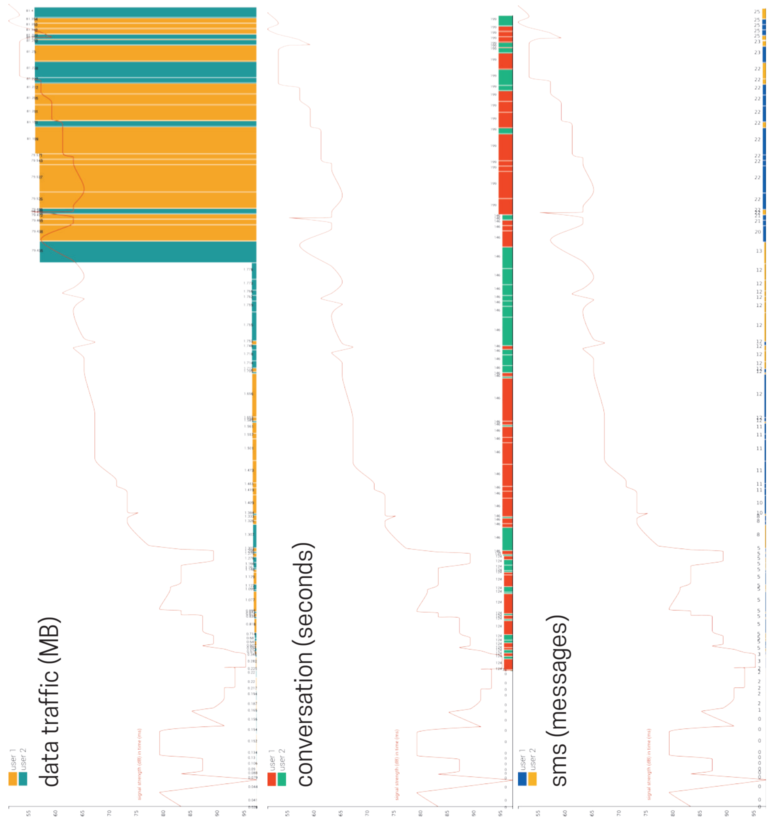


CONNECT OR NOT: visualisations of data on network traffic

Data packets are counted and represented in megabytes (MB); conversation and sms, measured in seconds or per message are converted to the same unit as data (1s = 1664bytes at 13kbit/s; 1sms -= 140bytes), showing a comparable value; value in seconds is indicated in the graph; signal strength is indicated too, with a changing line in red

Bühne A, ZHdK, Zurich, 24 November 2013, from 13:39 - 14:25





presentation at "Stage Digital II", Bühne A, ZHdK, Zurich, 28 November 2013, from 13:25 - 13:52

Connect or Not

3.2

Zavod K6/4 (Kersnikova), Ljubljana, Slovenia
February 2014

Connect or Not installation was presented using the existing light infrastructure of the Klub K4 in Ljubljana. It collected data through Connect or Not Android application, which was made available in the Google Playstore for this occasion.

This iteration of Connect or Not was produced as part of an artistic residency at Zavod K6/4 (today Kersnikova) in Ljubljana. It included collaboration with the technical team of the venue and a workshop open to participation. The results of these collaborations significantly improved both production and perception of the work.

details on technical development:
http://emperors-wiki.kucjica.org/doku.php?id=connect-or-not-ljubljana

THE SETUP

The system was seamlessly embedded in the existing club space, using six Robe scanners (moving lights). The lights were controlled through an Arduino with a DMX shield. A puredata patch running on a laptop was listening to the OSC transmission on a particular channel (determined in the Android app and same for all smartphones) and controlling movement and colour of the lights. Visitors were invited to move freely through the space, communicate with people present as well as remotely and observe the effect of this communication on light behaviour.

hardware

· 6 Robe ClubScan 250ct moving lights

· Arduino Uno

· DMX shield by Conceptinetics

· laptop (Thinkpad X220 running LMDE Mate Edition)

· TP-Link TL-WR703N wireless router (OpenWRT squashfs factory firmware)

· smartphones [tested with:

- Samsung Galaxy Mini (GT-S5570)
- Sony Ericsson Xperia U (ST25i)
- HTC HTC Desire C (golfu)
- Samsung Galaxy Star (mint)
- HTC HTC EVO 3D X51 (shooteru)]

software

· Connect or Not app, v 1.1

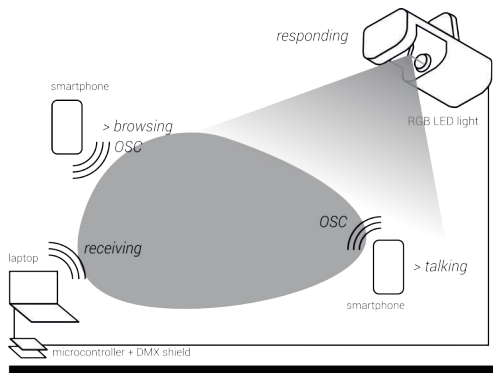
· Arduino DMX Simple library, customized

· arduino.pd

· puredata patch with OSC server and lights controls

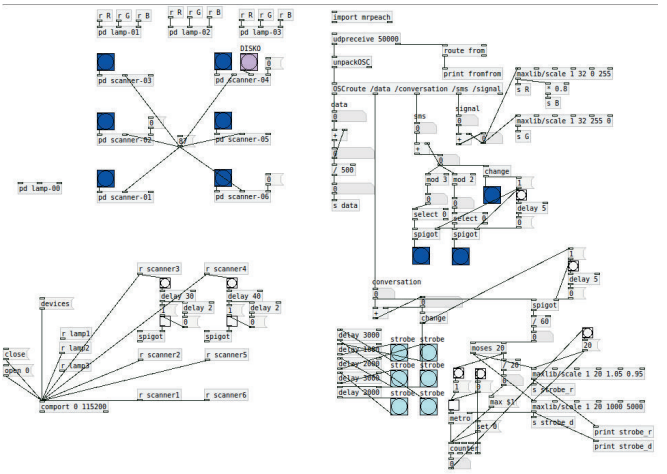
Robe ClubScan 250CT

CONNECT OR NOT INTERACTION SCHEME

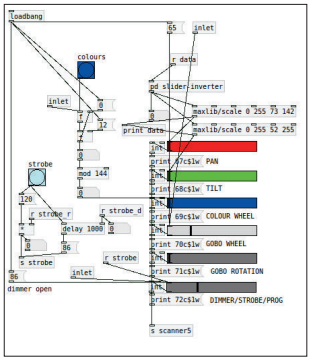


INTERACTION

Once the app was installed on visitors smartphones (available in Google Playstore), they initiated the OSC transmission (by pressing "play" on the screen) and the system started receiving their data. A laptop with a PureData patch (details below) was used for this purpose. The OSC server (made of [udpreceive] -> [unpackOSC] -> [OSCroute] objects) was indiscriminately receiving all communication on port 5000 within the UDP layer of wireless network created for the event. By default, the app sent a new reading every 10 seconds. Every time a reading was received the system would react - recalculate the position (TILT+PAN, see patch details on the next side) and the colour of the lights. Data packets (measured as the number of bytes sent and received by the device) would cause lights to move up, in proportion with the amount of traffic. Conversations (measured as the final duration of a call) would cause flickering of all lights, the speed of which was determined by the duration of the call (the longer the slower). An sms would reset all the ligth colours, counting both sent and received messages. Finally, signal strength (measured in db as the availability of base station's signal) would determine the intensity of lights.



main window of the PureData patch with the OSC server [udpreceive] -> [unpackOSC] -> [OSCroute] and light controls [print ch+val(



HARDWARE

Six scanners Robe's ClubScan 250ct acted as moving lights, projecting a cones of light in different directions. The scanners were daisy-chained and controlled from an Arduino Uno with a Conceptinetics DMX shield, using standard DMX communication (channel+value). DMX messages were generated in a puredata patch running on a laptop (Linux Mint Debian), connected to the Arduino through a USB serial port. All devices (laptop, smartphones) had to be connected to the same wireless network in order for the OSC transmission to work. TP-Link TL-WR703N wireless router with OpenWRT firmware acted as an access point. A fog machine was used to emphasize the light effect.

SOFTWARE

Android app Connect or Not in its' 1.1 version was installed on visitors phones. The app development is detailed in Chapter 6.2 of this thesis. The app used OSC communication protocol to transmit data through the UDP network layer and thus required all devices to be connected to the same wireless network. PureData patch with the OSC server and light controls was developed for this presentation, according to the specifications of elements used (ClubScan 250ct, Arduino DMX Conceptinectis) shield. The interface between the main controls (puredata patch) and lights - Arduino with a DMX shield was using a customized DMX simple library (pin 2 set to HIGH, using pin 4 for output).

EXPECTATIONS

– Observe the quality of interaction; do the visitors make the connection between their actions (i.e. watching an online video) and the reaction of the installation; once they understand the principle, do the visitors change their behaviour to achieve a particular impact on the installation (i.e. try to generate more or less traffic)

- Spontaneity of use and manipulation: once the application is installed, how (un)natural it is for the visitors to use their devices to trigger a reaction from the system

CONNECT OR NOT presentation notes, interview

Klub K4, Zavod K6/4 (Kersnikova), Ljubljana, Slovenia
February 2014

PRESENTATION CONTEXT Exhibition - demonstration at the K4 underground space, showing the progress made during the artistic residency at Zavod K6/4 (today Kersnikova) in Ljubljana.

AUDIENCE General audience, made of about twenty people. The majority (more than 60%) were working in culture and were practising artists or art students (including the members of Zavod K6/4 team involved in organisation and production of cultural events). Some were participating a workshop I gave about the system (6); some were their friends; others were completely unfamiliar with the system (5-6).

OBSERVATIONS The majority of event participants had smartphones compatible with the application and were able to contribute to the dynamic change of lighting in the space. They performed routine tasks on their phones (check mail, twitter, send sms or make phone calls) and observed light changes.

The atmosphere was quite spontaneous and lively, people really took up to their smartphones and interacted with the system in groups. They also called or texted their friends who were not present in the space, extending the reaction to a wider context of wireless communication. The requirement to connect to the same network was perceived as an obstacle to spontaneous collection of data.

The strongest reaction of the system happened when somebody connected to it for the first time - all the data, call duration and messages made on the phone would be sent to the system at once. In this case it was evident to the person that the reaction was a response to them. Otherwise, the visitors could not self-identify with the smooth and relatively constant changes in the light environment.

Generalisations about the experience were made combining direct observations and an interview, conducted with 3 participants. They were asked about their familiarity and expectations from the system, as well with the space where it was presented. They were able to observe some differences in reactions depending on types of communication (browsing, calling, texting). They found it both interesting to observe others interacting with the system as much as trying to interact themselves. Finally, they considered the setup rather successful in terms of focusing on this unusual type

of interaction. It did change their point of view on space, while the way the ambience of the room was reshaping was not obviously related to wifi signals or wireless communication in general.

Implement a way for self-identification of users **TO DO**

Implement position tracking, make the system's response more spatial

Experiment with more tangible, tactile interaction again

[1] Cultural worker, involved with organisation in the host institution **INTERVIEWEES**
[2] Artist, workshop participant
[3] Artist, unfamiliar with the system

Do you have previous knowledge of the space? **INTERVIEW**

[1]: Yes I have.

[2]: I knew the place where installation was set up before, yes.

[3]: No. I have never been to K4.

What did you expect to experience, knowing what the installation was about?

[1]: I didn't have any specific expectations. I was more curios to see how the whole installation works and what kind of physical responses I will experience in the club being involved with installation.

[2]: I expected something similar, because we worked quite similar things on workshop. So it was about app who reads off your phone signals and transate it to something we could sense in a space. We got the lights changes.

[3]: To see an interaction between my mobile phone usage and the light changes in space

What did you first think you should do?

[1]: I thought I have to download the app and try to experience the installation on my own.

[2]: At first I felt I need to start my app. (Because I had it installed already)

[3]: I didn't really think so much. It was more of a habit. Checking mails, twitter and perhaps I would make a phone call (not while in roaming, though!)

How difficult was it to perceive the reaction from the system?

[1]: For me it was quite confusing because I didn't know what a different reaction from the system means. Because of more people connected at the same time I didn't know what kind of reaction was a response to my action.

[2]: It wasn't difficult to get the feedback from it.

[3]: I found it hard to filter out what my action was causing to the system.

How immediate was the interaction, in your opinion? Did the system respond in the way and as quickly as you expected?

[1]: For the reasons I have mentioned in the answer above (more people involved at the same time and not knowing what does a different reaction means) I wasn't sure if the reaction is a reaction to my action.

[2]: It was quick as the app sensed those signals, quite accurate.

[3]: i didn't play enough with it to really tell if there were patterns which i could anticipate.

Were you able to observe the subtleties of different data passing through the system - when an SMS is received, when someone is browsing a lot, when a conversation happened... Was this readable?

[1]: I was able to observe the subtleties but I didn't get the every meaning of the reaction. For me I think it would be easier if I would read or hear or see an explanation before experiencing the installation.

[2]: I was able to differ light signals from sms or conversation... It was pretty much obvious.

[3]: Messages yes, browsing not so much. I think it depends on the amount of people participating during the installation. If I would be the only person with my phone connected to the system, I could perhaps easier understand the subtle correlation.

Was it more interesting to observe the others or interact with the installation yourself?

[1]: Both.

[2]: It was more fun to do it by yourself, because if I would just observe I wouldn't know what did they do to get the installation to display it.

[3]: To see others.

Did the interaction with this installation affected your experience of space in any way? Please describe.

[1]: I think the space was really good to focus on my and others interactions with the installation. There were no other distractions. The space has looked amazing with the effects we were making using the installation. Just seeing the space, changing lights and not knowing for the installation I wouldn't know that this kind of atmosphere is made by using wifi signals.

[2]: Hm, I guess I could say this installation affected my point of view on space in some way. I would

say, this installation is perfect for overtaking control, always knowing what is happening around you. It makes it (space) more under control and safe, since you can read signals around you.

[3]: Difficult to tell. The significant thing was not only the changing light was reshaping the ambience of the room, but the fact that all the people inside were "forced" to use their smartphones made them almost look like anti-social. just utilizing their phone instead of communicating (an interaction which I would expect from a club)

How easy to install and use was the Android application for you? Do you have any suggestions about additional information the app should send data about? Do you have any suggestions for the app at all?

[1]: With a friend's help it was easy to install it. However, I think it was a bit to dark in the space to read the leaflets with the instructions. In my opinion it would be good that the app would have some basic info explaining eg the meaing of basic reactions.

[2]: App wasn't a problem to install, it was really easy. One thing that bothers me, is that sometimes the app crashes and then it shows on, even though I don't use it right that moment

[3]: Very easy. Record, playback modus should be more intuitive. Perhaps an realtime log-visualization would be nice. And perhaps a setting to turn on/off any notifications from the app.

Connect or Not

3.3

Pavilhao CIVIL. IST. Lisbon
September 2014

A tangible version of the Connect or Not installation was developed during a working period at IST Lisbon. It included the interactive tent structure used previously in the Quadricone installation, connected with custom designed LED lamps whose reaction was coupled with that of the motors. This version of the installation also made use of Estimote location beacons to provide low resolution position tracking and make the system react according to the position of users. The result was an interactive architectural skin attached to the ceiling, whose form and colour would change based on the input from data collected on the use of wireless network infrastructures (using Connect or Not Android app). Starting from a regular arcade as one of the basic architectural forms, the skin would deform with 3G and Wi-Fi network traffic.

details on technical development
http://emperors-wiki.kucjica.org/doku.php?id=connect-or-not-lisbon

hardware

· stretchable fabric, 2.25x7m

· wooden frame from wooden bars, 5x5cm, 2.25x7m

· hooks, screws, staples…

· 4 HiTEC ultra torque servo motors, HS-645MG, modified for continuous rotation

· plexiglass wheels on motors

· Arduino Uno board

· Arduino Mega(ATMEGA1280) board

· custom made shield with connectors for motors and independent power

· 24W Universal AC Power Adapter, on 6v

· 4 custom made RGBW LED light boards

· 3 estimote BLE beacons

· laptop (Debian Wheezy)

· smartphones [tested with:

- Sony Ericsson Xperia Z (C6603)

- Samsung Galaxy Mini (GT-S5570)

- Sony Ericsson Xperia U (ST25i)

- LGE L-01F (g2)

- HTC HTC Desire C (golfu)

- Samsung Galaxy Note3 (hlte)

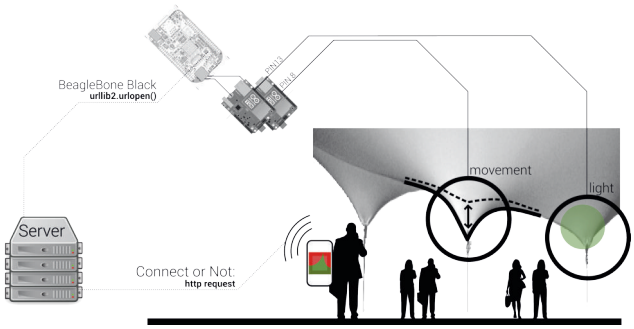
- Samsung Galaxy Star (mint)

- HTC HTC EVO 3D X51Samsung Galaxy Mini (GT-S5570)]

THE SETUP

The system was embedded in the space under a gallery in the Pavilhao Civil building atrium. The sheet of stretchable fabric was imagined as an activated part of the gallery ceiling, covering only a small portion of its length. The fabric was deformed by the movement of motors attached to it by strings, An additional light change indicated the activity of each motor, coinciding with the position of the smartphone to which the system was responding (determined in the Android app installed on the phone).

CONNECT OR NOT INTERACTION SCHEME



INTERACTION

Students, teachers, researchers were introduced to the setup on the first day of autumn semester and invited to install the Connect or Not app. The success rate was about 50% as many of them didn't have Android phones with sufficiently recent system. For the ones who obtained the application, interaction was straight-forward. They tested if the system recorded their traffic (moved the peaks down when browsing) and if it recognized their position. Position tracking was relatively slow and sometimes appeared irresponsive. Estimote BLE beacons broadcasting ranges were overlapping in order to ensure overall coverage which led to blurring of the information on users position.

HARDWARE

A large sheet of stretchable fabric, 7m x 2.25m was stapled onto a thin wooden frame and fixed onto the ceiling of a gallery in the building atrium. Small hooks were attached to four different points on the fabric, with about 3m long rope tied to each of them. The other side of the rope was rolled up on a custom-made wheel made of plexiglass, which was fixed to the motor. Four HiTEC HS-645MG ultra torque servo motors were modified for continuous rotation to allow for a long movement of the peaks (and stretching of the fabric). Motors were controlled by an Arduino Mega board with custom made shield, connected to a laptop.

Above each motor, a high-power (4W) RGBW LED light was installed and used to indicate motor's activity. The lights were controlled by another Arduino Uno board, connected to the same laptop.

SOFTWARE

Android app Connect or Not v.2.1, developed in collaboration with Louis Magarshack within a semester project with SINLAB. The application was further developed to include low-grain position tracking, using Estimote BLE beacons. Besides position, communication of the data from the phone was improved to include direct transmission to a remote server, thus bypassing the necessity for all devices to be on the same network. OSC transmission was preserved, but set to be disabled by default. Interaction was driven by a Python script which queried the data on the remote server and determined the output value for motor movement and light colour accordingly.

EXPECTATIONS

– Observe the quality of interaction; do the visitors make the connection between their actions (i.e. watching an online video) and the reaction of the installation; once they understand the principle, do the visitors change their behaviour to achieve a particular impact on the installation (i.e. try to generate more or less traffic)

software

· Connect or Not v2.1

· Arduino ShiftPWM library

· Arduino diskoLEDron.ino firmware (Uno)

· Arduino Arduino-Python 4-Axis Servo Control firmware (Mega)

· python script, get-values.py

· python libraries servoclass.py and ledclass.py

Connect or Not presentation notes

Pavilhao CIVIL. IST. Lisbon
September 2014

PRESENTATION CONTEXT Presentation at the university campus, Pavilhao Civil, IST, Lisbon. The installation was set up in the atrium, which is used by engineering students (architecture, computer science, civil engineering...) The exact location was in front of architecture studios, on the way to a student cantine.

AUDIENCE Students, teachers. There were several targeted presentations where architecture and computer science students were invited for a demonstration. Doctoral students were also invited for a demonstration prior to a focused discussion in the doctoral room.

OBSERVATIONS The setup provided visibility and attention, located in the large atrium of the Pavilhao Civil building. Being attached to one of its sides, it appeared somewhat out of the way, instead of forcing people to experience it without directly interacting (which was one of the original intentions).

Feedback about the experience was collected at several occasions, primarily in a discussion with PhD architecture students after having visited the installation; a similarly insightful feedback was given by a design-engineering professional, one on one. There were also students of architectures and computer science who were briefly interviewed after having tested the installation.

The users who successfully installed the pap interacted with the installation for a short period of time, until they would exhaust the 'language' of the installation. They would first verify if the system 'saw' them (if their actions were appropriately represented in the changes of peaks height) and if it could track their movement. They sent a few SMSAs and often wanted to make phone calls, in order to verify the diversity of responses. They did not push the interaction any further, by for example engaging group interaction. Instead, they preferred observing others.

Although it was successful in catching attention, the scale and relationship with the space where it was installed was perceived as problematic, or simply too big. The installation was 'lost' in the large atrium and did not provide an intimate space for people to interact. Similarly, this lead to a perception of movements as surface effects, rather than spatial, because they were mostly experienced from outside. Additionally, the structure with peaks in the middle descending towards the floor were perceived as being in the way of the users, discouraging them to experience the

installation from the inside. The meaning of the shape of the peaks was also questioned.

Low-grain position tracking provided an opportunity for self-identification. It was nevertheless not sufficient for users with a similar location and its response time was sometimes too slow to catch the actual movement of users.

FEEDBACK
PhD ROOM
September 16th

It is something **new**, something we haven't really seen before (*novelty). It is good at catching attention.

The **scale** is off, the containing atrium is too big for the installation and it thus cannot have a big impact on spatial experience of people passing by. The **location** is also problematic, as it gets lost in the atrium and people are shy in such a big space - they won't interact in a open way; the space is not intimate enough to explore, people are shy in front of everyone. It must be installed in a place where you have to go (like an entrance, a narrow corridor; its size and position must make it **unavoidable**

It is a **sufrace**, rather than an architectural **effect**. Do the shapes have more meaning? Maybe use less abstract shapes in the future? What about music (other outputs), foldable structures? There are three levels of discussion: the technological approach, the interaction design and the aesthetics; they (PhDs) are firstly interested how it looks and then how it works; With the strings and bricks (holding motors on the floor) being in the way, it doesn't encourage you to go in but to **stay outside**; The reaction is not so amazing (only one direction, up down)

INDIVIDUAL EXPERT FEEDBACK
September 17th

Scale is too small; there is not enough space for self-identification;

Increase identification, gamification (find yourself and what are you causing exactly)

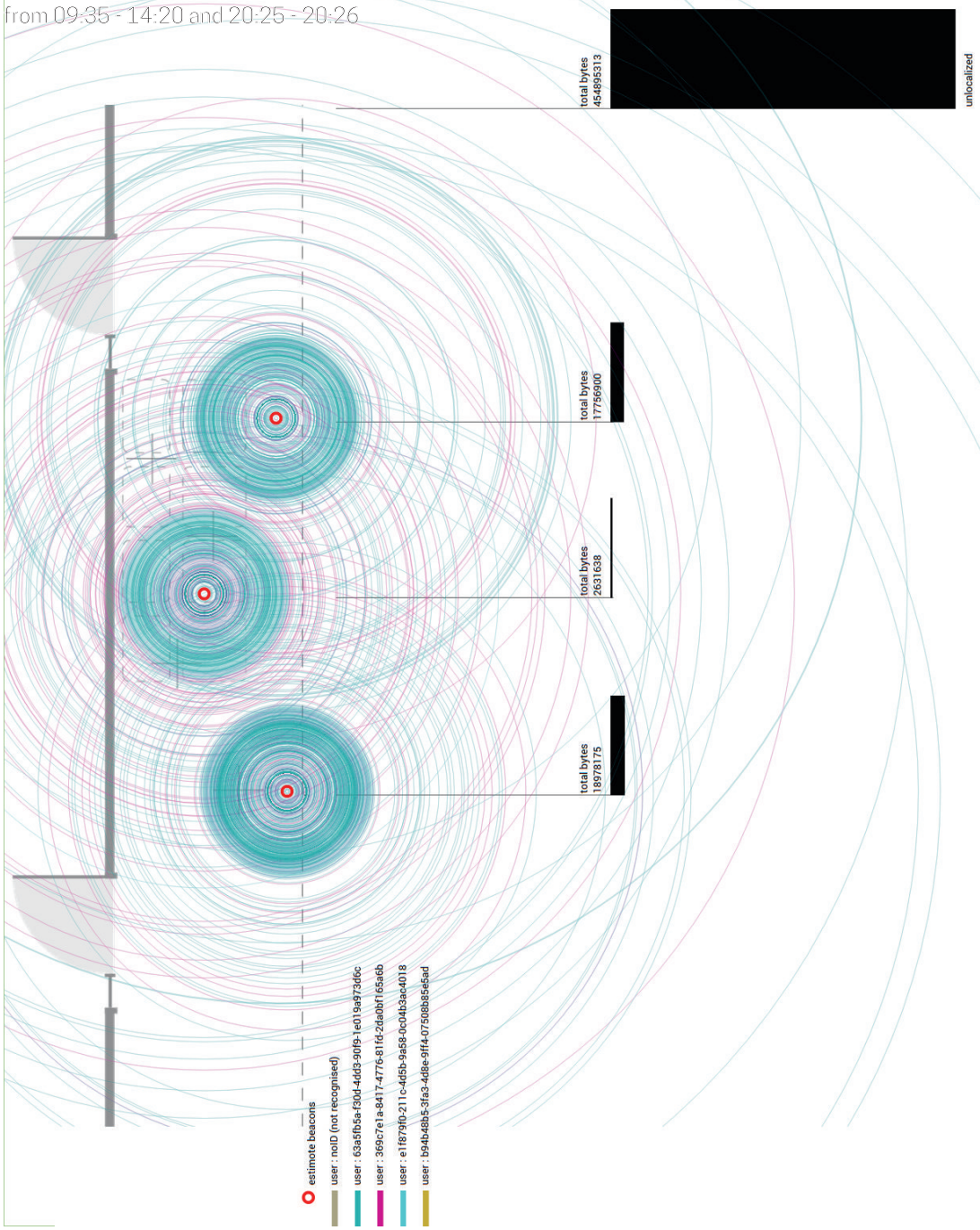
Connect or Not system with all points active and a lot of traffic (above).

The data gathered using the Connect or Not application with indoor positioning (Estimote beacons) is visualised on the following pages. The recording was done over the course of three days, from 15. to 17. 09. 2015. Overall, 10 different devices installed the application (8 different models listed in the "hardware" box at the beginning of this section). When active, the devices were sending messages every 5 seconds, updating the system about the phone's proximity to an Estimote beacon (or "0" if no beacon was around), the number of bytes, sms and conversation minutes since the last time the message was sent. Visualisations show accumulation of these messages, distributed in space (according to the Estimote beacons positions). Different users are presented by different colors, and the size of a circle is proportional to traffic load. Total bytes per position are also included, represented by the size of a black rectangle below each position.

A typical message from a device to the server looks like this:
message ID ; phone ID (annonymised) ; timestamp ; bytes (n) ; conversation (min) ; sms (n) ; estimote ID

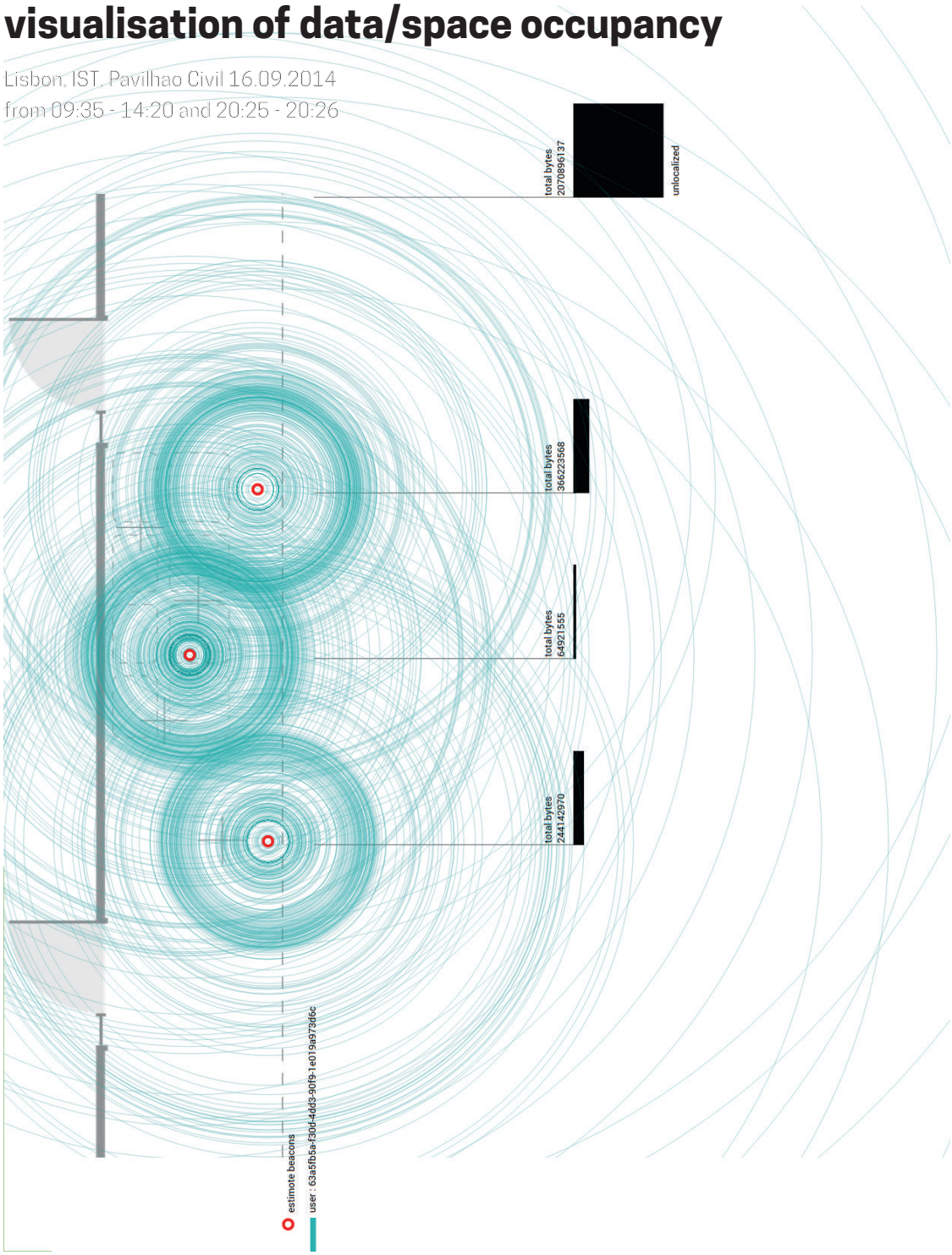
visualisation of data/space occupancy

Lisbon, IST, Pavilhao Civil 15.09.2014
from 09:35 - 14:20 and 20:25 - 20:26



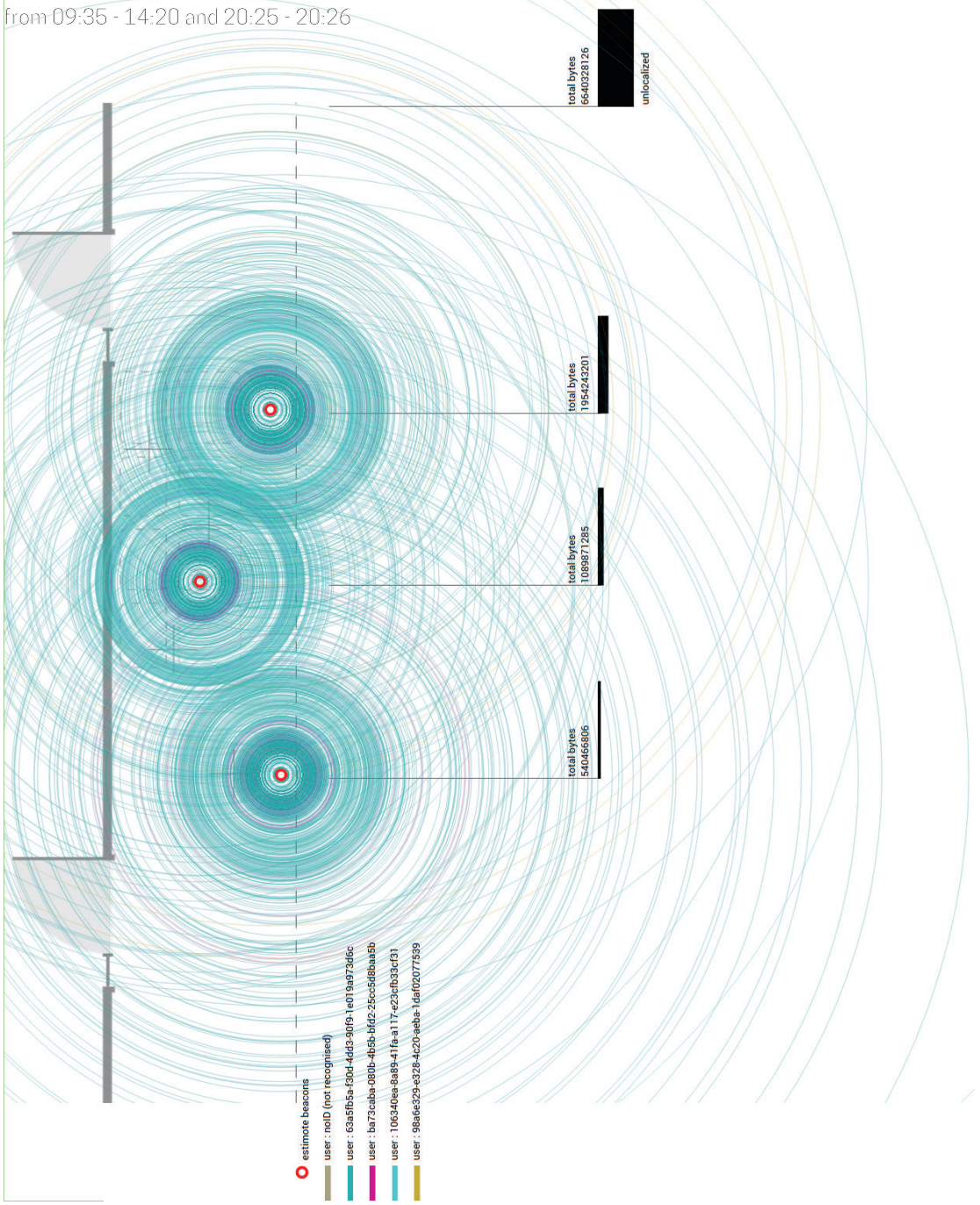
visualisation of data/space occupancy

Lisbon, IST, Pavilhao Civil 16.09.2014
from 09:35 - 14:20 and 20:25 - 20:26



visualisation of data/space occupancy

Lisbon, IST, Pavilhao Civil 17.09.2014
from 09:35 - 14:20 and 20:25 - 20:26



Appendix 4
Position tracking with Connect or Not

comparison between precision of the Redpin indoor positioning system implemented in the Connect or Not Android app and Estimote beacons. Tests conducted in the BC building on the EPFL campus, between offices BC121 and BC117 (both roughly 7x7m)

The following images document the position tracking function of the Connect or Not application. Position tracking relies on two independent implementations: Bluetooth beacons from the Estimote company, and Wi-Fi fingerprints. Estimote beacons broadcast a coninous signal with their ID and once a phone is in the range of a beacon this information is written in the application database. Wi-Fi finterprinting is using the Redpin localisation system, developed by Philipp Bolliger and colleagues at ETHZ (see e.g. Philipp Bolliger, 'Redpin - Adaptive, Zero-Configuration Indoor Localization through User Collaboration'). Fingerprinting consists of scanning for surrounding Wi-Fi networks and Bluetooth devices while standing still. The key idea is that the set of networks in a given spot is enough to identify it uniquely.

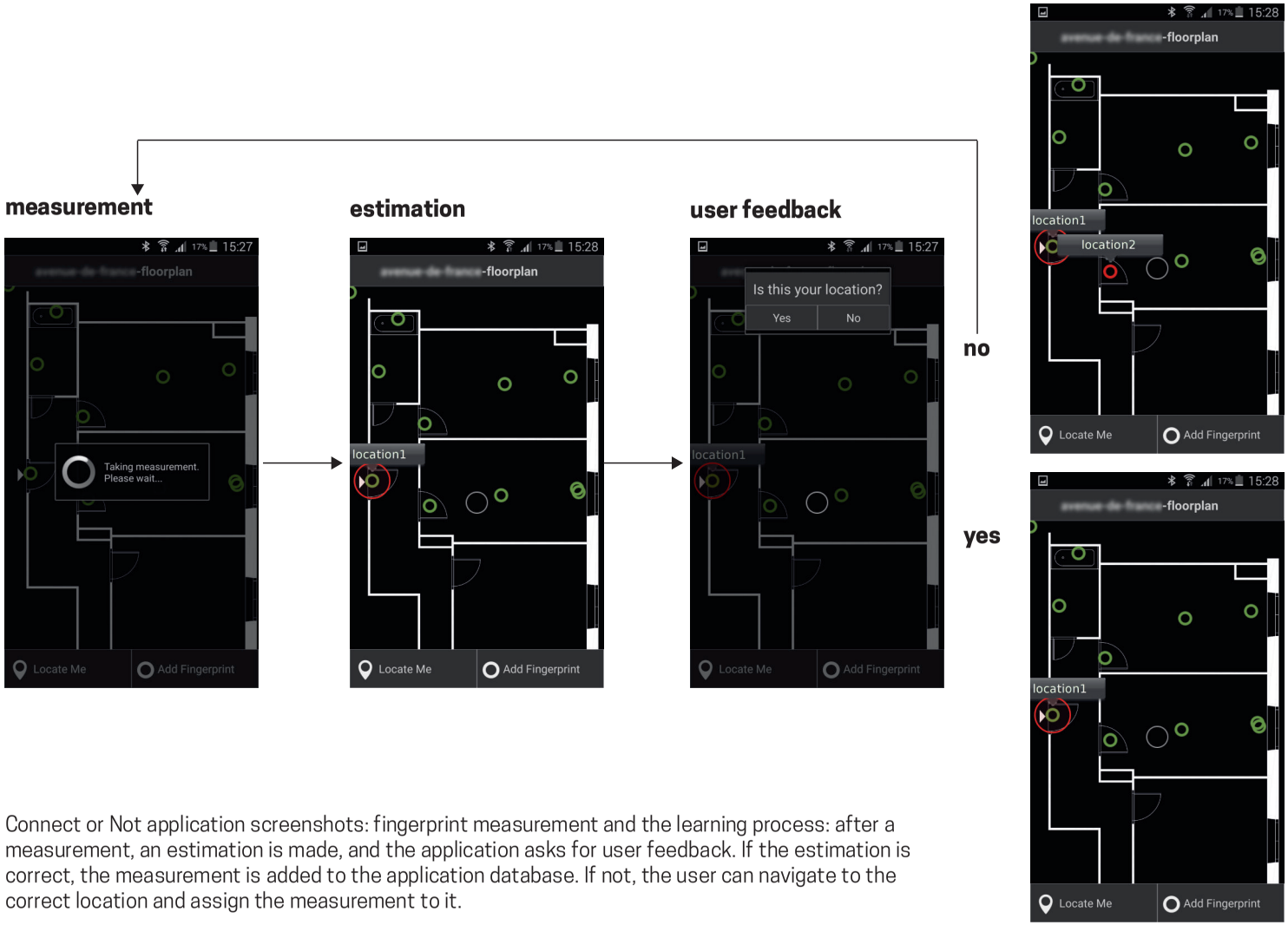
Measurements were taken at two occasions, with a period inbetween used for improving and teaching the system. Teaching consists of taking multiple measurements while standing still at an already measured location and correcting the system's estimation of the device's position. If the system localized the device correctly, the user answers "yes" to the opo-up which appears after the measurement. If the location is wrong, the user is asked to select the correct location on the screen.

First tests were recorded in December 2014. Movement of the smartphone (thin yellow lines) between 9 positions (yellow circles), which correspond to predefined Wi-Fi fingerprints, is tracked by two systems: one is based on Estimote beacons (red circles) the other on Wi-Fi fingerprints (green circles). The information on the actual position and the system's estimation is a combination of the application data and notes made by the person measuring on their actual location.

These first measurement show a very low recognition rate for the Wi-Fi fingerprint system, while Bluetooth beacons demonstrate a certain accuracy.

After the learning process, new tests were recorded in August 2015. We can observe a growing recognition rate of Wi-Fi fingerprints. At the same time, the precision of the Estimote system is limited to the number of beacons and their distance (3 beacons with the broadcasting range set to minimum, 1.5m). Estimote estimation cannot be improved in software, although there were some efforts to distinguish between two neighbouring beacons by the number of times their ID was received between measurements.

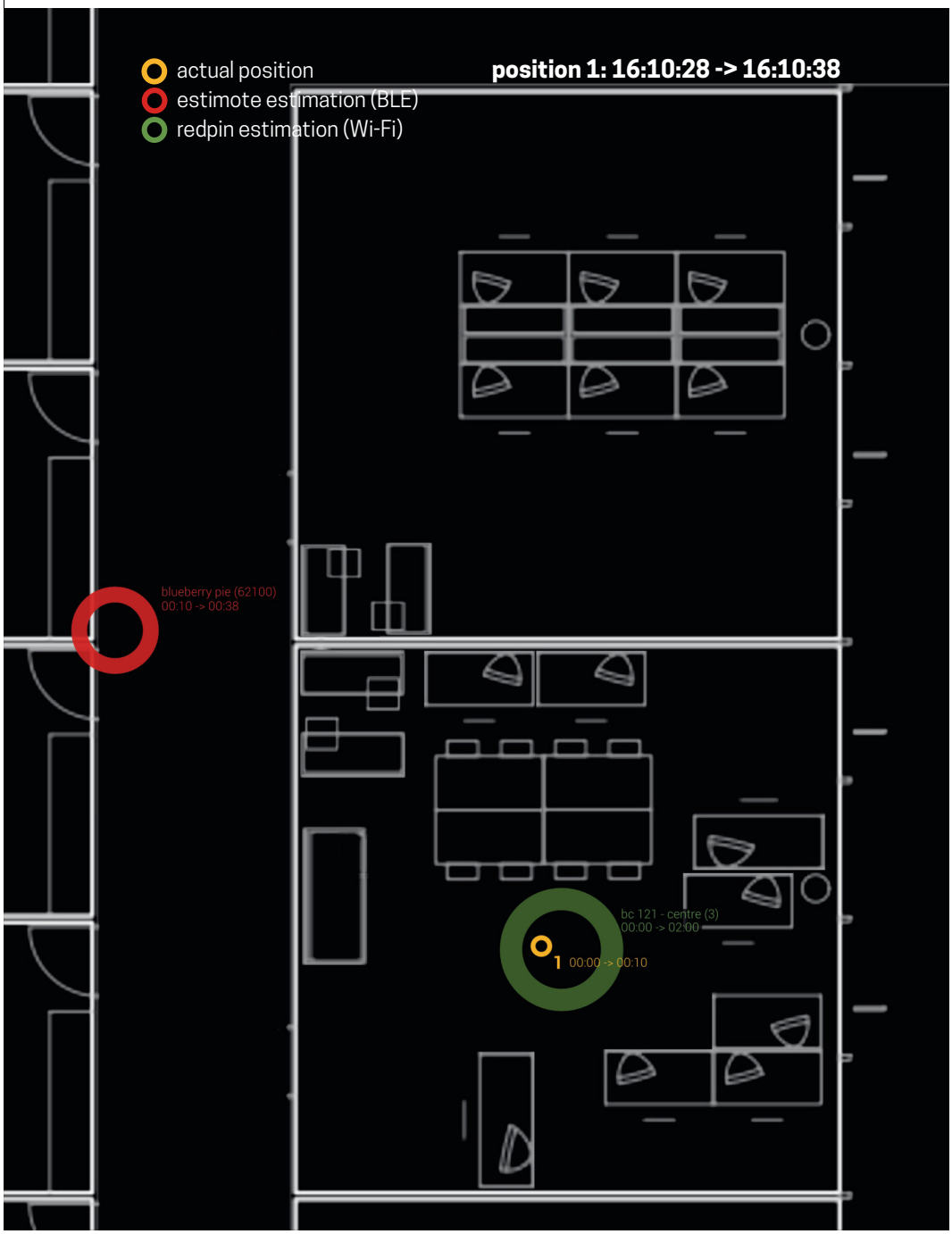
The conclusion from the measurement tests is that, after the learning process Wi-Fi outperformed Bluetooth beacons significantly.

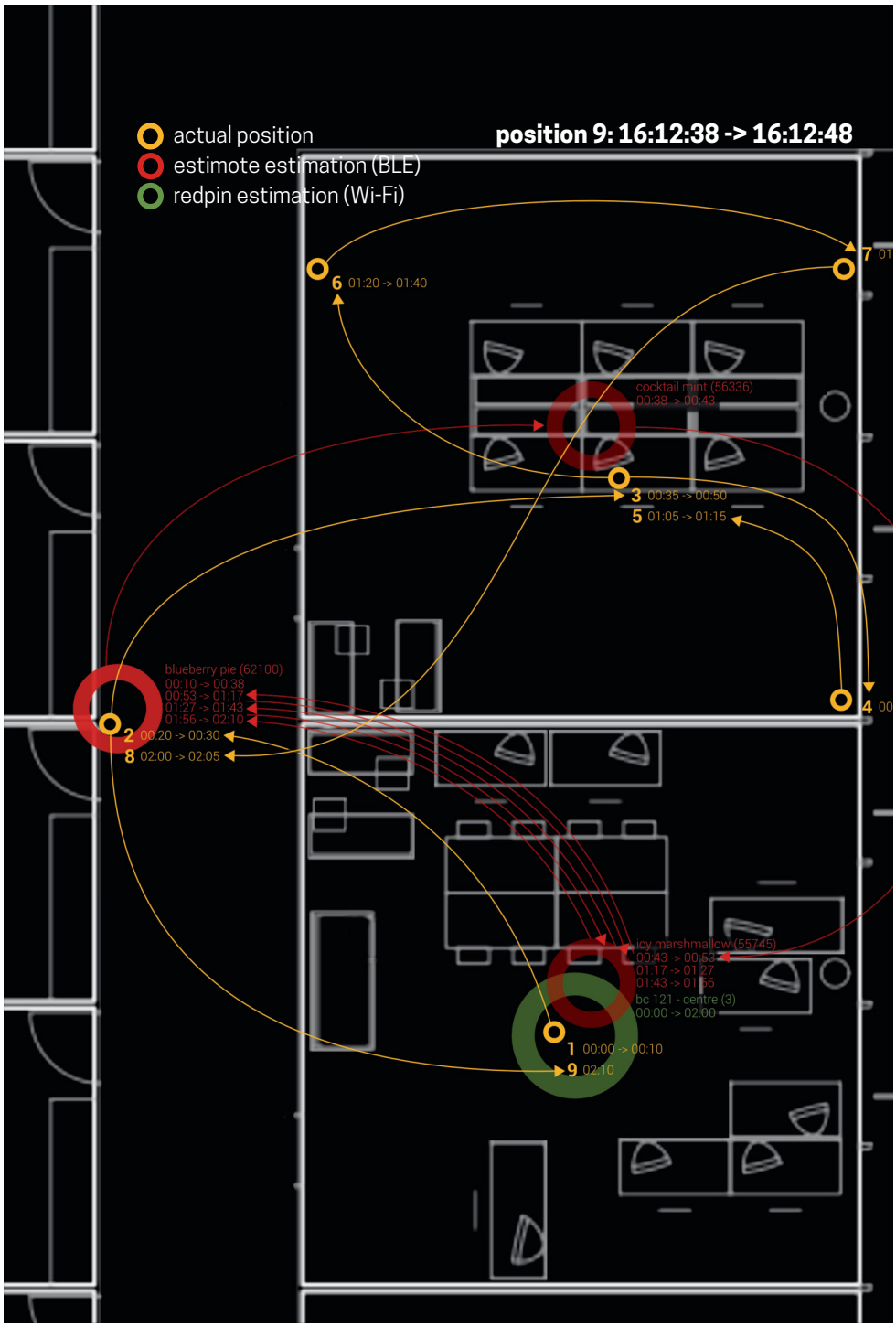


Connect or Not application screenshots: fingerprint measurement and the learning process: after a measurement, an estimation is made, and the application asks for user feedback. If the estimation is correct, the measurement is added to the application database. If not, the user can navigate to the correct location and assign the measurement to it.

Connect or Not position tracking

BC office 117 and 121. EPFL. Lausanne
12 December 2014. 16:10. duration 2'20"

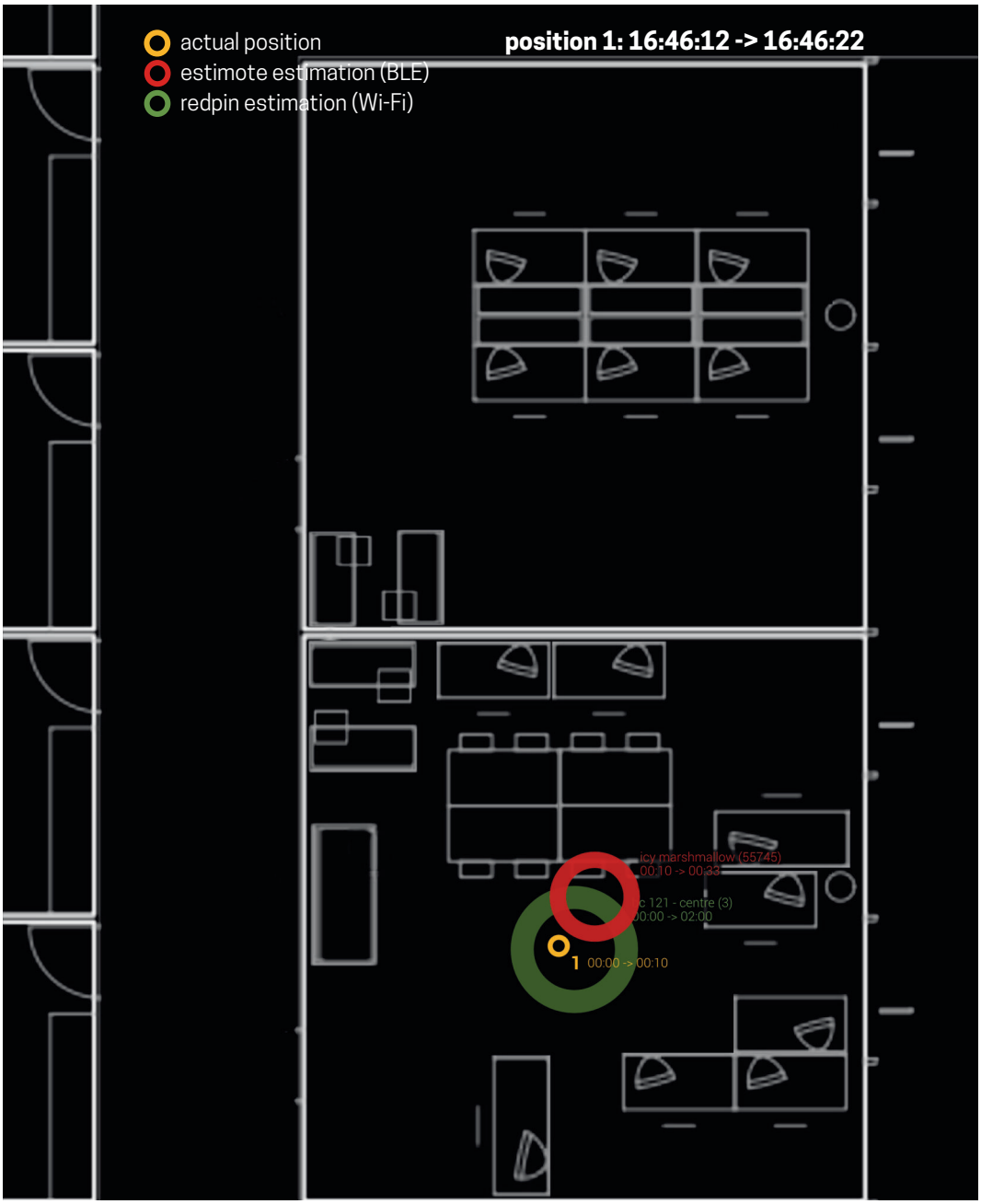


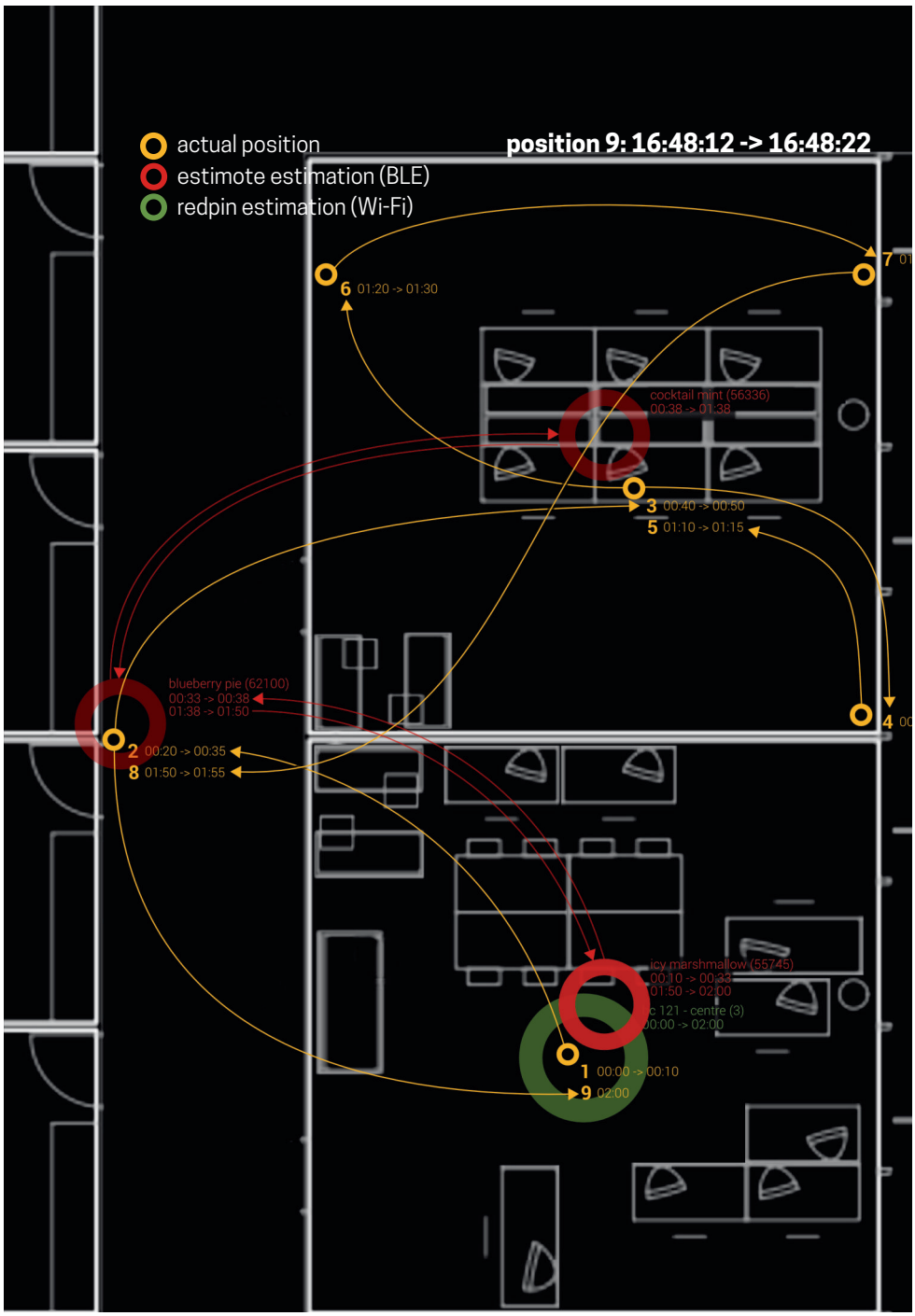


Positions 1-9 are existing Wi-Fi fingerprints made using the application. Sending interval is set to 5s.
Estimote beacons are set to broadcasting power of 16dB (about 7m in range); there are 3 beacons at positions 1, 2 and 3

Connect or Not position tracking

BC office 117 and 121, EPFL, Lausanne
12 December 2014, 16:46, duration 2'10"

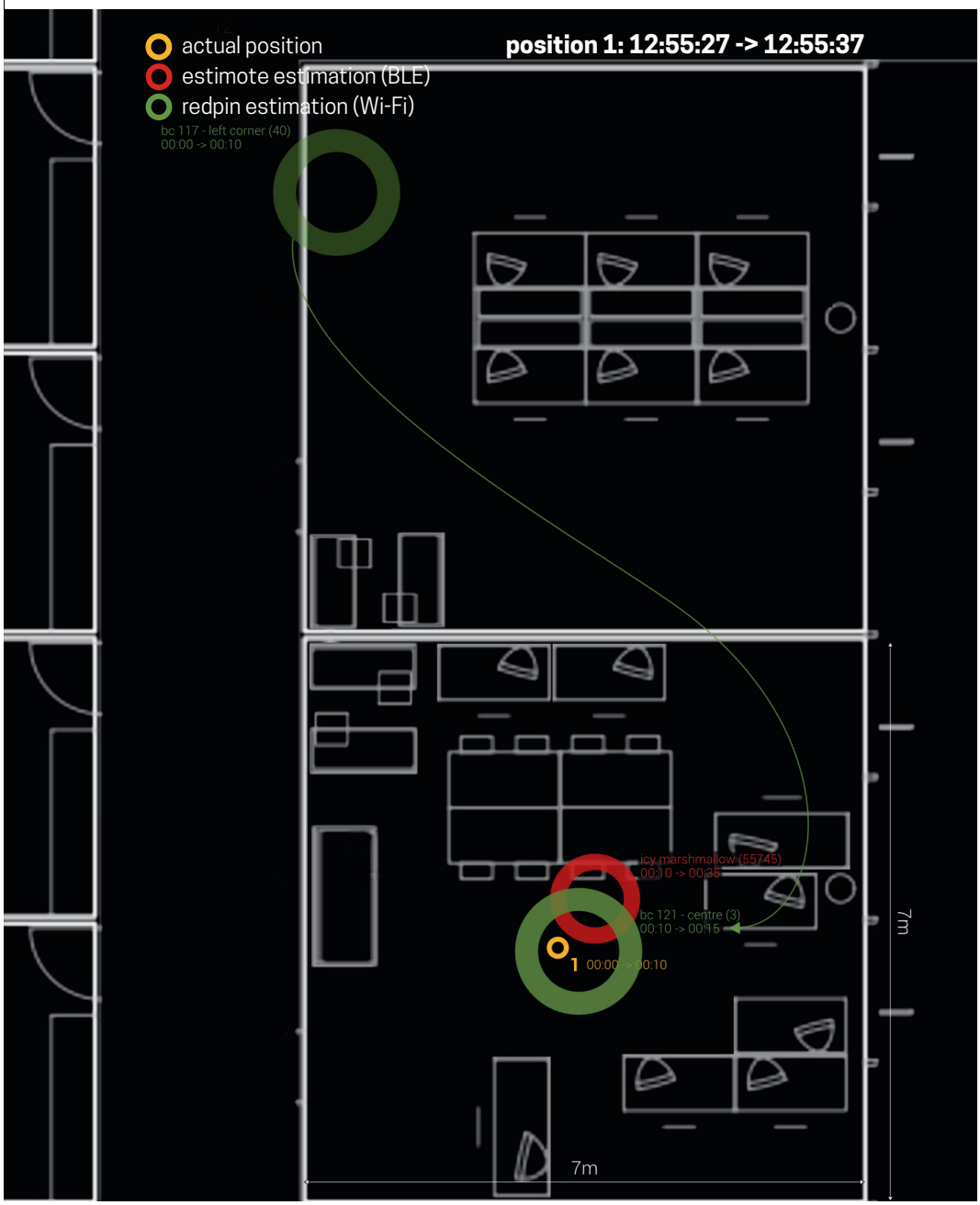


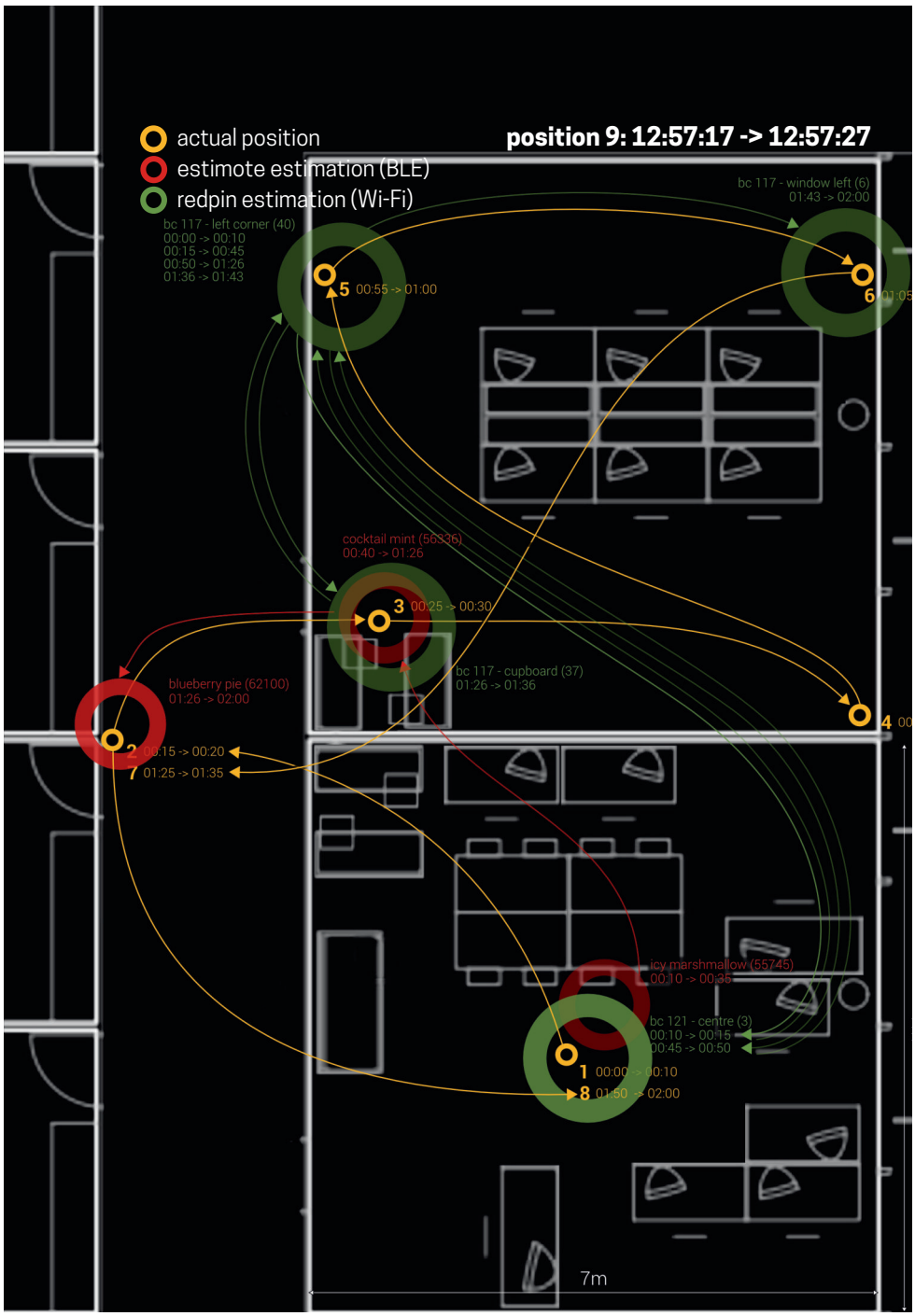


Positions 1-9 are existing Wi-Fi fingerprints made using the application. Sending interval is set to 5s. Estimote beacons are set to broadcasting power of 16dB (about 7m in range); there are 3 beacons at positions 1, 2 and 3

Connect or Not position tracking

BC office 117 and 121, EPFL, Lausanne
17 August 2015, 12:55, duration 2''

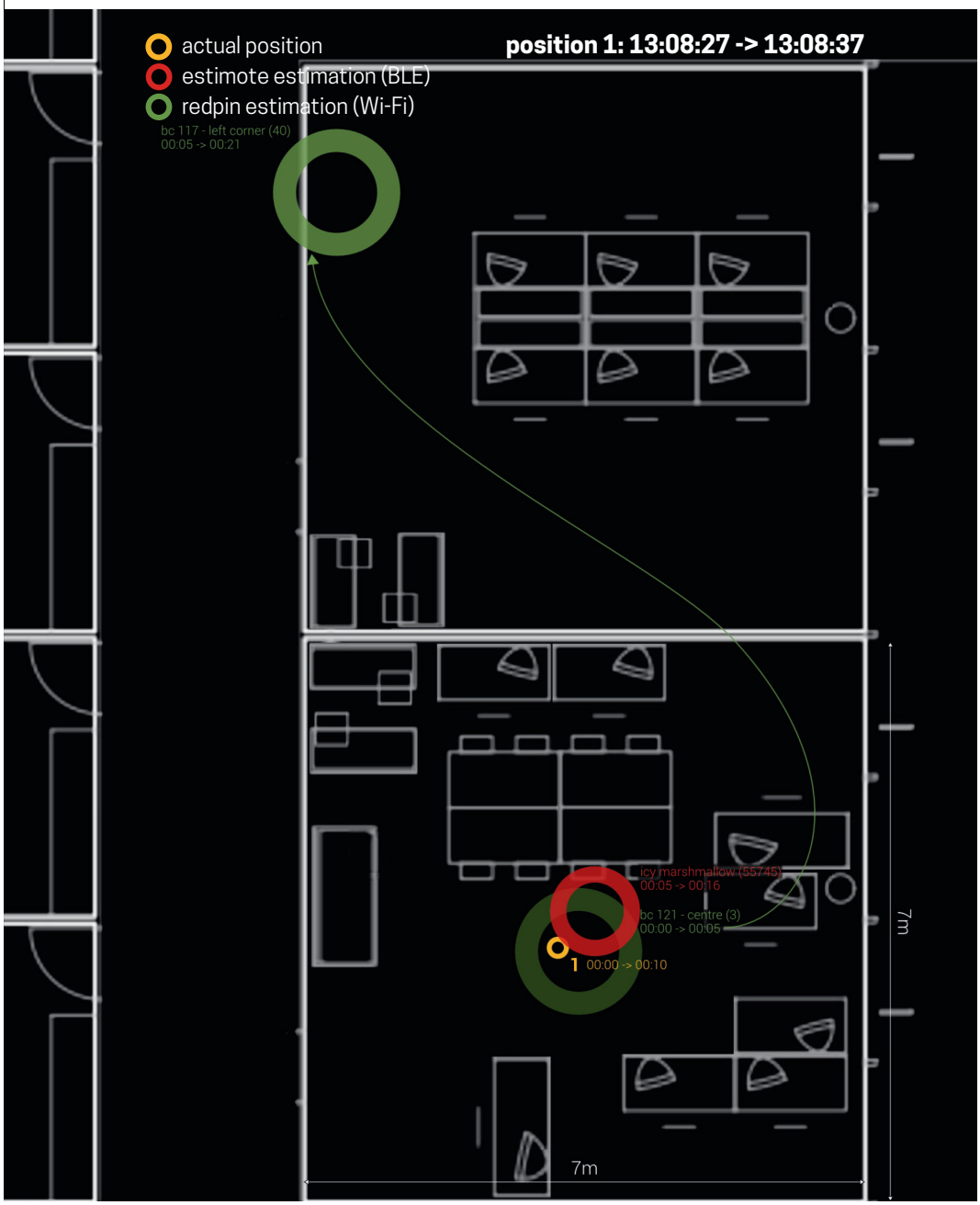


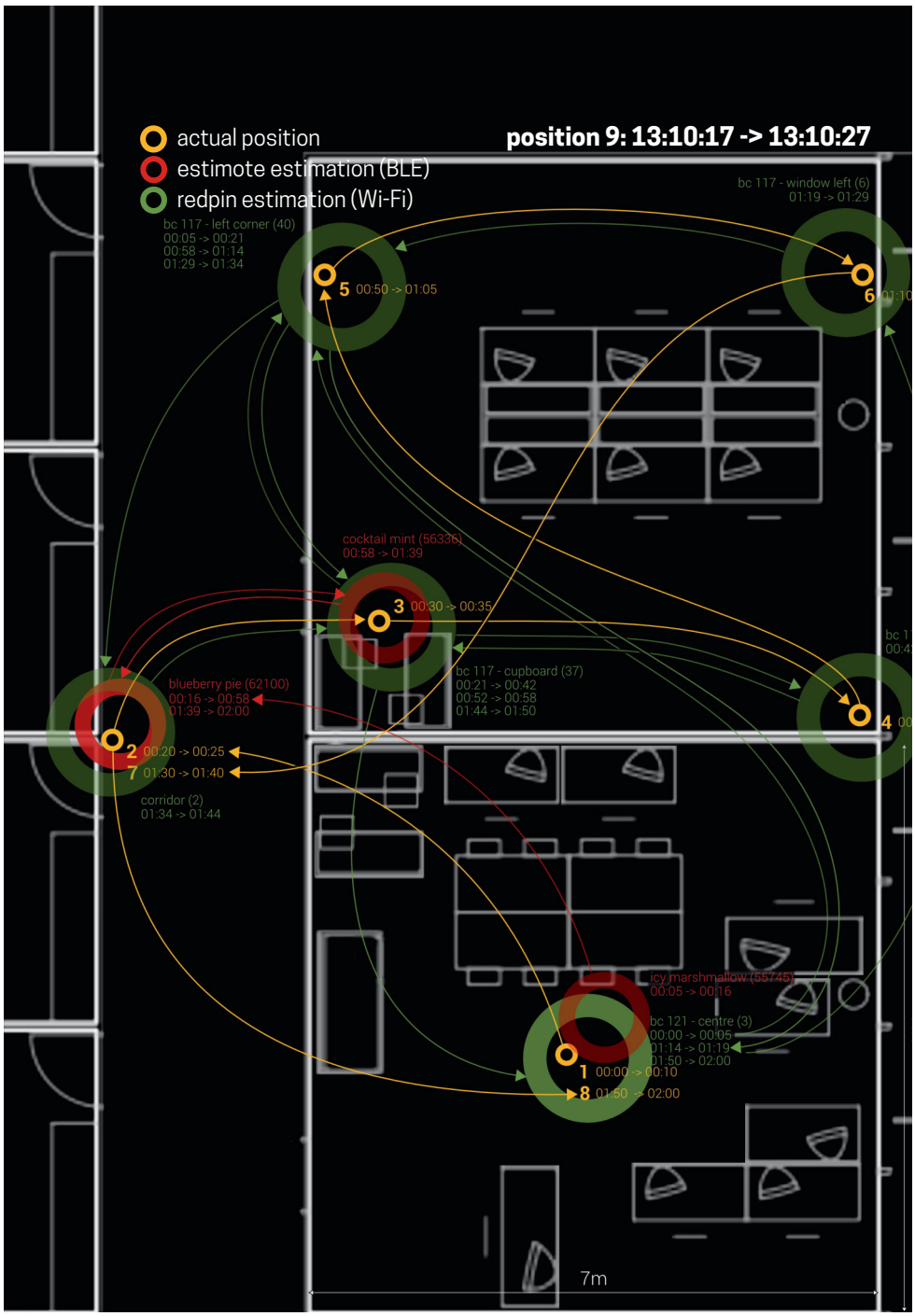


Positions 1-9 are existing Wi-Fi fingerprints made using the application. Sending interval is set to 5s. Estimote beacons are set to broadcasting power of 16dB (about 7m in range); there are 3 beacons at positions 1, 2 and 3

Connect or Not position tracking

BC office 117 and 121, EPFL, Lausanne
17 August 2015, 13:08, duration 2'





Positions 1-9 are existing Wi-Fi fingerprints made using the application. Sending interval is set to 5s. Estimote beacons are set to broadcasting power of 16dB (about 7m in range); there are 3 beacons at positions 1, 2 and 3

Curriculum Vitae

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Born on the 23rd of August, 1980 in Belgrade, Serbia
Languages: English, French, Serbian

Education

September 2011 – present

PhD Candidate at IST, Lisbon and EFPL, Lausanne, Joint-Doctoral Initiative programme; grantee of the FCT Portugal

2010

Graduated from the Media Design Master, Networked Media, at the Piet Zwart Institute, Willem de Kooning Academy, Rotterdam, The Netherlands

2007 - 2008

ArtScience, Interfaculty between the Royal Conservatory in The Hague, Fine Art Academy in The Hague and Technical University in Leiden, The Netherlands

2006

Graduated from the Faculty of architecture, Department for Urban Planning, University of Belgrade, Belgrade, Serbia

Employment

September 2011 – April 2014

Research assistant at SINLAB, EPFL / HETSR La Manufacture, Lausanne

August - December 2009

Patchingzone, a trans-disciplinary laboratory for urban games in public space, Rotterdam

March 2007 - August 2007

Associate in the studio for architecture and urban planning DAAM, Belgrade

April 2006 - March 2007

Assistant in the Research Centre (IPC) on the Faculty of Architecture, University of Belgrade

November 2004 - January 2005

Internship at DIL Inzenjering, Belgrade, Serbia

Teaching

July 2015

Jury Master Thesis Media Design HEAD, Geneva

2014-2015 autumn semester

Apprendre la thèse en sciences sociales et en architecture, doctoral seminar Architecture et sciences de la ville (EDAR)

2014-2015 autumn semester

Development of the Connect Or Not Android application,semester project
Systèmes de Communications - Master semester 3

April 2012 spring semester

Home 2.0 Cabane Augmentée, Atelier LDM

June 2010

Eat it! City Simulator, invited lecture
Crosslab, Master art et Design, Willem de Kooning Academy, Rotterdam

Teaching: workshops

January 2014

Connect or Not, interfacing wireless communication with tangible systems, MMC Zavod 6/4, Ljubljana, Slovenia

February 2012 – July 2015

Unpleasant Design workshop, workshops on designing with unpleasantness in mind, at Critical Make, Basel; AMRO 2014, Linz; Urban Knights, Berlin; LIFT Geneva

June 2011 – April 2012

Make your own solar cells, workshops on DIY production of dye-sensitized solar cells based on the Graetzel cell, in Salzburg, Linz, Vienna, Ljubljana, Yogyakarta, Belgrade

Selected Publications

Savic, S., and Heitor, T., 2014. Probing the Network: Architecturality of Wireless Infrastructure. In: Proceedings of the 2Nd Media Architecture Biennale Conference: World Cities, MAB '14. Aarhus, Denmark: ACM, pp.69–78.

Savic, S., and Huang, J., 2014. Connect or Not: Exploring Seamless Infrastructures through Out-Bodied Interaction. In: City | Data | Future. UrbanIxD Symposium. Venice, Italy.

Savic, S., and Huang, J., 2014. Research Through Design: What Does it Mean for a Design Artifact to be Developed in the Scientific Context? In: A Matter of Design. Proceedings of the 5th STS Italia Conference. Milan: STS Italia Publishing, pp.409–423.

Sempere, A., Savic, S., Huang, J., Badura, J., and Barchiesi, A., 2013. Experience Catalyst and Architecture: Towards a New Tradition. In: José Pedro Sousa and João Pedro Xavier, eds., Future traditions: rethinking traditions and envisioning the future in architecture through the use of digital technologies. Porto: Porto: FAUP Publicações.

Savicic, G., and Savic, S., 2013. Unpleasant design. Belgrade.

Selected Exhibitions

2015 Diskohedron: White Mirror Series, Short Cuts (curated by Daniel Sciboz), Centre Pasquart, Biel, Switzerland; with Gordan Savicic and Philipp Lammer

2014 Connect or Not, MMC Zavod K6/4, Ljubljana, SI

Quadricone, Les Urbaines festival, Espace Arlaud, Lausanne, CH

2010 Eat it! City Simulator, Test_Lab: The Invisible City, V2_ Institute for Unstable Media, Rotterdam, NL

2009 Dvorište Zgrade (Courtyard: a retrospective), Magacin u Kraljevica Marka, Belgrade, Serbia

Med!aphosis, curated by Selena Savic et Marija Djorgovic, Dom Omladine, Belgrade, Serbia

2008 InFaces: Revisited, HackFemEast, Kunstraum Bethanien, Berlin, Germany

Other engagements

since 2013

Co-founding and contributing editor of Contour Journal, an interdisciplinary peer-reviewed journal on research in and beyond architecture