BIT BY BYTE: UNDERSTANDING AND ENGAGING UBIQUITOUS COMPUTING IN THE BUILT ENVIRONMENT THROUGH INTERACTION DESIGN

by

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(Under the Direction of Judith Wasserman)

ABSTRACT

In the mid-1990s, technologist Mark Weiser identified four fundamental relationships between people and computers: the mainframe, personal computer, distributed computing and ubiquitous computing eras. Each successive relationship is characterized by smaller, cheaper, and more numerous computers. We are now on the cusp of ubiquitous computing, in which computers will disappear seamlessly into our environment, challenging us to re-conceptualize the role of computers in our lives and in our landscapes.

These challenges extend to the practice of environmental design. Current design processes employ computers, but largely ignore the potential of embedding computation within the built environment. This thesis examines current research concerning ubiquitous computing, human-computer interaction, and hybrid space to better understand emerging relationships between digital information, computation and the built environment. This thesis recommends the practice of interaction design as a means of designing appropriate interactions between people and ubiquitous computing technology in the context of physical space.

INDEX WORDS: environmental design, interaction design, hybrid space, pervasive computing, ubiquitous computing, urban informatics.

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DEDICATION

I would like to dedicate this thesis to Craig Page for his absolutely essential and unwavering support during its creation. He was there for me every step of the way, especially during the *years* when I was certain this chapter of my life would never come to fruition.

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INTRODUCTION

> A few thousand years ago people of the Fertile Crescent invented the technology of capturing words on flat surfaces using abstract symbols: literacy. The technology of literacy when first invented, and for thousands of years afterwards, was expensive, tightly controlled, precious. Today it effortlessly, unobtrusively, surrounds us. Look around now: how many objects and surfaces do you see with words on them? Computers in the workplace can be as effortless, and ubiquitous, as that. Long-term the PC and workstation will wither because computing access will be everywhere: in the walls, on wrists, and in "scrap computers" (like scrap paper) lying about to be grabbed as needed. This is called "ubiquitous computing." (Weiser, 1993)

Every few years, Microsoft releases video productions to communicate the direction the company sees technology moving. These Future Vision Productions[1] provide us with a good idea of how Microsoft expects interactions between people and computing technology will occur in 5, 10 or 15 years. A pair of these videos[2], released in 2009 and 2011, is notable for its depiction of human-computer interaction that has moved, not just beyond desktop computing, but also beyond the highly portable devices that we carry with us almost everywhere today. Microsoft's future vision predicts that, by 2019, computation will occur primarily in, on and around the common everyday objects and surfaces that make up our built environment.

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[1] Available on YouTube as "Office Vision" ("Office Vision," 2012).
[2] Available on YouTube as "Productivity Future Vision (2009)," and "Productivity Future Vision (2011)" ("Productivity Future Vision (2009)," 2009; "Productivity Future Vision (2011)," 2011).

While watching the video productions from 2009 and 2011, the predicted shift from computing with dedicated devices to *an environment of computation* is not immediately apparent. At first, everything seems in-line with today's computational paradigms, and the radical departures Microsoft predicts become only gradually apparent. I want to take a moment to call attention to a few of these departures. Many of the key themes highlighted in Microsoft's future vision are the same themes that I will discuss throughout this thesis.

First, while watching the Future Vision Productions, it is apparent that the computing devices shown are aware of their context. The devices know at least something about where they are, and they understand—to varying degrees—what typically happens there. They also understand how they should *behave* in a variety of situations. For example, in many scenes, handheld display surfaces readily volunteer information that is relevant to present (or imminent) situations. The information provided is informed by what *is happening* or *will soon happen* nearby, as determined by an analysis of the current physical location and knowledge of what typically happens there. The depiction also indicates that the behavior of computing devices is informed by behavioral protocols. In public contexts, Microsoft indicates, a display should react differently, by providing different types of data than it would in private contexts.

Secondly, structural and architectural surfaces are co-opted by computing technology to act as sites for human-computer interaction. In many scenes, structural glass windows are shown either displaying information about events occurring out of sight, or superimposing information concerning objects currently within a person's view. In one example, a window in an office building provides a worker with information about the health of a green roof he is affiliated with in a distant location. In another example, a taxicab window volunteers additional information about a building as it moves into sight, identifying it as the location of a scheduled appointment the following day. Both of these interactions build on the common, reflexive act of looking through a window to gather information about the surrounding environment. Microsoft suggests that this very ordinary interaction, when enhanced with computation, can provide a viewer with more information about their environment than is naturally available to them.

Lastly, computation is depicted *ubiquitously*. It is shown happening nearly everywhere around us. The environment portrayed in the Productivity Future Vision videos is saturated with computational, interactive possibilities; and data moves freely between the many depicted computing devices. Coffee cups communicate the temperature and the level of liquid they contain on their outer surfaces. Information literally spills out of objects onto surfaces when the objects are placed upon them. In one scene, placing a cookbook on a kitchen counter causes recipes to spill out onto the countertop, where they can be manipulated with gestures. In many other scenes, data is easily plucked from one display and dropped onto another while computation, and interaction with the data, continues seamlessly from one device to the next. In many ways, data is rendered nearly tangible through its deeply embedded association with the objects of our everyday interactions.

In Microsoft's future vision of our relationship with computers, everything is connected to everything else. Physical places are deeply enriched and enlivened by the inclusion of digital information. Physical and social context matters to the software we interact with, and our software makes decisions about when and how to inform us of relevant data based upon its innate understanding of social situations. Etiquette informs software, helping it to choose the most appropriate action, and the most appropriate means of communicating that action from the current mix of locally available hardware.

Microsoft's Productivity Future Vision predictions have, historically, been very accurate. Future technology described by Microsoft in the 1990s is now commonplace. In a famous keynote address delivered at the Comdex electronics convention in 1994, Microsoft founder Bill Gates promised a skeptical audience that, in the near future, we would all use handheld networked computers instead of pagers; we would carry tablet shaped smart displays instead of laptop computers; our television content would be under our control; and we would be able to pause and resume media content on-demand.

There is no reason to suspect that Microsoft's most recent future vision predictions are any less accurate than those of the past. It may take 5 years, or 15, but—as we will explore in more detail throughout this thesis—an emerging consensus of researchers and experts indicates that computing devices will become smaller, more numerous, and deeply embedded within the built-environment. This sets up a situation in which the implementation of future computing technology, and people's interactions with it, are moving into physical space, an area traditionally designed and organized by the practitioners of environmental design and planning. If, as predicted, the practices of environmental design and human-computer interaction are on a crash-course and destined to collide, there is need for concern, and action. It is time to consider the consequences of embedding computation within the built environment. As discussed in this thesis, the imminent arrival of ubiquitous computing devices and human-computer interactions within the built environment offers practitioners of environmental design a valuable source of invigorating new opportunities.

Given the tremendous, disruptive potential that the emergence of widespread, ubiquitous computing might bring to the design and management of the built environment, I find it surprising how little is being said within the field of landscape architecture concerning its impending arrival. This thesis participates in—and seeks to expand—an important conversation concerning the emergence of ubiquitous computing and human-computer interactions within the built environment that I feel is of interest to everyone who participates in the practice of environmental design, and its related disciplines.

Problem: The Designer's Incomplete Understanding of Computing

Although, in general, landscape architects have incorporated emerging computer technology into their design processes, they have not yet fully considered computation as a vital and inevitable component of the built environment. Landscape architects are not fully aware of the design opportunities that the emergence of ubiquitous computing offers when fully integrated into the built environment. As a result, they have not widely considered the role of ubiquitous computing and digital information within the built environment or their own role in designing for its integration.

Within the field of landscape architecture, computers have found wide acceptance as an aid during the design process. GIS, used during site inventory and analysis, accelerates time-consuming manual routines pioneered by Ian McHarg. CAD software facilitates efficient and flexible drafting practices, making once-costly revisions much easier to accomplish. Graphic production software like Photoshop enables the rapid generation of cohesive sets of presentation graphics. In each of these roles, computers streamline events within the design process by facilitating actions that were—to some extent—already in place. These are the traditional, and the most commonly understood, roles of computing in the practice of landscape architecture.

As computers have increased in computational power, new programs, leveraging improved computational processes, have arisen to make use of their ability to process large amounts of data. These processes have no direct counterparts in a non-computerized design process. Digital morphogenesis[3] and parametric design[4] are examples of processes that leverage computational power in novel and productive ways. These, and other computationally dependent processes, fall into an emerging field known as Design Computing[5]. The generation and development of form using computation is a very interesting and fruitful topic for exploration, but it is not the topic of this thesis.

This thesis addresses the lack of attention given to the situation and embedding of computing within the built environment. Simply stated, the idea of incorporating computing into the built environment, as an element *of* the built environment, has not received the attention within the practice of landscape architecture that its tremendous potential merits. The current understanding of computing within the discipline is incomplete. Computing is not yet understood holistically, as an element within the fabric of the built environment that is capable of persistently activating spaces with novel human-computer interactions. Specific examples of overlooked opportunities for new design applications are given below in an effort to clarify this position.

- Computing has not been adequately explored within the profession in terms of its ability to sense and respond to user interactions within a site. The human-computer interaction

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[3] In architecture, a computational means of generating form through the application of mathematical optimization processes (Leach, 2009).
[4] A process based on consistent relationships between objects, allowing changes in a single element to propagate corresponding changes throughout the system (Meredith & Sasaki, 2008). Consider the software Rhino with the Grasshopper plugin for example.
[5] Design Computing is concerned with the development of a new generation of design software, application of simulation, analysis, and fabrication in the design process, and utilization of digital technologies to create smart environments ("Design Machine Group," 2012).

(HCI) concept of ubiquitous computing has the potential to activate the built environment as a site for computation and the manipulation of digital information. Architecture can guide and temper the interactions between people and computing devices within the built environment. Opportunities exist to create designs for this purpose, and to develop these designs based upon the Mark Weiser's vision of *calm technology* (Weiser, 1991).

- Computing has not been adequately explored within the profession as a tool that can allow visitors to embed their own digital assets within the environment as elements of physical places. In this scenario, interaction between assets brought into a designed space and assets persistently present within the designed space could interact, incorporating user-supplied data as a means of democratizing the place, and thereby "softening," or (re)contextualizing the place (Noble, Low, Rules, & Remix, 2011 para. 3).
- Computing has not been adequately explored within the profession as a means of enhancing the built environment with a persistent presence, an externalized, digital cultural memory, which evolves at the site over time and in response to inputs. In this scenario, the exchange of data is potentially bi-directional, and could influence assets brought to it even as it is itself influenced by visitors. In such a scenario, a digital landscape could evolve over time in much the same way a cultural landscape emerges.

Context: Digital and Physical Realities are Increasingly Blended

Digital information exists as a layer that overlays physical space and contains data correspondent to the physical world (Applin & Fischer, 2011; Bilandzic, Jones, & Foth, 2011; de Souza e Silva, 2006). The current technological trajectory of computing predicts that digital information will dissolve into the built environment as ubiquitous computing becomes commonplace (Weiser, 1991, 1993; Weiser & Brown, 1996). As computing becomes embedded within the built environment, there exists an opportunity for digital information to become (re)contextualized and to contribute to sense of place (Ciolfi, 2003; Ciolfi & Bannon, 2007; Ciolfi, Deshpande, & Bannon, 2005; Dourish, 2006; Iaconesi & Persico, 2012). Embedded computing also allows for interactive environments. Environmental designers can practice interaction design (IxD) to engage this quality of computationally embedded spaces (Ciolfi & Bannon, 2007; McCullough, 2005, 2007). Therefore, an opportunity exists for landscape architects to expand their understanding of computing and to actively engage with interactive digital information through their designs for the built environment.

As the idea of computing has evolved, scholars in the field of human-computer interaction (HCI) have predicted that computation will manifest a constant presence within the built environment in much the same way written language has become a part of the world around us (Weiser & Brown, 1996). Computation will mediate and facilitate many of our social interactions within the environments we build. Consider the act of checking-in on Facebook as an example of this sort of mediation, where technology mediates the announcement of a person's presence in physical space to others. In the words of Malcolm McCullough, Associate Professor of Architecture and Technology Design at the University of Michigan, "The role of computing has changed. Information technology has become ambient social infrastructure" (McCullough, 2005, p. 21). As a form of social infrastructure, McCullough believes, computation occurring within the built environment is increasingly aligned with architecture.

For as long as we have had the faculties to imagine, we have dreamed alternate realities into existence. Art gave us the ability to intersect our fantasies with the physical world and share them with others through representation and narratives. Technology has given us the ability to grow our art and to communicate it on a larger scale. More recently, technology has given our art the ability interact with us.[6] In this way, technology has again fundamentally altered our perception of the world we live in. Our constant use of technology has created a "virtual layer of information and interaction opportunities that sits on top of and augments the physical environment" (Bilandzic et al., 2011, abstract para. 1). Social networks including Facebook, Twitter, Flickr, foursquare, and Google+, are spatial constructions entered into by millions of people every day, and people are increasingly finding ways to merge their digital and physical social experiences (Bilandzic & Foth, 2011 para. 5)[7].

With increasing frequency, our bodies move through the physical world while our minds are elsewhere; immersed in the digital world of our collective creation. Although we have always nurtured the ability to simultaneously divide our attention between many *ideas*, increasingly today we divide our attention between many *places*. We maintain personal representation in digital online spatial constructions (e.g. the Internet, social networks, online gaming communities) even as we participate actively in physical space. We figuratively stand in multiple situations (as both avatars and our natural embodied selves) simultaneously (Applin & Fischer, 2011). Current trends in environmental design fail to take this evolution of space(s)—and our use

[6] McCullough explains,

> […] Computers became the first technology to provide two-way engagement. Despite common misuse of the word, not everything that is operable is interactive. A film may stir deep reactions; a chisel might let a sculptor feel that work is flowing; a lathe may have several buttons and controls; and a telephone lets people interact remotely; yet none of these technologies is itself interactive. Only when technology makes deliberative and variable response to each in a series of exchanges is it at all interactive. (McCullough, 2005, p. 20)

[7] Each of the social network examples given are hybrid spaces, most manifestly so when accessed through a mobile platform (i.e. smartphone) that ties information about a user's physical location to online functionality (e.g. check-ins with Facebook and foursquare). The hybrid aspect of these social networks is currently underemphasized. It can be enhanced by external means to create more elaborate hybrid experiences. Consider ConnectiCity research for examples (Iaconesi & Persico, 2012).

of it—fully into account when proposing design solutions. As we continue the work of designing the built environment as a collection of places that, among other purposes, encourage specific modes of behavior (e.g. the domesticity of a home, the spirituality of a church, and the reverence of a cemetery), we must learn to design for the inclusion of the new digital information that will increasingly comprise our computationally active society (Bilandzic et al., 2011).

Practitioners of environmental design need to consider the foundational role that physical architecture can play in directing the emerging presence of computation in our built environment. Physical architecture, through its long established ability to establish meaningful contexts, can guide the emergence of computation in physical space. Landscape architects, as creators of meaningful places, are well qualified to participate in designing the interaction of people, technology, and architecture in the process of place making (McCullough, 2007).

The primary question this thesis seeks to answer is: "What is ubiquitous computing, and what are the implications of its emergence for landscape architects?" The thesis will propose methods for landscape architects to expand their practice in order to engage with and benefit from the changes that ubiquitous computing will bring to the built environment.

Purpose: To Introduce Ubiquitous Computing and Interaction Design as a Means of Engaging It

Through this thesis, I seek to introduce ubiquitous computing to landscape architects as an emerging technological concept for their consideration and engagement. The thesis introduces the idea that digital information—revealed within the physical environment through ubiquitous computing technology—is an integral component of place. The idea of hybrid space is introduced as a framework through which designers can better understand the types of places created by embedding ubiquitous computing technology within the built environment. Lastly, the practice of interaction design is introduced and proposed as a means of engaging with ubiquitous computing devices and digital information within physical space.

Research Methods

In pursuit of the stated goal, a series of literature reviews and analysis is employed towards its resolution. First, I provide an introduction to the emerging technology of ubiquitous computing through a review of the literature, covering the origin of ubiquitous computing, its foundational theory and its evolution. The literature review examines ubiquitous computing from both a general and an architectural perspective in an effort to highlight the elements that are most relevant to the field of landscape architecture. The literature review answers the question, "What is ubiquitous computing?"

Second, I review the literature of the emerging field of Interaction Design (IxD), focusing on the ideas of embodiment, context, place and its common typologies. I undertake this work in an effort to answer the question "Why should landscape architects be concerned with ubiquitous computing and why are they well suited to meaningfully engage it?"

Third, I introduce the idea of hybrid space, and review the literature in the field of human-computer interaction in an effort to answer the question, "How should environmental designers understand the spaces that result from the introduction of digital information within the built environment?" Lastly, I describe and analyze past and present attempts within the fields of architecture, landscape architecture and planning to engage with ubiquitous computing and interaction design in the built environment.

Definitions

Many of the ideas expressed in the following chapters are technical in nature involving specialized terminology. Below is a short list of terms for reference while considering the ideas presented in this thesis. This is not an exhaustive list of terms, but should serve a useful purpose as a supplement to the footnotes included within the text.

- Augmented Reality – On the spectrum of reality stretching from Physical Reality to Virtual Reality, specifically refers to elements of virtual reality that can be viewed synchronously with physical reality.
- Calm technology – In computing, describes a means of presenting information to users in a manner that avoids overwhelming them with too much information delivered simultaneously. Calm technology should enable users to sense and manage information that immediately interests them, while maintaining peripheral awareness of other information that is easily brought into focus when the user chooses.
- Human-computer interaction (HCI) - Involves the study, planning, and design of the interaction between people and computers. HCI is a multi-disciplinary field involving computer science, psychology, engineering, ergonomics, sociology, anthropology, philosophy, and design (Card, Moran & Newell, 1983; Faulkner, 1998; Head, 1999). HCI is concerned with the design, evaluation, and implementation of interactive computing systems for human use (Card, Moran, & Newell, 1983).
- Hybrid space - Space that is comprised of both physical and virtual space. When physical space is linked by computer-mediated means to another physical space, or to a source of digital information, a hybrid space is created as a result of the human user's perception of the combined space (Harrison & Dourish, 1996).
- Interface design – In computing, the study and design of the methods of data collection and communication by computers, with an emphasis on usability by human users.

- Interaction design (IxD) – The practice of designing interactive digital products, environments, systems, and services (Cooper, Reimann, & Cronin, 2012, p. 610). McCullough states, “the discipline of interaction design has been built from foundations in our understanding of cognition,” and that, “increasingly, this work recognizes the importance of ‘cognitive background’: the cumulative perceptions of enduring structures that fundamentally shape human abilities” (McCullough, 2005, p. 27).
- Situated computing – The use of computing technology in situ, where the actual context of use has a perceived impact on the outcome of the computation that occurs.
- Ubiquitous - Existing or being everywhere at the same time. Constantly encountered. Widespread (Webster, 2012).
- Ubiquitous computing (a.k.a. pervasive computing, physical computing) – An era in computing, following the era of Personal Computing, in which computation will become deeply integrated into the fabric of the built environment.
- Virtual Reality - On the spectrum of reality stretching from Physical Reality to Virtual Reality, specifically refers to a reality whole contained within a digital environment.

Chapter Outline

Chapter 2 provides an introduction and analysis of ubiquitous computing technology. The concept behind the technology is introduced. The origin and evolution of the technology is discussed and the field of literature is narrowed to an environmental design interest in the topic. Chapter 3 provides a review of the hardware and software components of ubiquitous computing technology to familiarize non-specialists with the subject.

Chapter 4 introduces the concept of hybrid space as a framework through which environmental designers can better understand the types of places created by embedding ubiquitous computing technology within the built environment.

Chapter 5 introduces the practice of interaction design, and recommends it as a method of engaging with digital information provided through ubiquitous computing technology in the built environment.

Chapter 6 provides an examination of past and present applications of ubiquitous computing technology and interaction design in real-world case studies. The cases are briefly considered in terms of their application of the ideas and methods described in this thesis.

CHAPTER 2

UBIQUITOUS COMPUTING: ORIGIN AND CONCEPTS

This chapter provides an introduction to ubiquitous computing, including the emergence of ubiquitous computing and its evolution. It then narrows in scope and provides a look at ubiquitous computing in terms of what is most interesting to designers of the built environment. The literature review focuses first on the field of ubiquitous computing at large. As we move toward the present time, the focus of the review narrows to projects of interest to practitioners of environmental design and planning.

Computing Eras

“The important waves of technological change are those that fundamentally alter the place of technology in our lives. What matters is not technology itself, but its relationship to us” (Weiser & Brown, 1996, p. 1).

In the mid 1990s, technologists Mark Weiser and John Seely Brown, while conducting research in the field of human-computer interaction (HCI) at the Xerox Palo Alto Research Center (Xerox PARC), published a series of papers that gave rise to the modern understanding of ubiquitous computing. Weiser provided historical context for ubiquitous computing by identifying four distinct eras of computing defined primarily by our relationship with computers. Weiser and Brown summarized the eras as follows: the *mainframe relationship*, the *PC relationship*, the *distributed computing relationship*, and the *ubiquitous computing relationship*

(Weiser & Brown, 1996). Today, we are leaving the era of distributed computing and entering the era of ubiquitous computing.

Weiser described the first trend or era in our relationship with computer technology as the *mainframe era*, and described it as a relationship in which a few experts had exclusive access to a computer (Weiser & Brown, 1996). In this classification system, any time *many people share a computer* it is a mainframe-era type of relationship. The relationship between computing technology and its users in the mainframe-era was characterized by physical separation. The mainframe computer, due to electrical and mechanical needs, required a specialized environment in which its needs were prioritized over those of its human operators. These dedicated environments were noisy, and equipped with massive cooling systems that made them inhospitable to humans.

The second trend or era in our relationship with computer technology is one that Weiser described as the *PC era*. Weiser explained that the "personal computer relationship is personal, even *intimate*. You have your computer, it contains your stuff, and you interact deeply with it. When doing personal computing, you are occupied, you are not doing something else" (Weiser & Brown, 1996, pp. 2-3). The relationship between computing technology and its users in the PC-era is a one user to one computer relationship. Any computer with which you have a personal relationship, or one that fully occupies your attention, is a personal computer. Today's smartphones are personal computers, albeit highly portable ones. This is an important point to make as we introduce the idea of ubiquitous computing. In Weiser's classification system, any *one-person to one-computer* relationship is a PC-era relationship.

At the time Weiser wrote about these ideas in 1996, the mainframe era was quickly receding, moving from standard practice into niche roles within scientific, academic and military institutions, and people in most of the developed nations were fully immersed in PC-era relationships. Based upon his observation of historical, current and emerging relationships between computer technology and its users, Weiser predicted that the next major eras in the relationship between computer technology and people would emerge and be characterized by *lots of computers sharing each of us*.

Weiser imagined that these ubiquitous computers would consist of the hundreds of computers that deliver information to us through the Internet, and the ambient computers that regulate our environments—those "imbedded in walls, chairs, clothing, light switches, cars – in everything" (Weiser & Brown, 1996, p. 4). The fundamental characteristic of ubiquitous computing is the endowment of things in the world with *computation* (Weiser & Brown, 1996).

The third and fourth major eras in the relationship between computer technology and people are concerned with the shift to ubiquitous computing. Weiser's predictions concerning these eras have proven surprisingly accurate. Today, many computers share each of us, and as a result, our idea of what a computer is and does is beginning to change. Consider as examples, the infrastructure encountered by the average person on their way to work each morning and the array of computers it contains. In our automobiles, many embedded, single purpose computers work together to direct the operation of the engine, suspension, climate control, information, entertainment and safety systems. As an automobile moves though roadways, traffic cameras monitor traffic patterns and direct signal lights to load-balance the flow of vehicles over the roadways. In the buildings they arrive at, people use intelligent load-balancing elevators and key-card operated doorways as they make their way to their personal computers—which are, of course, the general-purpose boxes with dedicated displays that sit on their desks.

We have not yet—at a large scale—entered the ubiquitous computing era. For the most part, we remain a society of personal computers users. However, as our notion of what does and what does not constitute a computer begins to change, our relationship with our computing devices will also change, leading us to widespread adoption of ubiquitous computing-era relationships.

The Major Trends in Computing	
Mainframe	**many people share a computer**
Personal Computer	**one computer, one person**
Internet - Widespread Distributed Computing	**. . . transition to . . .**
Ubiquitous Computing	**many computers share each of us**

Table 1. Weiser's and Brown's trends in computing (Weiser & Brown, 1996, p. 2).

Calm Technology: Weiser's vision for the implementation of ubiquitous computing

In anticipation of the emergence of ubiquitous computing, Weiser and his colleagues envisioned a new model for making sense of and coping with the increase in computing and data that the average person would encounter during the course of an average day. Weiser called for a new way of thinking about computers, one that takes into account the human world and places computers in the background, so we can become aware of their presence transitionally, as desired, and on our terms (Weiser, 1991). Weiser describes this position in his often repeated remark, "If computers are everywhere they better stay out of the way, and that means designing them so that the people being shared by the computers remain serene and in control (Weiser & Brown, 1996, p. 7).

The idea that computing should evolve from an event that demands our full attention into a multitude of events that we perceive and become aware of peripherally, as naturally and progressively as we perceive other meaningful events in the ambient environment (i.e. weather, background conversation, street life), is known as *calm technology* (Weiser & Brown, 1996). Weiser theorized that calm technology, because it sought to re-frame computation as the product of "machines that fit the human environment instead of forcing humans to enter theirs," would make "using a computer as refreshing as taking a walk in the woods" (Weiser, 1991, p. 104).

This reimagining of the way humans and computers interact is an important companion to the idea of ubiquitous computing. Without this fundamental shift in perspective concerning how we will receive and understand the constant flow of computation occurring all around us, Weiser theorized that our increased exposure to data would prove overwhelming.

This is almost certainly the case. It is a common sight in crowded urban environments to see people distractedly interacting with their smartphones, much to the inconvenience of other people. This appears to be an example of a personal computing relationship demanding the full attention of their users when it might be required elsewhere. As the designers of these urban environments, landscape architects should certainly be able to appreciate the need for a new sort of relationship between people and technology. Ubiquitous computing implemented as a calm technology moves our interactions with computing technology into the periphery, and should provide inspiration and guidance as we attempt to design environments to accommodate people and their evolving methods of digitally mediated social interaction.

Ubiquitous Computing Comes of Age

"There are many ubiquitous computings" (Greenfield, 2006, p. 11).

Early academic and corporate interest in ubiquitous computing

Weiser is credited with the vision that launched the ubiquitous computing movement. He envisioned environments deeply integrated with computing and communication capabilities. These environments would be intensely computational, yet gracefully integrated with human users. Unfortunately, his vision exceeded the capabilities of the technology of his day, and as a result, Weiser and his colleagues at Xerox PARC were unable to implement the ideas they described (Saha & Mukherjee, 2003). Weiser's death in 1999 deprived the emerging field of its leading, visionary proponent.

Since Weiser's time, many of the technologies he and his colleagues envisioned have become commonplace. Major universities and industry launched initiatives to research and commercialize the technology described at Xerox PARC. These projects, described in more detail below, have given rise to a wide variety of technologies and studies that touch on ubiquitous computing.

In the mid 1990s at MIT, Professor Hiroshi Ishii founded the "Things That Think" initiative (TTT) which gave rise to a tangible media that extended computation out into the walls and doorways of everyday experience (Ishii & Ullmer, 1997). TTT conducted research with the goal of embedding computation into both the built environment and everyday objects. They found success in many areas and pioneered technology such as sensor networks, ambient information displays, biometrics[8], video streaming, video indexing, and RFID[9] technology. TTT is still active in 2012 and continues research in areas concerned with ubiquitous and pervasive

[8] A method of verifying an individual's identity based on measurement of the individual's physical feature(s) or repeatable action(s) where those features and/or actions are both unique to that individual and measurable (*Guidance for Industry Part 11, Electronic Records; Electronic Signatures — Scope and Application*, 1999).
[9] Radio-frequency identification. "…RFID is seen by some as the inevitable replacement for bar codes" (Roberts, 2006, p. 6).

computing enterprises. The mission of the Things That Think Consortium is to invent the future of digitally augmented objects and environments (MIT, 2012).

The Portolano Project, founded in the late 1990s at the University of Washington, concerned itself with ways to deliver data to the "easy-to-use, low-maintenance, portable, ubiquitous, and ultra-reliable task-specific devices proposed in Weiser's vision of ubiquitous computing" (Esler, Hightower, Anderson, & Borriello, 1999 para. 1). Portolano investigated then-current networking protocols and methods for handing-off devices from one network to another, seamlessly, as a user moved through space. They recognized that a key idea in providing data to devices in a ubiquitous computing relationship was that the user should not need to be concerned with the process (Esler et al., 1999). Their work establishing cooperation and integration among protocols at many scales pioneered network-handling behavior exhibited by smartphones today including long range cellular networks, mid range Wi-Fi networks and short range Bluetooth and RFID.

The research project Endeavour, founded in the late 1990s at UC Berkeley, is notable for the scope of its ambition. The project's goal, of radically advancing human understanding through the use of information technology, by making it more convenient for people to interact with information, devices, and other people, is a broad one. The final product of Endeavor research was to be a revolutionary Information Utility, able to operate at planetary scale (Katz, 1999). Continuing through the proposal for their work, it becomes clear that the research team envisioned something that was self-propagating, if not entirely self-aware.

The software presence behind Endeavour would be an Intelligent Agent, a concept under development within the field of Artificial Intelligence. An Intelligent Agent is an autonomous entity, which observes its environment through sensors and acts upon its observations using actuators (i.e. it is an agent) and directs its activity towards achieving goals (i.e. it is rational) (Russell & Norvig, 2006). The Intelligent Agent that Endeavour envisioned was not designed to remain in a laboratory setting. It was designed to arbitrarily and automatically distribute itself among other computing devices, to explore network paths, and to adapt itself in order to operate on newly discovered hardware platforms in an effort to satisfy its needs for services and advertise its own services to others (Katz, 1999). It was intended to live within the computing devices ubiquitously embedded within the built environment. Its creators intended it to inhabit the "MEMS[10]-sensors/actuators and other capture and display devices that go well beyond … today's server, desktop and portable computers" (Katz, 1999 para. 3). The Endeavour project is notable for its vision of combining Artificial Intelligence and ubiquitous computing (Katz, 1999).

Project Aura, founded in 1999 at Carnegie Mellon, shared many of the goals of Portolano. Aura focused on the critical problem of exploiting resource-rich environments without the need for user knowledge or intervention. A strong focus of the research sought to "support continuity in the face of mobility and dynamically varying resources" (Sousa & Garlan, 2001 abstract, para. 1). Restated, the research focused on providing a means for a user—and her associated computing resources—to become aware of, and interact with, other computing resources encountered while moving through physical space.

To accomplish this, the research team proposed creating a "personal *Aura*" to act as a proxy between a user and any computing devices they encountered (Sousa & Garlan, 2001 Introduction, para. 3). It is notable that Project Aura sought to address "a new primary locus of concern–*namely the scarce resource of user attention* (italics mine)," rather than focusing

[10] Micro-Electro-Mechanical Systems. MEMS must contain some sort of mechanical functionality, whether or not the element is mobile. Outside of U.S.A. they are called 'Microsystems Technology' or 'micromachined devices'(MEMSnet, 2012).

primarily on hardware/software infrastructure problems (Sousa & Garlan, 2001 Introduction, para. 3). I see this human-centric focus as an attempt to acknowledge and prioritize the human-centric vision espoused by Weiser during his initial envisioning of ubiquitous computing.

The Oxygen project, an ongoing project founded in 2000 at MIT, aims “[to bring] abundant computation and communication, as pervasive and free as air, naturally into people's lives” ("MIT Project Oxygen," 2012 para. 1). Like Carnegia Mellon’s Aura, Oxygen recognizes that, in a post-PC-era future, computation should be human centered. Oxygen takes a strong stance on this issue. Its project statement opens with the following condemnation of Mainframe era and PC-era computing relationships:

> For over forty years, computation has centered about machines, not people. We have catered to expensive computers, pampering them in air-conditioned rooms or carrying them around with us. Purporting to serve us, they have actually forced us to serve them. They have been difficult to use. They have required us to interact with them on their terms, speaking their languages and manipulating their keyboards or mice. They have not been aware of our needs or even of whether we were in the room with them. Virtual reality only makes matters worse: with it, we do not simply serve computers, but also live in a reality they create. ("MIT Project Oxygen," 2012 para. 1)

Research conducted as part of the Oxygen project sought to free people from these perceived abuses.

Oxygen researchers believed the following goals must be met before Oxygen could be considered successful: Oxygen must be ubiquitous—that is, situated and embedded everywhere in the world. It must be a nomadic presence; capable of delivering our data wherever we go without our intervention. It must be a powerful, adaptable, and efficient entity. It must be intentional, in that it must understand the intent of our commands, rather than relying on us to explicitly direct it. Lastly, it must never shut down or be unavailable ("MIT Project Oxygen," 2012).

At Microsoft Research, the EasyLiving project was initiated in 2000 to develop technologies for intelligent environments. Intelligent Environments are typically spaces that contain a myriad of devices that work together to provide users access to information and services (Brumitt, Meyers, Krumm, Kern, & Shafer, 2000). They allow the dynamic aggregation of diverse I/O devices into a single coherent user experience (Brumitt et al., 2000). Microsoft placed emphasis on creating an environment that monitors itself from both a sensory (input) and control (output) perspective. EasyLiving is an ongoing project, and Microsoft maintains an active interest in intelligent environments. Much of the work discussed in recent FutureVision productions is a part of Microsoft's EasyLiving research.

Collectively, these academic and corporate research projects represent the early period of post-Weiser research into ubiquitous computing. In many ways, these projects reflected the idealistic nature Weiser so often employed in his foundational writing on the subject.

In a review of the literature conducted in 2003, Saha and Mukherjee noted a high degree of fragmentation within the academic and industrial community conducting research concerning ubiquitous computing. They concluded that, when taken together, these projects represent a broad-based, but only loosely cooperative effort to make ubiquitous computing a reality (Saha & Mukherjee, 2003). Quite a lot of research was being conducted, but a general lack of agreement among major participants was slowing acceptance of the technology outside of the academic and corporate research communities (Greenfield, 2006).

Writing in 2006, technologist Adam Greenfield notes both the growing excitement and the lack of cohesion in research surrounding ubiquitous computing. In his book *Everyware: The Dawning Age of Ubiquitous Computing*, Greenfield attempts to introduce the idea of ubiquitous computing to non-technical users, an audience that had been largely neglected since Weiser's time, and to provide a single term under which non-technical audiences could discuss the increasingly broad range of research emerging in pursuit of ubiquitous computing.

Greenfield's motivation for writing his book is noteworthy, and I think, commendable. Greenfield coined the term, *everyware*, in an attempt to gather together the many related ideas surrounding ubiquitous computing and to fold them neatly into a single term appropriate for non-technical use. His stated motivation for doing so was to capture the qualities the many fields conducting research in ubiquitous computing have *in common* rather than focusing on *the differences* and minutiae each individual approach brought with it (Greenfield, 2006). Greenfield reflects,

> From the user's point of view, I'd argue, [the many and various fields touching on ubiquitous computing] are all facets of a single larger experience. It involves a diverse ecology of devices and platforms, most of which have nothing to do with 'computers' as we've understood them. It's a distributed phenomenon: The power and meaning we ascribe to it are more a property of the network than of any single node, and that network is effectively invisible. It permeates places and pursuits that we've never before thought of in technical terms. And it is something that happens out here in the world, amid the bustle, the traffic, the lattes and gossip: a social activity shaped by, and in its turn shaping, our relationships with the people around us. (Greenfield, 2006, p. 16)

Greenfield's attempt to introduce a single, widely accessible term to describe—collectively—the research happening around ubiquitous computing is admirable, but the research community remains heavily invested in established terminology. The idea of everyware does not appear to have gained much traction in the literature. Still, I do want to note that I admire the spirit of Greenfield's everyware. I fully believe that the whole is more important than any one discipline's approach, and—for the layperson including myself—discipline specific distinctions within the larger body of research are largely unimportant.

It is also worth noting that Greenfield's book was published by the AIGA Design Press publishing house, distributed under Peachpit's New Riders brand—a brand better known for distributing how-to style instructional texts than scholarly works. Although Greenfield now considers his choice of publishers a mistake[11], it is indicative of the growing level of interest within the general public that a mainstream publisher choose to published a book describing the emergence of ubiquitous computing.

An Environmental Design Interest in Ubiquitous Computing

Situated Technologies Pamphlets

Following the publication of *Everyware* in 2006, Adam Greenfield coauthored a series of pamphlets with Mark Shepard, Assistant Professor of Architecture and Media Study at the University at Buffalo, State University of New York (Greenfield & Shepard, 2007). The pamphlets collectively formed "The Situated Technologies Pamphlet Series," published by the Architectural League of New York. The pamphlets undertake an investigation of the implications of ubiquitous computing for architecture and urbanism. The pamphlet series seeks answers to the

[11] Greenfield was unhappy that his book went to press "with an imprint primarily known for how-to manuals for aspiring Web developers and Photoshop jockeys" and said of his choice, "It was a mistake, and it was my own; I was both overeager and insufficiently confident in my book's merits" (Greenfield, 2012).

questions, “How are our experience of the city and the choices we make in it affected by mobile communications, pervasive media, ambient informatics, and other Situated Technologies? How will the ability to design increasingly responsive environments alter the ways we conceive of space?” (Greenfield & Shepard, 2007, pp. 4 - 5).

Situated technologies, according to Greenfield and Sheppard, are of interest to environmental designers. Situated technologies are ubiquitous computing devices tied to specific space, where data is collected by sensors, processed computationally, and returned directly to the site as observable information. Both objective and subjective data can be processed in this manner. Examples of objective data that can be processed this way include ambient conditions such as lighting, temperature, humidity, wind speed, and sound levels. Subjective data includes cultural, social, and aesthetic qualities of a site, collected in real-time or accessed from a database of historical information. Specific examples of subjective data collected in situ include interpretations of objective data (e.g. crowdedness, colorfulness, healthfulness), historical events, and culturally significant information (e.g. holidays, traditions). By incorporating and revealing these site specific qualities through digital mediation, situated technologies privilege local, context specific and spatially contingent data (Greenfield & Shepard, 2007).

Today, situated technologies (often associated with building management systems) are routinely installed within the built environment. These devices have tremendous potential to affect interactions in designed space, but environmental designers are largely absent from discussions concerning this technology, surrendering the responsibility to engineers and technologists. As a result, architecture rarely engages with situated technology effectively. Engineers use situated technology too conservatively (i.e. heating and cooling systems), while technologists are limited to developing technologies that build upon existing architectural forms.

Consider, for example, the recent trend of projecting information onto building skins. Technologists employ projection as a means of modifying the existing architecture, but the architecture itself barely contributes anything to the effort. Greenfield and Shepard wonder, "What opportunities lie beyond the architectural surface as confectionary spectacle […]?" (Greenfield & Shepard, 2007, p. 5). They assert that opportunities exist for environmental designers to engage situated technology more directly. Rather than being an accessory *to* a design, interactions with technology can become an integral part *of* a design.

Greenfield and Shepard describe the emergence of the idea of *ambient informatics*. They suggest that the term refers not to specific technology installed into the fabric of a site, but to the overall condition or state that such technology will give rise to in its use within a site. Greenfield and Shepard define ambient informatics as "a state in which information is freely available at the point in space and time someone requires it, generally to support a specific decision" (Greenfield & Shepard, 2007, p. 11).

Ambient informatics goes a step beyond simply declaring that computation will be present, ubiquitously, at a given location. A site imbedded with situated technology has the ability to provide site-specific information to visitors, to support decision making there. This is not generalized computation. Rather, it is targeted information delivery, informed by site. Instead of using a smartphone, for example, to research information about a site, the information becomes an inherently observable feature of the site. In effect, a site gains the ability to curate its own informatics. It features the computational infrastructure needed to make use of the information, and the devices necessary to communicate the information. With the inclusion of situated technology, the range of site-specific features an environmental designer can work with is greatly expanded.

Greenfield and Shepard note that the act of curating the information present in a site can be a cooperative affair, designed to activate citizen engagement through a process known as *read/write urbanism*. Read/write urbanism is a way of describing a state in which ambient informatics enables citizens to inscribe their subjective thoughts, actions and desires into the fabric of the city itself, through digital mediation. Through ambient informatics, the persistent, virtual layer of digital information and interaction opportunities that sits atop the built environment is pulled close to the physical world, and made interactive (Bilandzic et al., 2011). The citizenry can engage with the digital information freely, using tools available in situ, and leave their imprint anchored in place, available for others to interact with (Greenfield & Shepard, 2007). As Greenfield and Shepard note, "[The] city's users are no longer bound to experience passively the territory through which they move but have been empowered to inscribe their subjectivities in the city itself…" (Greenfield & Shepard, 2007, p. 12).

This idea brings designers of the built environment into an area of controversy. If environmental designers engage in this sort of design work, they become involved in the debate concerning people's attention and distraction, their disassociation with physical infrastructure as they engage with digital infrastructure. Greenfield and Shepard provide an example of this situation:

> For example, I recently spent the afternoon in a garden at my favorite watering hole in Brooklyn and sat next to a couple who were chatting. The guy was constantly shifting his attention between his conversation partner and his new iPhone. Now it's common when talking to someone to glance away periodically at other people or things happening around you (I would suggest this is a fundamental attraction of urban environments), but what's different here is that Mr. iPhone's attention is constantly shifting between virtual

> and actual modes of presence. To me, the interesting questions are: What happens when the virtual and the actual are not understood in terms of a strict dichotomy but rather a continuity or a gradient? How might we design for scenarios like this (Greenfield & Shepard, 2007, p. 32)?

Greenfield and Shepard suggest that this is a case of redefined adjacency. I would assert that this also involves the way we embody information, and is not something that is new to digitally mediated encounters[12]. People walked about distractedly in public spaces long before telecommunications revolutionized our conversations. Greenfield and Shepard suggest that "the previously sovereign social and material environment of actuality, with its almost boundless ability to press claims for attention on the 'user,' is losing a great deal of this primacy, because at any given time you're no longer merely 'next to' the person you're sharing a table with. You're also next to the people who happen to be co-present with you in whatever shared presence artifact you're using" (Greenfield & Shepard, 2007, p. 32). This idea will be discussed in greater detail in a discussion of hybrid space in Chapter 4.

Unfortunately, Greenfield and Shepard are unable to provide an easy answer for this situation. It is almost certain that the use of smartphones will continue, and that awkward social situations will continue to arise due to distracted smartphone users. I propose that part of a solution might be found in Weiser's idea of calm technology, with its emphasis on moving distractions to our peripheral attention, and that part of the solution may lie in context-aware computing, and the idea of appropriateness, which we will discuss in detail in Chapter 5. At the moment, it is sufficient to simply acknowledge that this area is likely to remain controversial,

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[12] This idea is returned to, and elaborated on, in Chapter 4, in our discussion on hybrid space.

and that it is a situation that will persist with or without the involvement of environmental designers and the built environment.

Toward the Sentient City

Writing for the Architectural League of New York in 2010, Keller Easterling, Professor at the Yale School of Architecture, examines the role of digital infrastructure in the modern city (Easterling, 2011; Shepard, 2011). Easterling asserts that designing infrastructure is the same as designing action. It is a matter of potentiality. By designing a system made for motion, you are in effect designing a moving system. She maintains that, although many professions, including environmental design, see materiality only in objects, other professions, such as theater, see actions themselves materially, as the essential raw material of their profession (Easterling, 2011).

This rethinking of material and action is undertaken to illustrate the point that sometimes, by designing an object, you are also designing an action, or a cascade of actions. Socio-technological constructions such as power grids, computer networks or interstate highway systems tend to "influence the desires of the social networks that reciprocally shape them" (Easterling, 2011, p. 156). These socially influencing constructs have agency, of a sort, serving as non-human agents in social networks (Easterling, 2011).

Easterling posits the questions, "If infrastructural organizations are performing, what are they doing? If their performance is indeterminate, how are they designed" (Easterling, 2011, p. 156)? To be able to provide answers to these questions, designers must assume the ability to design active forms—to design spatial agents that are both form and also action. These active forms often produce actions in agents they encounter (be they people, or other infrastructures), and therefore the active form a designer creates may move beyond the conventional physical site undergoing design (Easterling, 2011).

In this way, an environmental designer designing a digital infrastructure (e.g. the interactions with technology that result from incorporating ubiquitous computing technology into a site) is able to magnify the effect their design will have on a community. This is not an idea unique to digital mediation. Physical architecture is often employed as a means of changing the course of human behavior in an area. It is normal enough for a city to build a police station in a rough neighborhood in an attempt to turn it around. What an environmental designer working with digital materials does is to decide what digital information should become embedded in the site, and what effect that information should have upon the place they are creating there.

Easterling cautions designers to proceed thoughtfully when entering this new arena of design. She notes that infrastructure can deprive people, or empower them. Although the powerful often decide where infrastructure is installed, it is a medium that invites repurposing. She advises designers to avoid "digital installations that signal technological anthropomorphism or dynamism with an animation of blinks and beeps," but rather to focus on "heightening an awareness of … a relational agency existing in the urban environment" (Easterling, 2011). Very simply restated, designers should avoid installing a system that talks more than it listens. As environmental designers expand into these new areas of design work and begin employing digital infrastructures within the places they create, they enter into an area where action often is the form they are designing.

Easterling's work supports the idea that environmental designers, due to the emerging presence of ubiquitous computing devices within the built environment, are moving into a new area of design, but there is no reason to leave the traditional aspects of the practice behind. As we will explore in Chapter 5, McCullough makes a defense of architecture in the face of ubiquitous computing. I suggest that the digital infrastructure Easterling describes is actually a hybrid space, an idea that will be discussed in detail in Chapter 4. Easterling's argument that architecture should participate in urban discourse, as a medium for citizen participation echoes similar ideas expressed by Greenfield, McCullough, Bilanzdic and Foth, and touches on the emerging field of Urban Informatics. (Foth, 2011; Foth, Choi, & Satchell, 2011; Greenfield, 2006; Greenfield & Shepard, 2007).

ARGON AR

Driven in part by the desire to create better in-game experiences, researchers at Nintendo and Microsoft have pursued devices aimed at the human-machine interface. Affordable sensing devices, originally intended as video game console controllers including the Nintendo Wii Remote (released in 2006) and Microsoft Kinect (released in 2010), deliver sensor rich devices at commodity prices, bringing gesture recognition, voice recognition, and optical tracking to new levels of performance and affordability.

Many of the gyroscopes, accelerometers, and magnetometers[13] commonly found in today's smartphones were developed for use in the video game industry. Today's smartphones—each one a highly mobile portable computer in its own right—have released a flood of computational power and sensing into the built environment. Sensors commonly found in smartphones provide location and orientation data, and feature radio-frequency identification (RFID) and near field communication (NFC) capabilities capable of forming ad-hoc networks with other computing devices they are likely to encounter. NFC, in particular, features prominently in Google's Google Wallet, a service that allows smartphones to interact with point-of-sales computers to conduct wireless credit card style transactions (Molen, 2010). Smartphone

[13] Gyroscopes, accelerometers and magnetometers are used to track motion relative to a fixed position. These sensors commonly provide 4 or 6 degrees of freedom (DOF), allowing software to measure the sensors' movement along X, Y, and Z axis (translation) as well as rotational direction (rotation).

devices, as a whole, are undergoing active development as platforms for delivering additional services that extend well beyond traditional cellular telephone purposes. Taken collectively, the sensing and communication technologies present in today's smartphones have the potential to form the sort of ad-hoc computing clusters described in the Portolano Project.

Augmented Reality Browsers, an emerging class of new services provided by smartphones, are of interest to environmental designers and planners because of their ability to provide a contextual framework for digital information delivered through smartphone devices. Consider the growing number of augmented reality browsers developed for iPhone and Android platforms as examples. Popular applications such as Layar, Junaio, and (to a lesser extent) Georgia Tech's Argon, fall into this service category (Grubert, Langlotz, & Grasset, 2011).

Augmented reality browsers provide a method of immersing a person in a diverse collection of virtual information (html, image, audio, video or 3D model), superimposed on the world around them (Grubert et al., 2011; MacIntyre, Hill, Rouzati, Gandy, & Davidson, 2011). As commonly implemented on smartphone devices, digital information is overlaid onto live images of the physical world, captured through the smartphone's cameras. This digital information is typically downloaded through an Internet connection and then positioned in the physical world based either on recognition of a pattern, usually found on a physical marker placed in view of the camera (marker-based), or by using GPS coordinates (geocoded). In general, marker-based tracking is more accurate while geocoded information can be delivered with more flexibility because there is no need of a physical marker to view through the camera[14] (Junaio, 2012).

[14] My own experience in the Virtual Experiences Laboratory bears this out. Marker-based tracking is quite accurate on iPhone 3 and 4, while geocoded information is less reliable due to

SENSEable City Lab, MIT

The SENSEable City Lab at MIT is an ongoing research project dedicated to promoting the idea of the real-time city. The idea behind a real-time city is that the increasing number of sensors and hand-held electronics deployed in recent years into the built environment allows a new approach to its study, through the collection and analysis of geocoded data as it is generated. The SENSEable city lab's goal is to study how cities function by studying the new insight into city function that improved sensing provides.

In 2011, the SENSEable City Lab released a collection of essays covering a variety of topics undergoing research in the lab (Nabian & Robinson, 2011). The essays begin with a statement describing the impetus behind their research.

> Over the past few decades, an emerging suite of miniaturized, networked, and pervasive digital technologies has woven itself into our urban environment – our buildings, urban infrastructures, objects, and communication devices. These digital technologies are embedding a new functional layer over our cities, and are creating a digital nervous system with which we interact on a daily basis. Given this, and when considered alongside the unprecedented rate at which cities are being constructed, we are witnessing a paradigmatic shift across all aspects of urban research, including, architecture, governance, infrastructure, services management, transportation and urban planning. (Nabian & Robinson, 2011, p. 6)

A consequence of adding sensing technology to the urban fabric is that cities can start to work as real-time control systems (Nabian & Robinson, 2011). Control systems, regulated by feedback loops, are an idea borrowed from engineering, where they have been developed and

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limitations in the accuracy of the smartphone's GPS sensors. Geocoded digital information was often overlaid incorrectly in my experiments.

have resulted in increased efficiencies in terms of energy savings, increased robustness, and disturbance tolerance. Carlo Ratti of the SENSEable City Lab is currently researching whether or not cities can be envisioned as control systems, extending similar efficiencies and savings to complex situations at large scales.

In a mechanical system, such as those found in engineering applications, actuators (devices that respond to a change of state, thereby altering the course of action underway) control feedback loops and help to optimize the efficiency of a system. Ratti asserts that actuators are already playing a similar role in the living fabric of the city. A variety of mechanical actuators already exist (e.g. traffic lights, remotely programmed signage, scheduled public transit) in cities, and they help shape existing feedback loops. For example, schedules controlling traffic lights, trains, busses, etc. are routinely optimized based upon traffic and usage patterns. Ratti asserts that a hidden asset—a hidden actuator—exists in cities as well: the citizenry.

Humans are unique assets, in that they have the ability to act as distributed intelligent actuators when they are informed appropriately concerning expected behavior. Ratti argues that today's cities, because of their increased capacity for sensing and analyzing data—gained through the appearance of ubiquitous computing devices (i.e. sensors)—are now capable of returning information to citizens in near real-time (providing feedback and asking for action), so that citizens can act as intelligent actuators, altering feedback loops and establishing control systems for our cities (Nabian & Robinson, 2011). Ratti notes that this is not a form of mass control: "[Informed] citizens are all pursuing their individual interests in co-operation and competition with others, becoming prime actors on the urban scene. Processing urban information captured in real time and making it publicly accessible can enable people to make better decisions about the use of urban resources, mobility and social interaction" (Nabian & Robinson, 2011).

Consider, as an example, a situation in which real-time information on energy usage in a specific geographic area of a city is made available to citizens. This could be accomplished in a variety of ways. A simple means of indicating a need for reduced consumption would be to re-program signage in the area to ask citizens for reduced consumption. A more elaborate way would be to modify the appearance of the built environment in real-time (lighting, graphics, audible clues) to indicate reduced consumption is now needed.

As a result of receiving the message, some citizens will make a spontaneous decision to reduce their energy consumption, while others probably will not. The immediate result is that energy consumption will (probably) fall. Secondary results might include spontaneous conversations about energy consumption and spontaneous attempts to influence the opinion of citizens who either participate in reducing consumption or don't. As Easterling indicated, change in the digital infrastructure of an environment (the display of information concerning site specific energy consumption) produces ripples of action and knowledge (potential action) that extend beyond the boundaries of the physical site.

Through the kind of iterative process described here, by sensing, analyzing, communicating, and repeating, today's cities are capable of achieving improved efficiencies of operation. A sentient city (i.e. a city capable of sensing) is an active participant in its own operation.

Urban Informatics

Associate Professor Marcus Foth of the Urban Informatics Research Lab at Queensland University of Technology, writing in 2011, described the emerging practice of *urban* *informatics*, a transdisciplinary practice encompassing people, place and technology that can aid local governments, urban designers and planners in creating responsive and inclusive urban spaces and nurturing healthy cities. Foth considers urban informatics a means of creating "responsive and inclusive public spaces in the context of modern knowledge economies" (Foth, 2011, p. 3).

Urban informatics is a discipline that runs in parallel with many aspects of ubiquitous computing. One distinction that urban informatics claims is that while ubiquitous computing has no defined limitations on where it can be practiced, Foth notes that urban informatics is a strictly urban (or peri-urban) application of ubiquitous computing technologies (Foth, 2011). Also noted as a distinction between the two, *informatics* implies more of a connection to information systems and information science than to information technology, and therefore shifts the attention of urban informatics away from the hardware and more towards "the qualitative aspects of information exchange, communication and interaction, social networks, and human knowledge and creativity" (Foth, 2011, p. 4). Urban informatics is concerned with the effect of technology systems and infrastructure on people in urban settings.

Foth notes that an increasingly large amount of the average citizen's participation is expressed now in online forums and exchanges. One problem with expressing views concerning the urban environment in detached, online forums and social networks is that the argument is always presented out of context. Leaving a rant on Facebook concerning the closing of a corner grocery is a very different experience than standing in front of the grocery protesting, and the audience addressed through an online protest is different as also. Instead of delivering your message to the people who physically pass through the space each day, you are delivering your message to the people who cross through a different, digital space. By protesting online, you may change the mood of the digitally mediated space, but you are unlikely to change the mood of the physical urban space that is the actual target of concern (Foth, 2011).

To counter the growing disconnect between civic action and context, urban informatics employs digital mediation in an effort to restore real-world context to peoples' digitally mediated civic discourse. Urban informatics employs situated technology to provide forms of in place digital augmentation. These installations offer the ability to augment the experiences of citizens in physical urban spaces through mediation by digital technology that is directly accessible within that space. This can be accomplished through a variety of methods, including location-aware software on portable devices or through publically accessible devices, such as displays (Foth, 2011).

Keeping in mind the premise that urban informatics is concerned more with the people than the hardware; an opportunity exists for environmental designers to engage meaningfully with practitioners of urban informatics, providing them with a complimentary set of skills. This is true because, when designing a digital, urban infrastructure using ubiquitous computing technology, the hardware is often seen as architecture, or more specifically, as interactions that take place among architecture. An environmental designer can help design the experience of engaging the digital information in place, while urban informatics concerns itself more with how the information communicated affects civic action there.

Examples of urban informatics projects including "Discussions in Space" and "Amphibious Architecture" can be found in Chapter 6.

CHAPTER 3

COMPONENTS OF UBIQUITOUS COMPUTING

"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they disappear into it" (Weiser, 1991, p. 94).

"When everyday objects boot up and link, more of us need to understand technology well enough to take positions about its design" (McCullough, 2005, p. 67).

The review of the literature conducted in the preceding chapter dealt with ubiquitous computing primarily from a historical and theoretical perspective. I have attempted to establish both a broad impression of what the technology encompasses, and also a more narrow view of ubiquitous computing that should be of interest to practitioners of environmental design and its related disciplines.

Here, I narrow the scope again, now focusing specifically on the hardware and software components associated with ubiquitous computing. In some ways, this is a section that introduces the hardware and software as material components of ubiquitous computing, much as we would discuss the properties of any material being considered for use in a design at a site.

Although the idea of context will be repeatedly touched on in the following review, I try to keep the focus primarily on the hardware and software components themselves, rather than the impetus for their application. The ideas influencing their application, including hybrid space and interaction design, will be explored in greater detail in Chapters 4 and 5.

For the moment, I will say the following about context. It is sufficient to understand that the context a device operates in (and that it is aware of operating in) is related to the portability of the device, or lack thereof. As we discussed in the preceding chapter, situated technologies are of considerable interest to designers of the built environment, probably of considerably more interest than portable computers.

As an example, consider how a smartphone (a portable computer), carried as a personal possession, is understood very differently in terms of its nature and function than a computing device permanently embedded in a site is. From an architectural perspective, portable computers are often less interesting (and more problematic) because they exist at the scale of the body rather than at the scale of a room, building, street or public space in general (Greenfield, 2006). Portable computers move in and out of a site in unexpected ways, and—in general—are viewed more as *visitors* in a site than as *part of* a site. Situated technology is just that—situated. It is conceived of, and understood as, a part of the site where it is featured.

McCullough believes that environmental designers should concern themselves more with "the components of digital systems that are embedded in physical sites" than "the universal mobility that has been the subject of so much attention" in ubiquitous computing research (McCullough, 2005, p. 67). In his use of the term embedded, McCullough refers to the enclosed or concealed nature of the chips and software that perform computation. These embedded computers are most probably neither seen nor understood by their users as computers. They are computing devices concealed within everyday things. They are perceived and understood as part of the site itself.

It is important to reflect for a moment here that McCullough is not discriminating against all portable devices when he criticizes the relevance of portable computing to the practice of environmental design. Rather, he advocates for technology that is contextually aware and contextually relevant. In this regard, it is important for a computing device to be aware of, and informed by, the context of its use, even if the device itself is inherently portable. His argument against portable computing is more specifically an argument against the "anytime-anyplace universality" typically represented by portable computing devices connected to generalized repositories of data such as the Internet (McCullough, 2005, p. 74). For the purposes of this discussion, I will establish this rule: Any computing device that is aware of its context at the time of its operation is *embedded* in a site, and any device that is contextually ignorant is considered *portable*, and not specifically a part *of* the site during its period of operation.[15]

To clarify the above statements, consider the following examples concerning the use of a smartphone in a common situation. While sitting in a restaurant, it is possible to look up the day's specials on a restaurant's website using your smartphone's built-in web browser. In a typical, non-contextually informed scenario, you search for the restaurant's website, choose the result most likely to contain a menu, and hope that an up-to-date list of the specials is provided. A common frustration in this scenario is that too many similar results are returned in your search and they are difficult to choose between. This is true of the experience whether you are sitting in the restaurant while conducting the web search or somewhere else entirely.

This experience could be greatly improved if contextual information were provided as input to the smartphone during its operation. Consider how much simpler it would be to find today's specials if the smartphone simply *recognized* that you were in a specific restaurant, at lunch time, and—as a result of this contextual information—made information concerning lunch there readily available to you. Or, if the device recognized that you were not in the restaurant, it

[15] This observation sets the tone for much of the discussion that follows.

could also provide information about routes to reach the restaurant, and inform you if lunch service will have ended before you can possibly arrive there.

The difference between the approaches to solving the problem in the examples above is contextual. In the first example, the smartphone acts as a portable computer that is only visiting the restaurant. It makes no attempt to integrate itself into the place by accessing contextual information, such as its own location and the fact that its location corresponds to the restaurant's location. As a result, its operation is vague, unguided, and as a result the user experience suffers. In the second example, the smartphone draws on contextual information concerning *place* to guide its actions and responses. It uses location awareness (provided by GPS) to analyze situational data (that a restaurant resides at its current physical location at lunch time) to inform its operation and response. In the second example, the smartphone, during the period of its operation, acted as an *embedded* computer and provided a more focused response to the task it was given. This was possible despite its *overall* portable nature because it allowed itself to integrate with site-specific information.

In ubiquitous computing relationships, computers embedded within the physical environment, by maintaining contextual knowledge of their situation, are able to perform a more refined set of contextually appropriate tasks. They cease being generalist devices and become specialized devices. The tasks these computers allow us to perform are informed by the context of their use, which provides guidance concerning what information they return and how they return the information. Unlike general purpose computers, specialized computers consult their context to determine what they can do, or should do, to maintain appropriate behavior (McCullough, 2005). This is similar to the process a person uses to determine, based upon information from their environment, what is socially acceptable behavior in a specific place at a specific time. The scope of contextually informed behavior extends far beyond determining what to eat for lunch. Through this mechanism, it should become possible for our technology to learn that we whisper is museums and libraries, that we can speak loudly while walking on a crowded sidewalk, and that we don't interrupt important conversations unless the need is very urgent.

In order to reach the goal of contextual awareness, our computers must acquire new means of sensing and communicating with their environment, with us, and each other. This will require specialized hardware and software. The hardware is primarily dedicated to sensing and processing information, while the software constitutes some situational protocols to help embedded computing devices determine what sort of communication is appropriate at any given moment and location. Appropriateness, McCullough asserts, is really a question of etiquette. He explains, "If our growing constellations of devices and gadgets are to become any less obnoxious than the desktop computers they are intended to replace, they will have to acquire some situational protocols" (McCullough, 2005, p. 69). These situational protocols reside in software, and we will experience and interact with this situation-aware software very differently than much of the software we interact with today.

The changes required in our computing devices, and in our methods of operating our computing devices, may render them unfamiliar to many of us. It is therefore necessary to familiarize ourselves with the new capabilities, components and behaviors of ubiquitous computing devices if we want to be able to engage with them productively. This is especially true for practitioners of environmental design, who in addition to experiencing ubiquitous technology as end users will begin to experience technology as a material with which they will create the built environment.

Toward this goal, the following list describes essential concepts that I believe are useful for non-specialists to understand in order to engage with ubiquitous computing technology in an informed manner. This list provides a basic understanding of the hardware, software and protocols associated with this emerging technology. Whenever possible, I have restricted the content to aspects that I think are the most relevant and interesting to practitioners of environmental design.[16]

Sites are embedded with microprocessors

During the course of the average day, we encounter many devices containing microprocessors, although we may not recognize them as such. The devices are increasingly powerful. It is not uncommon for a single chip to hold an operating system, a network interface, an Internet protocol stack, and a web client. By the turn of the century, these devices had shrunk to 7mm, and today they are even smaller.[17] At this scale, computers are not recognizable as such by the average user.

Interconnectivity is key concern within the engineering community for computers operating at this scale. These devices are designed to easily, and frequently communicate with each other. This is true because, in general, as computers have decreased in size, they have also decreased in the scope of their responsibilities. They have ceased being general computational devices and become specialized devices. As a result of specialization, they need to communicate with a wider variety of devices to accomplish complex tasks. This communication is ad-hoc in nature, allowing the devices to share their status with each other and to receive ongoing

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[16] This list borrows heavily from McCullough, *Digital Ground*, pp. 72 – 94, which itself borrows from Steve Shafer (Shafer, 1999), and forms the basis of what McCullough feels non-specialists may want to understand regarding the functions of pervasive computing.

[17] There is currently debate concerning whether or not nanotechnology is a type of MEMS (MEMSnet, 2012).

instruction from other, nearby devices. In contrast to drawing from a universal source of information such as the Internet, this alternative is intermittent and local (McCullough, 2005).

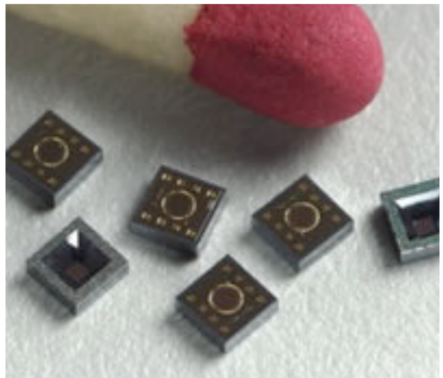

Figure 1. MEMS (Stone, 2005)

Sensors detect action within their environment

Recall Weiser's warning that computational devices must be able to see us coming in order to stay out of our way. After microprocessors, sensors are the second most basic element of embedded ubiquitous technology. Affordable sensors, commonly called MEMS, that measure moisture, sound and light levels, applied pressure, temperature and much more are readily available today at commodity prices (MEMSnet, 2012).

Sensors respond to changes in the state of a mechanical, electrical, magnetic, hydrostatic, flowing, chemical, luminous or logical medium. The change might be a discreet event, the attainment of a threshold, or the establishment of a pattern. Historically, sensors were mechanical and served a single purpose. For example, a bimetal coil sensor registers temperature on a scale as part of a simple thermometer. Today, digital sensors acting as part of an situated computing device gain the advantages of programmability and, by accessing microprocessors, computational ability. Electronic sensors produce digital data that can be stored in memory and interpreted statistically, over time, and in comparison to previous values held in a microprocessor's memory. This becomes especially useful when dealing with large arrays of sensors that collect data essential for recognizing patterns. Pattern recognition helps computers understand our complex behavior (McCullough, 2005).

Communication occurs spontaneously, and frequently

Ubiquitous computing relies on two-way communication between devices. As a result of their increased specialization, ubiquitous computing devices must work together in groups to accomplish tasks. Instead of the infrastructure heavy, intensively planned and predictable computer networks that characterize mainframe, PC and distributed computing relationships, ubiquitous computing depends on spontaneous communication over a constantly evolving network.

Communication links can be established between devices that are fixed or portable, specialized or general, constant or intermittent, and passive or interactive. Computing devices function as organisms in digital ecologies. Spontaneous combinations of devices and patterns of unplanned communication are desirable, and may allow unanticipated local capacities to emerge, beyond what the site's designer originally envisioned. For example, a small device that only occasionally needs some interactivity and cannot justify buttons or a display can offload its interface to a larger device (in this case, a touch sensitive display would be useful) in its vicinity, when it becomes available. The touch sensitive display might normally communicate real time information about ambient conditions at the site (temperature, etc.), but might also allow itself to be repurposed by another device it encounters.

For another example, consider that a device, upon arriving at a site, might access the computational potential of several smaller devices already present there and recruit assistance with a task it is working through. It might even transmit new software to the smaller devices, thereby spontaneously repurposing them, if that behavior is allowed. Networked communication thereby dramatically increases the capacity of a local collection of devices to adapt to incidental conditions, and to generate new conditions and outcomes unanticipated by the site's designers. (McCullough, 2005, p. 79).

This is an important and exciting concept. Establishing adaptability and interactivity within a spontaneously evolving community of devices allows for the emergence of new behaviors within those devices and the site itself. Within pre-ordained limits (or not), designers can plan for the digital assets present in a site to change over time, as a consequence of interactions with visitors. This situation establishes the potential for change in an otherwise timeless, digital landscape.

Through this process, through interaction with visitors, a compliant digital landscape can evolve and figuratively show the wear (so to speak) wrought by passing visitors in much the same way a physical landscape can. Consider how the steps to the left and right of the Arch at the University of Georgia have worn over time from the abrasiveness of visitors' shoes, and how a cultural tradition—to not walk under the Arch before graduation—has prevented wear on the stone at the center of the stairs. What digital characteristics of a site might prove equally susceptible–or be made resistant—to constant interactions with visitors and their digital assets? When thebuilt environment is rich with computational devices and digital information, an environmental design decision will need to be made concerning digital assets present at a site, governing what will, and will not, wear down and change over time.

Tags hold the potential to identify actors

In order to establish contextual awareness at a site, devices must be able to recognize who or what is present. Although pattern recognition software (e.g. facial pattern, landmark, defining feature, etc.) is rapidly improving in accuracy, the easiest way to reliably identify something is to simply "tag" it (McCullough, 2005, p. 80). Abundant precedent exists for this action. Barcodes, first UPC[18] code and now the QR[19], are reliable, highly recognizable tags, although unreadable without some sort of digital scanning device. The UPC code has now largely been replaced by the EPC[20] code, which adds the ability to broadcast itself to nearby receivers rather than relying on optical scanning.

In physical architecture, tagging can be found in historic examples. Ornamentation, inscription, and signage are analogous to tagging, and have marked buildings and public spaces with information intended for a variety of purposes. As we will discuss more in Chapter 5, physical architecture can help to establish the desired behavior of software present at a site, and tagging is a useful way to communicate the intent of architecture to digital devices.

Actuators enable behavioral feedback loops

Computer driven actuators—devices that alter a system's state when triggered by an appropriate condition—are the foundation of feedback loops that allow systems to monitor their own performance and to regulate themselves. Actuators, therefore, are at the heart of systems of distributed devices capable of monitoring their ambient environment (through sensors) and adjusting their behavior (directed by actuators) to regulate it.

Actuators are already extensively used within specialized environments such as automobiles. Airbags, antilock brakes, fuel injection systems, valve systems, steering systems, vibration isolation, suspension, even seat adjustments employ meters, timers, gates, and actuators to improve whole system response (McCullough, 2005). In architecture, actuators under the

[18] Universal Product Code. This physical barcode first appeared in 1974, and identifies kinds of items, not individual items.
[19] Quick Response Code. This physical barcode first appeared in 1994. It is a matrix barcode and features a larger storage capacity than a UPC code.
[20] Electronic product Code. This universal identifier can be physical, as a UPC code is, or use wireless communications protocols. It identifies unique objects, not just kinds.

control of resource management systems can adjust sunshades, modify HVAC system performance, and monitor electricity usage based upon the location of users in a building at any given time (McCullough, 2005).

Sculptural applications using this technology, such as "Hylozoic Soil," an interactive architectural sculpture created by Philip Beesley—Professor of Architecture at the University of Waterloo, Toronto—have moved sensors and actuators from supporting roles in building HVAC systems into the spotlight—literally—at museums and galleries. "Hylozoic Soil" employs proximity sensors and kinetic actuators to respond, with air movement, to the presence of people, who in return respond to the sculpture's apparent knowledge of their presence (Beesley, 2012). Installations such as these, experimental as they are, and housed in a museum setting, introduce people to the idea of sensing—even sentient[21]—architectures in a non-threatening way.

It is also worth noting that actuator driven feedback loops and sensors are commonplace in the maintenance and management cycles of structures such as bridges and dams and other structures with the potential to fail catastrophically (Sazonov, Li, Curry, & Pillay, 2009). These kids of systems will eventually find their way into more routine structures and can form the backbone of management plans at many levels throughout the built environment.

Controls make it participatory

Being surrounded by embedded technology, if it seems to be beyond our control, will prove a frightening experience. To avoid this, the ubiquitous computing devices we surround ourselves with need to involve us on some level in their operation. We should design interactive, not automated environments. Basic principles of interaction design include knowing "when to

[21] Sentient implies the ability to sense, without implying knowledge, as sapience would.

eliminate an obsolete legacy operation, when to automate, and when to assist an action. Know how to empower, not overwhelm" (McCullough, 2005, p. 85).

These ideas are very much in line with Weiser's thoughts on ubiquitous computing relationships. He cautioned that interactions in a ubiquitous computing relationship should make us more, not less capable. He stated, "Whereas the intimate agent[22] does your bidding, the ubiquitous computer leaves you feeling as though you did it yourself" (Weiser, 1993 para. 4). This seems especially relevant as we consider installing ubiquitous computing devices into the built environment. Instead of creating environments that—in the name of efficiency, or some other stated goal—steer people through their everyday activities, environmental designers should create an environment that informs users, providing them with access to abundant computation in order to inform their decision-making.

These decisions may be as simple as finding the shortest route home, or more complex, like keeping us only on the sunniest sidewalks if it's a cold and windy day. We should be cautious though, as environmental designers are often asked to provide guidance involving complex social, cultural, and historical interpretation. Clever, hidden technology holds the potential to privilege one narrative over another, and interaction, rather than automation, is one strategy environmental designers can employ to enable users to draw out a narrative of their choosing, rather than the narrative they are confronted with.

Display becomes ubiquitous

A fundamental concept in ubiquitous computing states that our interaction with symbols depends on their scale and their orientation to our bodies. Text in a pamphlet, for example, shouldn't be the same size as the text on a sign designed to catch the attention of passing

[22] Analogous to an Intelligent Agent, as in Project Endeavour.

motorists. Weiser acknowledged the importance of perceived scale when designing prototype devices at Xerox PARC. Weiser's team of scientists created three kinds of devices: Tabs, Pads, and Boards, each one successively larger, and also capable of performing more interactions. The size of the device, and its orientation to the body (worn, carried, or approached) suggests its use and its capabilities to its users (Weiser, 1991).

Fixed displays, of a variety of kinds, sizes and capabilities, may most clearly characterize situated technologies, and may serve as the best catalyst for bringing pervasive, ubiquitous computing into the architecture of a site (McCullough, 2005). These displays can be recognizable as a display, or their nature can be concealed in some way, perhaps as an structural, architectural element.

Consider, for example, Hiroshi Ishii's ambient ceiling, part of his ambientROOM project. The ambient ceiling attempted to peripherally communicate an awareness of the activity of a distant loved one, in the case of Ishii's research project, of a hamster in a cage elsewhere in the laboratory. The ambient ceiling depicts ripples, like those on the surface of a pond, whose frequency and intensity were mapped to local measures of ambient conditions—to the hamster's wheel. In this way, information that would normally remain unknown could move—peripherally—into the known (Ishii et al., 1998). The ambient ceiling displays symbols, and communicates information, without being recognizable in any way as a traditional computer display.

Consider, as a second example, the "Dangling String," an art project installed at Xerox PARC by resident artist Natalie Jeremijenko. Weiser described it as an 8-foot piece of "plastic spaghetti" that hung from a small electric motor mounted in the ceiling (Weiser & Brown, 1995, p. 1). An actuator controlled a small electric motor that reacted to input received by sensors monitoring data packets on a nearby Ethernet cable. Each bit of information that crossed the Ethernet cable caused a tiny response from the motor. A very busy network caused excited motion accompanied by a characteristic noise; a quiet network caused minimal movement and noise[23]. The installation was placed in an unused corner of a hallway so that the long string was visible and audible from many offices without being obtrusive. Weiser considered it "fun and useful, " noting that it met a key challenge in technology design for the next decade: how to create calm technology (Weiser & Brown, 1995, p. 1). Although the plastic string is not a display in the traditional form of a computer display, it visually communicates digital information and therefore mimics the role of a computer display. In the built environment, non-traditional displays offer a wide variety of opportunities to communicate digital information.

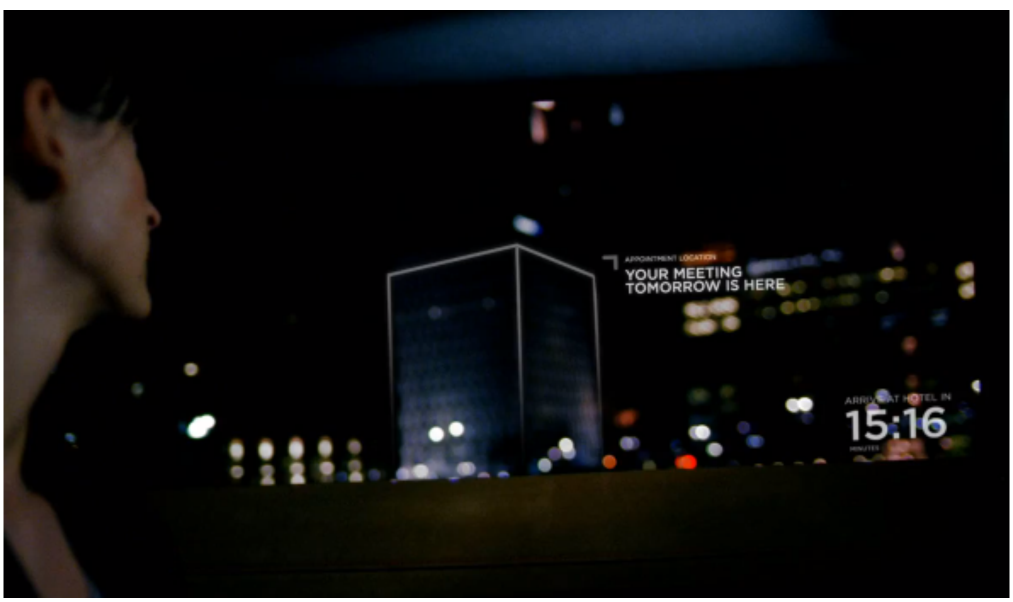

Figure 2. Display co-opts surfaces, here the window of a taxicab ("Productivity Future Vision (2011)," 2011)

[23] I feel that it is important to note the similarity between this application of pervasive computing and an important goal of eco-revelatory design: In each case, the design intent is to reveal to visitors, *in situ*, characteristics of a site that would otherwise have remained invisible and unknowable.

Mobile devices can access fixed information

Global Position Sensing (GPS) is a ubiquitous technology in its own right. GPS is now integrated into automobiles, smartphones, watches, alarm clocks, kitchen appliances and countless embedded computing devices. Easy access to accurate, global positioning information allows GPS enabled devices to provide site-specific information. Geographic information systems (GIS), another common contextual technology, are being created and expanded daily by major technology companies including ESRI, Google, Tom Tom, and Microsoft. Any data that can be assigned a position in physical space as a key to a record in a relational database (geocoded) can be delivered in context to a user through a GIS. For example, many common applications exist for smartphone platforms, enabling users to know more about plant identification, the history of a city, bar hopping, and tracking their friends[24].

Commonly, GPS is used as part of a 3-part system consisting of GPS, GIS, and a mobile computing device. In a typical usage scenario, a user employs a portable computer (smartphone) to access GIS information through an application running locally on the device. The queried GIS database returns only information relevant to the user's current location, as reported by the GPS equipped device initiating the query. The user, in response, receives contextually appropriate information from the GIS.

Augmented Reality browsers (AR), applications modeled on the process above, offer tremendous opportunity for environmental designers. As of 2012, the technology needed for truly engaging augmented reality experiences has not yet fully materialized. The situation will

[24] Consider as examples: Leafsnap, Streetmuseum, Yelp, and Facebook

improve as the accuracy and precision of positioning technology improves, and the user experience with augmented reality should also improve.

Augmented reality, when delivering contextual information using geocoded data, is capable of providing an embedded computing experience, despite the fact that the device running the augmented reality browser is most probably a portable computing device. In this scenario, the augmentation (i.e. digital data being revealed within the browser) is bound to a specific spot in the physical world. Because of this binding, the digital information is understood by the user as being embedded within the site. It can, therefore, be understood as a feature of a particular place and engaged accordingly. Environmental designers can employ augmented reality browsers to reveal characteristics of a site that are known only digitally, and reveal that information to visitors to strengthen the local identity of a site.

Software models represent a digital understanding of a situation

With the appearance of inexpensive, abundant, ubiquitous computing devices, developing good software becomes more challenging. As individual hardware components become more adept at detecting their surroundings, software must also evolve and learn how to accurately comprehend and also represent scenes and situations. “Representing scenes and situations becomes the essential challenge” (McCullough, 2005, p. 91). It is critical, for the acceptance of ubiquitous computing within the built environment that software developers get this piece of the puzzle right. A ubiquitous computing environment *cannot* respond appropriately to our needs if it has an incorrect understanding of what is happening. Conversely, we cannot communicate effectively with the computers present in a site if we are unable to understand what they are telling us.

Brenda Laurel, professor at the California College of Arts, proposed that a primary purpose of computers is to let people take part in shared digital representations of action (Laurel, 1991). For example, computers allow people to take part in shared representations of socializing when using social networking applications such as Facebook.

When the number of devices we engage with (during the act of computing) expands, and the devices are more diverse than a keyboard, a mouse, and a monitor, then our shared representation of action can be richer. As a result of the increased number of inputs involved, the software required to control such rich interactions needs to be very complex to handle all of the emerging possibilities. To provide guidance for the software, a location model is created. A location model is a software model of the environment surrounding a ubiquitous device, or a group of devices that provides guidance to the computers in complex situations.

A location model can be constructed incrementally based upon the shared input gathered by many sensors, or it can be established in advance and modified incrementally to accurately reflect changing conditions present at a site. A location model is equivalent to the computing devices' understanding of the situation they find themselves in. What they do with this knowledge is a matter of design, and a matter of ethics. Just as people are often required to make decisions governing their behavior, based upon rapidly changing conditions, ubiquitous computing devices must learn to respond appropriately in given situations.

Context, provided by architecture, can play a guiding role in the formation of a location model. Architecture therefore can figure prominently in the process employed by ubiquitous computing devices to determine the appropriateness of their actions. For example, software models may determine that some actions are appropriate in a home, but are inappropriate in a public space. A nearby display may be repurposed to show an incoming message from a loved one at home, while such as action is prevented in a public space. It is the job of an interaction designer to determine these behaviors, which create patterns, and these patterns in turn contribute to establishing the identity of a place.

Tuning devices overcomes architectural rigidity

When a ubiquitous computing device is initially embedded into a site, it quickly forms an idea, based upon its innate capabilities and its understanding of context, of what its interactions with people and other devices there should be like. If the device is going to interact meaningfully in the site, it cannot adopt a one-size-fits-all approach to its behavior. The meaningful integration of ubiquitous computing devices into a space is accomplished by *tuning* its interactions with us (McCullough, 2005). Tuning, in this sense, is a way of adjusting the device's software location map in order to assure that it understands its context. By tuning the location map, a designer provides contextual knowledge that helps determine what actions are appropriate. If devices are tuned poorly, interactions with those devices will lack contextual meaning[25]. Consider the example provided in the preceding section concerning displays situated in either public or private settings. Poorly tuned devices would result in poor interactions with the displays, possibly creating a situation in which a display is incapable of making a correct decision about what it should and should not display in a setting. A more detailed explanation of why environmental designers are uniquely qualified to tune devices involved in ubiquitous computing relationships

[25] This matter will be discussed in more detail in Chapter 5, but I want to share a personal experience here. While taking an engineering course, I had the opportunity to interact with engineering students. Our course syllabus emphasized that we would design (and, unfortunately, code) virtual *places* (not spaces), although I was probably the only student to immediately attach significance to the word choice. My suspicion that we were designing experiences as much as environments proved true. Many of the talented engineering students (who produced admirable computer code) were baffled by the idea that their work should achieve meaning beyond the analytical consideration of the code. When confronted with the idea that their project should be understood as a *place,* many students froze in fear. I was—and remain—very grateful for the excellent instruction in place making I received during many design studios.

follows in Chapters 4 and 5, but for now, we should understand that the tuning of interactions at a site is accomplished through incremental manipulation of configurations and settings on embedded devices, and configurable options in the software location models that they process (McCullough, 2005).

Tuning is based on qualitative, not quantitative analysis. It is an overall interpretation of the performance of human-computer and computer-computer interactions at a site. Just as acousticians tune concert halls, environmental designers have the ability to tune the interactions between devices and users in the places they design. Even if the function of an embedded device is, during the initial construction and configuration of a site, configured analytically using formulas and default settings, some tuning creeps in at the last minute (McCullough, 2005). McCullough notes that the prevalence of tuning in today's culture of technology usage is demonstrated by the widespread use of the word *tweak* (McCullough, 2005).

Concluding thoughts concerning ubiquitous computing components

The hardware and software components of ubiquitous computing environments are—despite their apparent sophistication—sentient, not sapient, creations. Sentience is granted by the ability to sense, while sapience is reserved for beings capable of understanding and creating meaning. Designers are sapient, and the responsibility of establishing meaning in their work cannot be offloaded to hardware or software components. Designers should instill within the hardware and software of ubiquitous computing a generalized contextual knowledge, useful for guiding the direction of interactions between people and computation within the context of a mutually understood place.

The built environment is not static, and any system of devices installed into it will need to evolve over time to avoid unintended rigidity that can make a place feel dated over time. The evolution of installed devices is a cooperative process, involving design input from a variety of sources, including continuous input from users, managers, and even the site itself. Devices present in a site can tweak themselves. To understand this more fully, McCullough advises us to expand our understanding of “sense of place” to include “places with sense.” He continues, “Smart spaces recognize at least something about what is going on in them, and they respond” (McCullough, 2005, p. 93).

The design challenge, then, becomes deciding what knowledge (i.e. what situational understanding) is amenable to change over time, and where should the knowledge reside? Some of the knowledge can reside in software that is easily reconfigurable (e.g. by passing users, by other devices), some can be implicit in occasionally reconfigured devices, and some is better off hard-coded into the site itself, and made resistant to change over time (McCullough, 2005). Some knowledge exists (as it does anyplace) entirely in the human, cultural understanding of the place, and is therefore configurable only by changing how people understand a place. It is the interrelationship of these many software, hardware and human interactions that, in an effort to control the evolution of a site, need to be carefully designed. The discipline of interaction design offers advice in meeting this challenge, and reusable software components and standard specifications will emerge to guide designers, but architects already seem well-qualified to understand and design the many ways people interact with places.

If tuning relied exclusively on spontaneous invention, it would be a slow process. If it were to constrain itself entirely to quantifiable functions, it would produce sterile results (McCullough, 2005). An in-between design solution is needed to provide “continuous, if not fully formalized knowledge,” to allow “invention to play off convention” (McCullough, 2005, p. 94). Environmental designers have the sort of continuous knowledge of place that is required for effective tuning of computing devices embedded within the built environment. McCullough explains:

> Persistent structures of form and environment should be able to accomplish half of the work of tuning aggregations of portable and embedded technology. If, for example, one is tuning smart gear for a café, a lot of the work should be accomplished by the fact that it is a café. Location and *type* (italics mine) have to matter. Otherwise, with everything possible at the same time, mostly chaos will result. (McCullough, 2005, p. 94)

McCullough's proposal is that the physical structure of the built environment should act as a foundational layer, providing context, and therefore *type*, as input, and thereby steering the evolution of the pervasive technology present in the site and informing the interactions occurring there.

A primary function of physical architecture in smart environments will be to guide the technology present in the site. Therefore, an opportunity exists for environmental designers to expand their professional interest and take advantage of opportunities to participate directly in designing the interactions between people, technology, and physical architecture that contribute to sense of place. This sort of design work occurs with increasing frequency within the discipline of interaction design (IxD). This idea will be discussed in greater detail in Chapter 5.

CHAPTER 4

HYBRID SPACE

This chapter introduces the concept of *hybrid space* and suggests its use as a framework through which environmental designers can better understand the type of place created by embedding ubiquitous computing technology within the built environment. Digital augmentation and mediation of the built environment offers designers new opportunities, and also new causes for concern. I believe that ideas, concepts, and techniques that originated with the concept of hybrid space offer valuable insight for the integration of ubiquitous computing technology with the built environment.

A Framework: Hybrid Space

> Cyberspace[26]. A consensual hallucination experienced daily by billions of legitimate operators, in every nation, by children being taught mathematical concepts... A graphic representation of data abstracted from the banks of every computer in the human system. Unthinkable complexity. Lines of light ranged in the nonspace of the mind, clusters and constellations of data. Like city lights, receding. (Gibson, 1984)

The concept of cyberspace applied to the Internet was responsible first for our view of physical and digital as disconnected spaces, second for our emphasis on the nodes of the

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[26] Author William Gibson, on his creation of cyberspace: "All I knew about the word 'cyberspace' when I coined it, was that it seemed like an effective buzzword. It seemed evocative and essentially meaningless. It was suggestive of something, but had no real semantic meaning, even for me, as I saw it emerge on the page" (Neale, 2000). Today, Cyberspace is commonly understood as the sum of all global communication networks, computer networks, and technology infrastructure.

> network instead of its spatial structure, and finally for the utopian view of a future in which social spaces would emerge mostly online. (de Souza e Silva, 2006, p. 273)

> Recently, we have witnessed a paradigm shift from cyberspace to pervasive computing. Instead of pulling us through the looking glass, into some sterile, luminous world, digital technology now pours out beyond the screen, into our messy places, under our laws of physics; it is built into our rooms, embedded in our props and devices—everywhere. (McCullough, 2005, p. 9)

Until recently, many technologists thought that the future of computing would center on virtual worlds. Science fiction writer William Gibson introduced the idea of cyberspace, a computer-mediated reality entirely separate from physical space in the mid 1980s. Cyberspace, as an uncharted frontier, captured the imagination of technology futurists for much of the 1990s, bleeding over into pop culture through numerous references[27]. Existing interest in Cyberspace and virtual reality coalesced around the emergence of the Internet and the World Wide Web. In the mid 1990s, it seemed the two ideas were nearly synonymous. Cyberspace, Gibson's meaningless term, had finally connected itself to a resource with emerging value. The idea of *visiting* a website, as if it were a place apart, finds its roots in this association with Cyberspace.

New, exciting technology, with the passage of time, becomes familiar. The term, *World Wide Web* is rapidly fading into memory. It slowly lost relevance in the face of the many new kinds of services delivered through the Internet that have very little to do with traditional ideas of what web pages are. The Internet itself, while growing in importance, is losing the mystique that

[27] Memorable pop culture examples include the 1992 film by Brett Leonard and Gimel Everett, "The Lawnmower Man," and the television personality Max Headroom.

surrounded its emergence. It is now taken for granted as a utility or infrastructure providing access to a pervasive repository of information.

Research carried out in the fields of anthropology, psychology, communication studies and rhetoric seeks to understand how people incorporate this knowledge repository into their lives (Bilandzic et al., 2011; Ciolfi & Bannon, 2007; de Souza e Silva, 2006). The idea that a "virtual layer of information and interaction opportunities […] sits on top of and augments the physical environment" is now receiving much of the attention in technical circles that used to be reserved for disembodied constructions like Cyberspace (Bilandzic et al., 2011 Abstract). The old idea of Cyberspace, as an information repository that sits apart from the physical world, has lost its appeal. This is due, in part, to the ease with which mobile computing (and soon, ubiquitous computing) now allows us to carry our digital information out into the physical world with us. Instead of leaving the physical world to enter our digital places, we seem destined to blend the virtual generously into the physical.

Referencing this combination of digital and physical space, McCullough asserts, "Digital networks are no longer separate from architecture. Unlike cyberspace, which was conceived as a tabula rasa, pervasive computing has to be inscribed into the social and environmental complexity of the existing physical environment" (McCullough, 2005, p. xiii). If environmental design has come into alignment with our networks of digital information, if the two will be experienced side by side within the built environment, then environmental designers need a way to understand and conceptualize the new hybrid space that results from the merging of the physical world and digital information.

The idea of *hybrid space*, an idea developed in the field of human-computer interaction, can act, I believe, as a framework upon which environmental designers can conceptualize and understand the new type of digital-physical space they are working in. Environmental designers are perhaps uniquely qualified to work with hybrid space, due in part to the concept's roots in the work of William H. Whyte and Christopher Alexander, work concerning the differences between spaces and places. Hybrid space has an inherent alignment with the act of place-making, and environmental designers, due to the profession's long history of engagement with place, are well suited to work in this area (Harrison & Dourish, 1996).

In order to frame this idea, I will briefly review some of the foundational work in this area concerning space, place, and human-digital-spatial interaction theory conducted by Steve Harrison and Paul Dourish, pioneering researchers in human-computer interaction theory.

Spatial Models of Interaction

In 1996, after more than a decade of research in human-computer interaction at Xerox PARC, Harrison and Dourish published a paper that considers how collaborative and communicative environments use notions of space and spatial organization to facilitate and structure interactions in environments comprised of both digital and physical elements (Harrison & Dourish, 1996). Harrison and Dourish conducted their research on spatial models of interaction while investigating the design of Computer-Supported Cooperative Work (CSCW) environments. CSCW is not important for the purposes of this thesis, beyond simply understanding that CSCW systems typically enable groups of people, located in physically separate spaces, to work collaboratively using digital mediation to facilitate communication between the parties involved (Harrison & Dourish, 1996). Teleconference systems are a simple example of CSCW systems, as are more complex online immersive meeting spaces, where digital avatars represent people.

Harrison and Dourish base their research in hybrid space on observations concerning the use of spatial metaphors and spatial organization in CSCW systems. Their research confirms that, in collaborative digitally mediated settings, designers can exploit people's natural familiarity with spatial organization in the physical world to improve their understanding of spatiality in digital environments. That is, digital mediation does not interfere with our common spatial methods of understanding the *relational orientation* of objects to our bodies. Even in digitally mediated environments, information can be understood by using concepts such as near, distant, above and below in relation to our perceived bodies (Harrison & Dourish, 1996).

Additionally, Harrison and Dourish confirm that ideas of *proximity and action* hold true in digitally mediated environments. In the physical world, action occurs (more or less) where we are. We pick up objects that are near us, not at a distance; we talk to people nearby because our voices travel only a limited distance; we carry things with us; and we move closer to things in order to view them more clearly. These ideas from the physical world are readily understood in digital space as well (Harrison & Dourish, 1996).

Harrison and Dourish conclude that collaborative virtual spaces, despite their reliance on digital mediation, benefit from our real-world understanding of spatial interaction, and give critical cues allowing us to organize our behavior appropriately in digital (virtual) space (e.g. moving towards people to talk to them, referring to objects so that others can find them) (Harrison & Dourish, 1996).

It was evident to Harrison and Dourish during their research that CSCW designers routinely employ spatial models (such as those examined above) to support interaction among workers, but Harrison's and Dourish's research suggests that it is actually a notion of *place*, not *space*, which frames interactive behavior between people in these models (Harrison & Dourish, 1996 Abstract). The specific methods of their discovery are beyond the scope of this discussion, but their findings are relevant and described below.

Place in Society, and the Built Environment

Within the field of human-computer interaction, Harrison and Dourish are credited with establishing key distinctions between space and place (Harrison & Dourish, 1996). They also establish social distinctions between space and place. Their work is based in part upon the work of theater scholars, architects and urban planners, specifically including William H. Whyte's ideas concerning urban plazas[28] and Christopher Alexander's architectural patterns[29].

Harrison and Dourish note that, in society, the idea of a place is often defined by what actions are, and are not, socially acceptable there. They provide an example derived from Goffman, in which theatrical frontstage is contrasted to backstage, and they note how a societal (the society of actors) notion of what is appropriate in each place is critical to the distinction between the two ("Discussions in Space," 2012). Additionally, they discuss work by Giddens concerning locales, a term that captures behavioral framing in a manner similar to Goffman's work. Giddens notes that it is usually possible to describe locales in terms of their physical structures, but that doing so is a mistake. Giddens describes how people use features of setting in a routine manner, and how doing so lends the space additive identity (Radovanovic, 2012). Harrison and Dourish conclude that Goffman's and Giddens' research, collectively, identifies qualities of human action, patterns of understandings, associations and expectations that infuse space with additional meaning, contributing to a sense of place (Harrison & Dourish, 1996).

Both Whyte's and Alexander's work claims to describe principles of physical design, "but actually [focuses] less on structures and more on the living that goes on within them"

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[28] Expressed in *City: Rediscovering the Center* (Whyte William, 1988)
[29] Expressed in *A Pattern Language: towns, buildings, construction* (Alexander, 1977)

(Harrison & Dourish, 1996, p. 3). Harrison and Dourish conclude that architects and urban designers are concerned with more than just the three-dimensional structures (space) that they design. They design places for people to be in. For architects and urban designers, "the idea of place is derived from a tension between *connectedness* and *distinction*" (Harrison & Dourish, 1996, p. 3).

They assert that *connectedness* is an idea related to the degree to which a place fits in with its surroundings. A place can fit within its surroundings by maintaining a pattern present in the surrounding environment (such as color, material, or form). Even if a place does not maintain the surrounding patterns explicitly, it must at least respond to them. If a place fails to maintain these relationships, we say that it is out of place, that it is too distinctive to be part of its surroundings. Without connectedness, it becomes its own distinct place, rather than remaining part of the other (Harrison & Dourish, 1996).

Therefore, one measure of placeness involves the degree to which a place reinforces or defines the pattern of its own context. This is problematic, because being a place also implies that it is somehow distinct from its context, and if it is too distinct, then it becomes out of place. The tension of being both *a part of* and *apart from* a surrounding context is resolved by defining the distinctiveness of a place in terms of the surrounding context, and vice versa (Harrison & Dourish, 1996). Perhaps strangely, the tension surrounding the point at which something becomes *out of place* helps us know that it was *part of a place* to begin with. In other words, it is sometimes most apparent that a place has ended when we realize that what we are now experiencing is a different place than before.

Importantly, while examining the ideas of space and place, Harrison and Dourish conclude, "This model of place will turn out to be a valuable way to think about and design places in computational space (digital space) as well as physical space" (Harrison & Dourish, 1996, p. 4). They recognize that the ability to conceptualize digitally mediated space as *place*—a conceptualization made possible in part by research taken from the fields of architecture and urban design—will become a valuable concept for use when conceptualizing how to design digital places.

Media Space

Harrison and Dourish define *media space* as space that integrates audio, video and computer technology in order to provide a rich, malleable infrastructure for communication. They note that media space is *space*, not *place*. They assert that media spaces are intended to provide the structure upon which place can arise, just as place arises out of space in the physical world. Media spaces are not designed as places, but are designed for people to make places out of them (Harrison & Dourish, 1996).

Users create a place within a media space by employing adaptation and appropriation of the technology. This idea applies to physical places as well as technologically constructed, digitally mediated ones. For example, a house becomes a home when we arrange it to suit our needs, by putting things in the house that reflect our lifestyle. Similarly, people make places in media spaces through the same process of adaptation and appropriation, by arranging the technology to suit their needs and desires.

Harrison and Dourish provide, as an example of the process of turning a media space into a place, a scenario in which a VideoWindow[30] system was installed in two locations. In the first location, the equipment was fixed in place and unavailable for spontaneous user relocation. In the second case, the video equipment was mobile. Users in the first location failed to become

[30] A VideoWindow is a system Harrison and Dourish created consisting of video cameras and displays employed to create a digitally mediated view into another space.

attached to the VideoWindow system because they could not adapt or appropriate the technology to their own desires. As Harrison and Dourish noted, “[The technology] was not theirs, and they could not make it theirs” (Harrison & Dourish, 1996, p. 4). In the second location with reconfigurable technology, users concluded “the media space offered something wonderful to those of use who experienced [it]” (Harrison & Dourish, 1996, p. 4).

Long-term studies of spaces joined together by media space show the emergence of place-centric characteristics and behaviors (Harrison & Dourish, 1996). Restated, when a media space persistently connects two spaces, the spaces, *as a result of the presence of the connecting media space*, become a new place. The individual spaces are then understood, collectively, as a new place, with the digitally mediated connection understood as a defining feature of that new place. In one example, in which two offices in a building were connected long-term by a media space, Harrison and Dourish found that new patterns of behavior emerged. These new behavioral patterns became apparent in the behavior of the direct participants—the participants whose offices were linked by the media space—but also in the behavior of other participants who were present in close proximity (Harrison & Dourish, 1996). Harrison and Dourish refer to this emergent type of space as *hybrid space*.

Hybrid Space

Hybrid space is a more complex form of media space. Hybrid space is the result of the hybridization of physical space and media space plus the *place* that emerges as a result of the (long-term) presence of a persistent media space in a physical space. This is an important idea to understand, towards which Harrison and Dourish provide the following example,

> Shared Office Etiquette. In [this example], two office-share participants observed a “shared office etiquette” arise amongst visitors to their offices. When someone arrived in

> the doorway or office of one participant to talk to him or her, they would begin their interaction by greeting not only the local participant, but also their remote partner, "present" across the audio and video link. In other words, visitors would behave in either office—a physical space—as if it were part of a shared office. Neither physical space was shared by two persons, but the shared place which they occupied, and which was acknowledged by visitors, was formed from the hybrid of physical and virtual space in the office-share configuration. (Harrison & Dourish, 1996, p. 6)

The two offices in the example are separate physical spaces joined persistently by a digitally mediated virtual connection (media space). Over time, Harrison and Dourish assert, a new *place* results from the persistent presence of the media space (which is itself seen as a new, unique site-specific feature).

This new place is made evident by the emergence of a new cultural behavior, the act of habitually greeting the distant participant across the media space connection. This new place is a specific type of place; one that Harrison and Dourish maintain exists entirely in hybrid space. The hybrid space encompasses the physical spaces (both offices), the media space (the communication link and the two offices it connects), and the culturally defined place that results from it all (the place in which the new greeting style is the norm).

Harrison and Dourish published their foundational work establishing the idea of hybrid space in 1996. Research in hybrid space continues to the present day, and has been engaged and expanded on by researchers in a variety of fields including anthropology, art, communication studies, computer science, Interaction Design, Information Systems, and Urban Informatics, to name a few (Applin & Fischer, 2011; Bilandzic & Venable, 2011; Ciolfi & Bannon, 2007; Crabtree & Rodden, 2008; de Souza e Silva, 2006; Foth, 2011; Kabisch, 2008).

Adriana de Souza e Silva, Associate Professor at the Department of Communication at North Carolina State University, has conducted research on hybrid space, updating the idea for consideration with today's mobile interfaces such as smartphones. Smartphones allow users to be constantly connected to the Internet, providing easy access to assets from the digital world from a variety of locations within the physical world.

Interfaces such as smartphones, because of their ability to create meaningful connections between the digital and physical worlds "define our perceptions of the space we inhabit, as well as the type of interaction with other people with whom we might connect" there (de Souza e Silva, 2006, p. 261). To restate this, by having a smartphone in our possession, it defines our expectations of the types of encounters we can have in a space (voice calls, text-messages, Internet access) and the scope of its ability to communicate defines our perceived social boundaries in our current space.

Hybrid space manipulates perceived spatial limits by enfolding remote contexts inside the present context (de Souza e Silva, 2006). De Souza e Silva also observes, "This connection is related both to social interactions and to connections to the information space, that is, the Internet" (de Souza e Silva, 2006, p. 262). De Souza e Silva's work thereby extends the idea of hybrid space to include interactions with data stored in computer databases, in addition to the previously discussed digitally mediated interactions with other people in real-time.

In de Souza e Silva's expanded definition, hybrid space is not constructed by or of technology itself, but "by the connection of mobility and communication, and materialized by social networks developed simultaneously in physical and digital spaces" and by our perception of the capabilities and boundaries of those conceptual spaces (de Souza e Silva, 2006, pp. 265 - 266). It is a type of space that can be created, spontaneously, whenever and wherever digital information is brought into the physical world and our perception of our ocial abilities and boundaries are affected as a result.

Although de Souza e Silva's work in hybrid space deals primarily with mobile infrastructure, research conducted by Andy Crabtree and Tom Rodden, computer scientists at the University of Nottingham, UK, establishes that the concept of hybrid space is also applicable to situated technology (e.g. ubiquitous computing devices embedded into the built environment) (Crabtree & Rodden, 2008). Their research expands on the work of de Souza e Silva to establish the concept of hybrid ecologies. Hybrid ecologies merge multiple physical and digital environments together (Crabtree & Rodden, 2008). Therefore, they are well suited to describe the complex configuration of space that results from embedding many ubiquitous computing devices within the built environment. For the purposes of the discussion that takes place in this thesis, hybrid ecologies are considered a subfield of the idea of hybrid space, with the advantage of being directly applicable to complex configurations of devices in ubiquitous computing scenarios.

Research conducted by Eric Kabisch in the Laboratory for Ubiquitous Computing and Interaction, University of California, Irvine, reminds us that the spaces into which ubiquitous computing devices are now being embedded are already embedded with cultural artifacts, practices, and infrastructures, and that adding a digital layer enhances, rather than replaces, the existing artifacts, practices, and infrastructures.

Whereas de Souza e Silva's research concerned methods of enfolding remote contexts into the local context, Kabisch's research explores opportunities to reveal hidden local contexts, and suggests that ubiquitous computing technology offers a means of digitally enfolding them within the local (visible) context. Instead of sourcing the digital information from remote contexts, Kabisch suggests that previously invisible, *local assets* that are digitally known can be revealed and combined in hybrid fashion, thereby rendering them visible within a hybrid space (Kabisch, 2008).

Kabisch's research further advances the idea of hybrid space to include site-specific digital information. Site-specific digital information can be pulled from GIS databases, and offers landscape architects new opportunities to work with digital material at heritage sites and cultural landscapes. Site specific cultural information, economic information, historical information, real-time environmental information—all of this can be folded into the local context, digitally mediated by embedded computation, creating a hybrid space informed by site specific conditions that would otherwise remain invisible.

Kabisch uses insight gathered from his research combining pre-existing, site-specific cultural artifacts and digitally mediated information to expand on the long-term societal acceptance of digital elements enfolded in physical space:

> I view hybridity as an evolving product of the cycle of practices through which technologies and technical practices become embedded into the world and society. […] As new technologies are introduced to society, their purity is apparent—they have yet to become entangled into the mangle of everyday practice. But through their ongoing use—and the methodologies and practices that accompany them—these technologies become hybridized with existing practices, artifacts, and infrastructures, embedding themselves into the fabric of our lived experience and our physical world. In relation to geographic information technologies, I see this process as occurring through a continuous cycle of sensing, representing, and acting in the world. Through each iteration of this cycle, the

purity of the embodied world becomes less distinct from the digital or technical practices we use to describe it. (Kabisch, 2008, p. 228)

Thereby, acceptance of hybrid space, although it may initially seem artificial, will—through iterative cycles of acceptance and familiarization—become embedded in society over time.

Much of what is present during a site inventory today was seen as radical at one time. As Weiser so often reminded us, even written language was a radical technology at once time, as were doors, arches, plumbing and electrification. Kabisch asserts that the manifestation of digital information, delivered into the context of physical space, will seem less apart from the real world as we accept the augmentation of physical space culturally, and the devices that provide the augmentation will soon be seen as artifacts that we expect in a built environment rather than as new technology.

Examples of interactive engagements with hybrid space

Microsoft's Future Vision productions attempt to illustrate new and emerging relationships between people and technology within an environment of computation. Many of the settings explored in the Future Vision productions are combinations of physical architecture mediated by digital means, resulting in hybrid places. It is useful to take a moment to review some of the examples Microsoft's Future Vision productions provide.

The hybrid space depicted in Figure 1 provides an example of an environment designed explicitly for the inclusion of digitally mediated information. At the front of the classroom, the physical surface of the wall is coopted by ubiquitous computing technology to become the site of computation. The computation serves the purpose of linking the classroom to another, similarly equipped classroom at a distant location. The resulting space that includes both physical classrooms and the perceived space of the connection between the two is hybrid space. This is a typical example of digital mediation of information shared between two physical spaces, and is reminiscent of Harrison and Dourish's foundational work in hybrid space.

In the designed space depicted in Figure 1, architectural forms and embedded computation work together to create a place that is understood as the cumulative result of both its physical and digital components. The Future Vision video shows students interacting with other across the digital mediation between the two classrooms. It is implied that the connection is a persistent one, and that the social behavior of the students is influenced by the presence of the

Figure 3. A hybrid space comprised of two classrooms and the digital mediation that connects them ("Productivity Future Vision (2009)," 2009)

digital mediation and the digital information it provides. The students understand the place they occupy—their classroom—as the totality of the physical classroom they occupy, plus the other classroom, plus the digital mediation and information that connects the two physical spaces.

The implications of hybrid space for environmental designers

The idea of hybrid space provides environmental designers with a useful framework through which they can understand the unique characteristics of the *places* that result from the inclusion of contextual, digital information within a site in the physical world. If a designer's goal is to establish a place that is understood as more than the sum of its physical characteristics, one that relies on a deep understanding and consideration of its *digitally revealed* characteristics, artifacts, and infrastructures as well as its physical characteristics, then they are designing a hybrid space, and can benefit from understanding what research in hybrid space has taught us.

Hybrid space is way of thinking about space that fully privileges digital information, delivered through embedded ubiquitous computing devices in the built environment. The digital information, in many cases, is understood as interactivity that occurs between people and the unseen ubiquitous computing devices embedded within a site (Bilandzic et al., 2011 Abstract). These interactions are essential to the act of place-making in hybrid space. By including interactions with digital information as an essential element of a design solution, environmental designers are moving beyond the use of digital information (e.g. computer graphics) as ornamentation, and acknowledging that digital information revealed within a site can be as fundamental a component of a designed *place* as are any physical characteristics or cultural information that is expressed through a design intervention.

In order to design these interactions, environmental designers should look to the practice of interaction design (IxD). We will do so in the following chapter.

CHAPTER 5

INTERACTION DESIGN

A Method: Interaction design

> "…[Interaction] design—the practice of designing interactive digital products, environments, and services. Like many design disciplines, interaction design is concerned with form. However, first and foremost, interaction design focuses on something that traditional design disciplines do not often explore: the design of *behavior*" (Cooper et al., 2012).

> "Interaction design is a tool for 'knowing what the user wants' (Cooper et al., 2012).

The emergence of interaction design

In 1979, Bill Moggridge and Bill Verplank, researchers at Xerox PARC, worked together designing the GRiD Compass, a product that, when released three years later, would be one of the world's first portable computers. From a technology standpoint, the GRiD's capabilities were modest. Design decisions targeted at improving its portability ultimately compromised its computational capabilities. It was the careful attention Moggridge and Verplank paid to its design that truly set it apart from its competitors. The GRiD was unique, due in part, to its lightweight form factor and magnesium clamshell case. It featured an innovative bus that allowed for easy expansion beyond its default capabilities, and allowed a number of scientific instruments to be attached with ease. Its operating system, known as GRiD-OS, was well suited to the tasks the computer was employed at; and its main customer, NASA, was pleased with it. Today, the GRiD Compass has been largely forgotten. It is predominately remembered as the project its designers, Moggridge and Verplank, were working on when they coined the term *interaction design* (Cooper et al., 2012).

At the time they worked on the GRiD Compass (1978 – 1979), Verplank worked on parts of the Xerox Star Graphical User Interface (GUI)—the world's first GUI and the basis of went on to become the basis of the GUI used on the first Macintosh computer (Interactions, 2012). Moggridge, with a (physical) product design background, designed the physical form of the Compass. As the product design came to a conclusion, Moggridge began assisting with the Compass's software and computational functions. Moggridge recalls the experience:

> I was surprised to find that I became absorbed in the interactions with the software almost immediately. I soon forgot all about the physical part of the design and found myself sucked down into the virtual world on the other side of the screen. All the work that I had done to make the object elegant to look at and to feel was forgotten, and I found myself immersed for hours at a time in the interactions that were dictated by the design of the software and electronic hardware. My frustrations and rewards were in this virtual space. As I gradually mastered my personal computer, almost all of the subjective qualities that mattered most to me were in the interactions with the software, but not with the physical design. At that point I realized *that I had to learn a new sort of design, where I could apply as much skill and knowledge to designing satisfying and enjoyable experiences in the realm of software and electronic behaviors as I had with physical objects*. (italics mine) (Moggridge, 2006, p. 13)

Moggridge's background in the design of physical objects provided him with a different set of design expectations that did the computer science backgrounds of individuals working in HCI design at the time. He felt computer scientists "wrote code and had a technical and performance-based vision of design requirements" that was ultimately incompatible with the kind of radical innovation he envisioned (Moggridge, 2006, p. 14). He reflects:

> I felt that there was an opportunity to create a new design discipline, dedicated to creating imaginative and attractive solutions in a virtual world, where one could design behaviors, animations, and sounds as well as shapes. This would be the equivalent of industrial design but in software rather than three-dimensional objects. Like industrial design, the discipline would be concerned with subjective and qualitative values, would start from the needs and desires of the people who use a product or service, and strive to create designs that would give aesthetic pleasure as well as lasting satisfaction and enjoyment. (Moggridge, 2006, p. 14)

This, Moggridge notes, is the origin of interaction design as a distinct discipline. He delivered the first presentation advocating the formation of the practice of interaction design, based upon the principles described above, in 1984.

Due to the relative youth of the field of interaction design, many of its foundational texts are more in the form of instructional texts than scholarly reflections on theory. In their foundational instructional work, Cooper, Reimann and Cronin note that, in 1995, more than a decade after its inception, the young field of interaction design was still a frontier wilderness, populated with a core group operating mostly in the shadow of more established areas such as software engineering. Cooper, Reimann and Cronin attribute a sudden expansion in the field of interaction design to the emergence of the World Wide Web, and the need for online digital content, in the form of web pages, to comply with emerging “ease of use” standards (Cooper et al., 2012, p. xxix). Although work involving the World Wide Web, due in part to technical limitations of the medium, did little to advance methods and techniques of interaction design, it established the practice and the need for the consideration of *user requirements* in the corporate world of digital information publication (Cooper et al., 2012).

Cooper, Reimann and Cronin briefly discuss the merit and the meaning of the term interaction design, and consider the field’s place among other design disciplines. They note that interaction design has borrowed from other, more established design disciplines, but also assert that it has moved beyond them to establish itself as a unique discipline. They note that industrial designers and graphic designers “have attempted to design digital products, but their emphasis has been largely on static form, not the design of interactivity, or form that changes and reacts to input over time. These disciplines do not have a language with which to discuss the design of rich, dynamic behavior and changing user interfaces” (Cooper et al., 2012, p. xxx). They also consider whether or not it is possible to actually design an experience. They note that designers in many disciplines “hope to influence the experiences people have by carefully manipulating the variables intrinsic to the medium at hand” (Cooper et al., 2012, p. xxx). Traditionally, environmental designers have attempted to influence the behavior of visitors to sites by combining characteristics of materials, lighting, the interpretation of form, etc. to create an experience in a space. Cooper, Reimann and Cronin believe that interaction design goes somewhat beyond this, influences people’s experiences by designing the actual “mechanisms for interacting with a product” (Cooper et al., 2012, p. xxxi).

A turn in the field of interaction design: Moving from screens to physical space

Although it is difficult to determine exactly where the idea started, researchers and practitioners within the field of interaction design now recognize that the methods and techniques of the practice are applicable outside of screens, when they are applied to ubiquitous computing interactions in physical space. In the published literature, evidence suggests that this turn in the practice of interaction design may have gained popularity through research and application in the museum setting, perhaps as a part of virtual heritage studies (Ciolfi, 2003; Erickson, 1993).

From within the field of interaction design, advocates call for the application of the discipline's techniques to ubiquitous computing (Bannon, 2011; Ciolfi, 2003; Ciolfi & Bannon, 2007; Ciolfi et al., 2005; Erickson, 1993; Kaptelinin & Bannon, 2012). Within the field of environmental design, McCullough, Greenfield, Sheppard and others advocate for this interpretation of interaction design (Greenfield, 2012; Greenfield & Shepard, 2007; McCullough, 2005, 2007; Shepard, 2011). McCullough's statement that "human life is interactive life, in which architecture sets the stage" neatly summarizes his idea of the relationship between the two disciplines (McCullough, 2005, p. xiv). McCullough believes that physical architecture can inform interaction design, and that interaction design is the key to conveying contextual information, inherent in physical architecture, to the host of computational devices that ubiquitous computing will bring into the built environment.

Lastly, within the field of human-computer interaction, Dourish, author of influential work concerning embodiment, hybrid space, interaction design and the application of these ideas and practices within the physical world, has written about ubiquitous computing and how it serves as an extension of earlier work he conducted. Dourish published a paper in which he reflects on the interest his previous work which established the idea of hybrid space and his work with embodiment has generated in the fields of environmental and interaction design. He updates and clarifies his position and expectations concerning the integration of computation into physical space writing:

> …once computation moves off the desktop, computer science suddenly has to be concerned with where it might have gone. Whereas computer science and human-computer interaction have previously been concerned with disembodied cognition, they must now look more directly at embodied action and bodily encounters between people and technology. […] We look on space here as infrastructure, not just a technological infrastructure, but an infrastructure through which we experience the world. Drawing on studies of both the practical organization of space and the cultural organization of space, we begin to explore the ways in which ubiquitous computing may condition, and be conditioned by, the social organization of everyday space. (Dourish & Bell, 2007 Abstract)

Although Dourish does not specifically endorse the field of interaction design as the means through which HCI should interface with ubiquitous computing, his argument that space is an infrastructure with the capacity for cultural organization makes an excellent point of departure to discuss of the implications that his work holds for designing interactions in digitally mediated physical environments.

Interaction design moves into the built environment

Writing in 2003, Luigina Ciolfi, Lecturer in Interaction Design in the Department of Computer Science and Information Systems and researcher at the Interaction Design Centre at the University of Limerick, Ireland, reconsiders work in context-awareness and its significance on behavior in digital environments first undertaken by Harrison and Dourish. Ciolfi, writing from within the field of interaction design, is one of the first to explicitly examine the relationship between interaction design, ubiquitous computing and the built environment (Ciolfi, 2003).

Ciolfi proposes that ubiquitous computing devices may become primary input and output devices for computation occurring within the built environment (Ciolfi, 2003). In the same way Moggridge helped to develop the field of interaction design by expanding the focus of HCI researchers, Ciolfi expands the focus of interaction design to account for interactions between humans and computers within the physical world and the built environment.

She notes that the arrangement of computationally aware objects, and even the way people move and act within spaces, can potentially be seen as interactions with hardware and software. She criticizes the application of historical techniques and methods from HCI and interaction design to ubiquitous computing situations, because traditional techniques and methods were originally intended for "totally different interaction paradigms and systems" (Ciolfi, 2003 1 para. 2). Techniques used for gathering input in traditional applications of interaction design, for example, were developed to gather data from interactions between people and screens, and therefore have only a two dimensional understanding of space and no meaningful sense of context awareness.

Ciolfi asserts that research within HCI and interaction design has inadequately considered how people physically inhabit the environment, and presses for an increased sensitivity to place—in opposition to simple, geometrically measurable space—as a consideration in interaction design work. Traditional methods and techniques in HCI and interaction design emphasize determination of the relationships between behavior and environment by measuring physical qualities of the locale itself (i.e. a stimulus–response mechanism associating structural features of space to patterns of behavior). This works well in virtual space (screen space), but less well in physical space.

In addition to the physical occupation of space, Ciolfi notes that sense of place also involves memories, experiences, and patterns of behavior associated with a space. She asserts that these must be taken into account for effective interaction design (Ciolfi, 2003). According to Ciolfi, interaction design techniques must be aware of the *place*—not just the *space*—in which they are employed in order to engage effectively with ubiquitous computing technology. Ciolfi clarifies her position:

> We believe that focusing on the experiential nature of space and place, going beyond the analysis of geometric and structural features, and clarifying significant aspects of this experience can provide a valuable contribution to Interaction Design for ubiquitous and pervasive technologies. It is not just a new physical environment that we are ultimately designing, but also activities and experiences within it supported and mediated by technology. (Ciolfi, 2003 sec. 2 para. 3)

Ciolfi makes the same argument, from an interaction design perspective, that is later made by McCullough (McCullough, 2005). This is the point of overlap between the fields of interaction design and the practice of architecture, voiced by both Ciolfi and McCullough. They independently advocate the use of contextually informed interaction design techniques to make sense of ubiquitous computing technology embedded within the built environment (Ciolfi, 2003; McCullough, 2005).

To address the previously discussed shortcomings in the translation from virtual to physical space within the practice of interaction design, Ciolfi advocates for an expansion of the design process employed by interaction design practitioners when creating interaction solutions for situations involving ubiquitous computing technology. She proposes a variety of extensions to current practices:

> These approaches all extend the concept of physical space so that it encompasses not only its structural, geometrical essence, but also the dimension of its experience by one or more human actors. Another important issue is that these experiential concepts of space highlight the relationships between the features of the space and cultural, social and personal elements, proposing them as the fundamental aspects of the experience to be taken into account. These philosophical perspectives share our concern to bring the individual, social and cultural aspects back together with the physical, structural elements, in order to shed a new light on the concept of experience of space and place. (Ciolfi, 2003 sec. 2 para. 5)

Ciolfi notes that placing an emphasis on the experiential aspect of the physical environment has implications for both the theoretical and methodological aspects of interaction design. On the theoretical side, she suggests that the individual, social, cultural and physical aspects of the human experience of space and place have to be understood when designing for ubiquitous technology. Designers need to shift away from an understanding that puts the development of system infrastructure on one side and an analysis of users' activities on the other. They should instead seek a more complex understanding of the situation, where they view "the user's experience as localized, inextricably linked with its physical surrounding by means of individual, social, cultural and structural/functional relationships between the two" (Ciolfi, 2003 sec. 3 para. 1-2).

On the methodological side, design practice requires reconsideration and extension of existing methodologies. These include, during the data collection phase, collecting surveys of particular spatial arrangements of the environment, and observation sessions focused on features of the physical space and aspects of place appreciation expressed by users. Users should be involved in the design process, and particular emphasis should be placed on understanding their feelings, attitudes and memories associated with a locale, "through their recollection of stories, materials and artifacts that might be associated with the particular place" (Ciolfi, 2003 sec. 3 para. 1-2). Environmental designers are well suited to engage these suggestions, which are intended by Ciolfi as advice for practitioners of interaction design who wish to work with ubiquitous technology integration within the built environment.

An Environmental Designer's Perspective on Interaction Design

> Notions of what a computer is have not kept pace with realities of how digital systems are applied. As ambient, social and local provisions for everyday life, those realities have become part of architecture. Whereas previous paradigms of cyberspace threatened to dematerialize architecture, pervasive computing invites a defense of architecture. In sum, my essential claim is that interaction design must now serve our basic human need for getting into place. (McCullough, 2005, p. xiv)

Writing in 2005, McCullough's work examines possible interrelations between the fields of interaction design and architecture, in the context of the emergence of pervasive computing (McCullough, 2005). McCullough approaches the analysis from the perspective of an environmental designer.

McCullough, realizing that computation will enter the built environment, examines the implications of such an event for environmental designers through the lens of interaction design. McCullough believes interaction design and physical architecture can operate in a reciprocal relationship. He believes that the move of ubiquitous computing into the built environment, rather than threatening traditional environmental design, will strengthen it (McCullough, 2005).

In an effort to understand how this relationship can work, I will briefly examine how the introduction of digital information into the social discourse traditionally carried out in the built environment has proven disruptive, and then examine how environmental design, interaction design, and ubiquitous technology can work together to provide a solution to this problem.

Social discourse

Human beings are social creatures. The built environment has long served as the primary setting of human socialization. Now, technology has altered both the means and sites of our social discourse. Today, we routinely communicate remotely, asynchronously, and indirectly (e.g. text messaging, email). Portable digital systems, worn, carried, or embedded into physical situations, alter our methods of interaction, creating a challenge for designers of the built environment. When a design solution has been employed (at all) in the creation of these new, largely digital, processes and places of socialization, it is the design solution of engineers, not the design solution of architects. Software engineers too often pursue features, and interface designers too often pursue ease of use. Neither discipline understands the importance of incorporating persistent, cultural knowledge within the creation of new digital social infrastructures in the same way that environmental designers understand the cultural importance of the built environment as the scene where human socialization has traditionally occurred (McCullough, 2005).

McCullough suggests that social, psychological, aesthetic, and functional factors are crucial when designing any kind of social infrastructure, including a digital one. Technology cannot be pursued for its own sake, especially when technology is designed for deep integration within society. The built environment has long served as a form of social infrastructure. It provides contextual clues for action and behavior, and in doing so, has helped establish social norms that benefit society as a whole (e.g. private vs. public realms, civic legibility, codified behavior in traditional contexts). McCullough asserts that "we understand our better contexts as places, and we understand our better designs for places as architecture" (McCullough, 2005, p. 3). The built environment helps society express what actions are considered *appropriate* in what places. McCullough believes that appropriateness must surpass efficiency as the key measure of technological success (McCullough, 2005).

A problem with the continued accumulation of technology, in the absence of a concern for appropriateness, is its perception by people as a form of information pollution (Shenk, 1998). This is an idea we should all be familiar with. Consider as examples of information pollution: junk email, unsolicited text messages, and the endless robo-calls of each election cycle. Even physical objects, like gasoline pumps, now spew advertisements from embedded speakers and broadcast advertising across their digital readouts while dispensing fuel. Recall Weiser's admonition that as technology becomes increasingly pervasive and ubiquitous, it needs to learn to stay out of our way. In order for it to stay out of the way, it needs to know something about where it is, and what behavior is considered appropriate there.

Interaction design and architecture can work cooperatively in an environment embedded with ubiquitous computing to save us from information pollution. Interaction design, like environmental design, is concerned with context. Interaction designers study how people learn, operate and assimilate technology—usually information technology. They study how technological mediation (i.e. digital mediation) influences what people are doing, and how they do it. Interaction designers emphasize particular mechanisms of product usability, and they do this in terms of work practices, social organizations, and physical configurations. They are informed by the context in which interactions with technology occur. If interaction design moves into the physical environment, this context will be provided by the physical architecture of the built environment.

Context

Flows of digital information need meaningful contexts, "much as a river needs banks unless it is to spread aimlessly like a swamp"(McCullough, 2005, p. 47). Meaningful context provides organization to flows of data, preventing a swamp of dematerializing, place-less information. The built environment easily organizes flows of people, resources and ideas. In a classical example, architectural form announces civic function. In the most well functioning civic spaces, a glance around will inform a citizen concerning the function of major institutions, including city hall, churches, government buildings, and private structures. This is not accidental. Time honored forms provide contexts, carrying meaning, and that meaning is communicated generationally through a society.

A critique of modern cities is that this process of architectural form communicating function has broken down (McCullough, 2005). Nevertheless, in modern cities, the built environment organizes flows of resources effectively. Even in a city as fractured as Atlanta (from a classical perspective on urbanism), the architectural form of highways and railways provides structure for the flows of resources moving in and out of the city each day. This is not accomplished by the physical structure of the arteries of travel alone. A cultural understanding of what highway cities are like aids society in planning the movement of resources. An interstate off-ramp has its own ecosystem of businesses and services, and today's highway savvy travellers understand this ecosystem. Without architectural form and the contextual knowledge it communicates, the flow of information would proceed more chaotically. As digital information becomes associated with architectural form, the guidance that the built environment offers should be passed on to digital devices as well.

In the emerging digital city, architectural form has acquired a digital layer (Bilandzic et al., 2011; McCullough, 2005). This layer is, in part, the result of changes in the way society communicates and processes cultural information. This digital information will require codification within the built environment, as does more traditionally generated cultural and societal information. Society is growing less inclined to access their digital social information in discreet, dedicated situations involving personal computers (Bilandzic et al., 2011). Interaction design offers the potential for people to go beyond simple information exchange with personal computing devices. Interaction design offers environmental designers the ability to design provoking and situating interactions within the built environment between people and a variety of emerging social and cultural practices currently represented only by digital information (e.g. discourse on social networks, interactions with situational information stored in databases) (Shepard, 2011). To say this in a different way, interaction design, when practiced by environmental designers, offers an opportunity to engage social interactions currently confined to de-materialized, digital space and to bring them out of digital space and into the societal space of the built environment.

Layers of technology, historically, have tended to augment, rather than replace architectural forms. As with past layers (e.g. electrification, mechanical equipment, and transportation), digital technology is likely to extend physical architecture rather than diminish it. New layers of technology take advantage of the built environment's duration as an older, persistent grounding structure that has shaped environmental predispositions by providing context. In contrast to technological fads, built environments act as enduring backgrounds. When a new technology layer integrates itself into the built environment, through alignment with architectural forms and practices (conceptually, as well as physically), its design becomes directed inward toward the regular inhabitants of the place (McCullough, 2005). It gains in authenticity, but also learns to provide service from its association with the social services that the built environment provides.

The innate concern that interaction design shows for context brings it in line with environmental design. This is critically important. Environmental design and interaction design both address how contexts shape action: "Architecture frames intentions. Interactivity, at its very roots, connects those mental states to available opportunities for participation (McCullough, 2005, p. 47). To restate this simply (if less gracefully), architectural form within the built environment, by providing contextual clues, suggests what is possible at a site, and interaction design translates the perceived possibilities into possible actions.

Whereas early work with human-computer interactions focused on linear workflows with measurable models of conditioned response, interaction design is concerned with peoples' expectations. Based upon a contextual understanding of what a site is about, people form expectations of what actions are possible there. These expectations in turn limit possibilities, and in doing so, help to shape the flow of digital opportunities seen as appropriate at a site.[31]

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[31] This simplified logic is based upon my reading of topics in phenomenology, embodiment and cognition that go well beyond the scope of this thesis. I apologize for the oversimplification of

Although any action is technically possible in a place, architecture informs interaction design of which actions are socially acceptable in a particular context.

Persistent Structures

The more enduring an environment is, the more capable it is of shaping our expectations, without fully saturating our attention. Restated, a well-established place is more capable of shaping a visitor's expectations than is a temporary structure or a hastily constructed place, and it does so peripherally—without explicitly trying. For example, if you visit a quintessential Parisian café, you are more likely to expect an accordion player to spontaneously perform than you would be in a Parisian-style café installed in a strip-mall in Boise, Idaho, even if the strip-mall café had a sign proclaiming, "accordion players are welcome here." This is an important characteristic of built environments. We sense authenticity (another way of saying persistence) peripherally, and authenticity reinforces our expectations of what is possible in a situation (McCullough, 2005).

Type

Casting daily life into certain kinds of architectural forms reflects lasting social agreements about social categories and values. This is how physical constructions also become social constructions. This is one way, for example, that an institution (a social construction) can be said to have scale and identity (physical qualities) (McCullough, 2005). Consider the case of the University of Georgia, as a land grant institution, and the way in which its identity altered when it's physical space (its land holding) was reduced from agricultural lands and campus, to campus alone. This reduction in the configuration of its physical space had implications for the societal understanding of the University as an institution, of its focus and priorities.

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very fine work done by McCullough in analyzing and applying the work of Dourish and others to this topic.

When spatial/institutional relationships are repeated often enough, they form architectural *types*. Examples of types common in urban settings include sidewalk cafes, bars, boutiques, intimate courtyards, or Gingko tree lined streets, to name just a few. Types can explicitly declare and communicate social values and meaning. For example, a public library deliberately places expectations on behavior, based upon its recognition as a public library (McCullough, 2005). Churches also do this well, as do bars. Types are a way for people to represent livable arrangements to each other. They help us make the link from body to building to city to landscape to universe. Architectural types are habitually used, enduring frameworks. As such, they provide an obvious base for context-based interaction design (McCullough, 2005).

When designing using architectural types, "too much convention becomes stultifying; too much invention becomes inane" (McCullough, 2005, pp. 58 - 59). McCullough asserts that types enable at least as much as they restrain, and that typological design is not about rigid rules, but a collection of essences that play out differently each time. Technological change has often modified types, and reconfigured cities in the past, but it has rarely done away with them. Types are adaptable, and as a result, technology, more often than not, contributes to the overall resiliency of types (McCullough, 2005).

Defending architecture

Like environmental design, interaction design relies upon context, upon people recognizing habitual situations and basing their behavior in response to what is perceived as possible in the current setting. As we established earlier in our discussion of hybrid space, interaction designers have taken notice of context and have begun to look at methods of applying their practice in physical space, by engaging pervasive computing throughout a physical environment. As McCullough notes, "The more that principles of locality, embodiment, and environmental perception underlie pervasive computing, the more it all seems like architecture" (McCullough, 2005, p. 63).

McCullough believes that interaction design can remedy usability, performance, and inhabitation problems within the built environment; aspects of environmental design that the practice has ignored in its preoccupation with architectural form. He believes, also, that interaction design can benefit from association with environmental design. Environmental design can teach interaction design about environmental perception, context, and appropriateness (McCullough, 2005). Interaction designers can learn to read the built environment, and extend its embodied environmental and cultural knowledge to interactions with digital information in a manner that contributes to, rather than detracts from, the formation of place. As McCullough notes:

> Interaction design extends, and does not abandon, previous works of place making. It takes advantage of physical contexts as frames and cues for its social functions. It begins to reflect scale and type in its pursuit of site-specific, context-aware systems, and location based services. It shifts focus from technological novelty to more enduring cultural frameworks (McCullough, 2005, p. 63).

Cooperation between the built environment and information technology is likely to become increasingly necessary as technology digitally mediates more of our social discourse. When social discourse moves out of the built environment and into digitally mediated environments, the built environment loses an important aspect of its function, and a lively source of animation. Pervasive computing can be layered upon the built environment, as many other emerging technologies have been. The built environment can absorb pervasive computing, and through it, the digital layer of information that overlays the physical world. It can do this just as it absorbed electrification, and revolutionary shifts in modes of transportation. In doing so, it does not give up its ability to change again (McCullough, 2005; Shepard, 2011).

Successive layers of technological change, some relevant today, some obsolete, represent a form of cultural capital. They tell the story of our advancing technology and how it has changed our society, and the world we make for and of our society. “Identifying, valuing, and contributing to the appreciation of the cultural capital that is the built environment should be an important role for pervasive computing, the latest layer of spatial adaption. Successful applications toward that goal will become regarded as natural, or at least appropriate technology. Others will just get in the way” (McCullough, 2005, p. 64). McCullough considers this layered, contextually bound application of ubiquitous computing, tied in place by contextually informed interaction design, a means of defending the practice of architecture in the face of the erosion of place threatened by the propagation of placeless technologies (McCullough, 2005).

Environmental designers provide guidance by creating within the built environment “a fixed form for the flows engineered by pervasive computing” (McCullough, 2005, p. 64). Underneath all of the layers of accumulated technology, the built environment remains. As an older, more understood form of technology, it has more fundamentally shaped our expectations of what once happened, is happening, or could happen in the spaces we move through. It embodies the cultural idiosyncrasies that make space into place, and remains an important part of our cognitive background (McCullough, 2005).

Reflection on the potential for change offered by ubiquitous computing and interaction design within the built environment

McCullough’s work concerning the intersection of environmental design, interaction design, and ubiquitous computing are foundational, and thorough, but they are not above critique. McCullough considers his 2005 work on the subject a defense of architecture, and as such, it carries an agenda. A critique I have of McCullough's work in *Digital Ground* and subsequent publications is that, to an extent, McCullough deemphasizes the potential of the emerging presence of ubiquitous computing for substantially rethinking the practice of environmental design.

McCullough falls back, at times, to making a defense of the traditional roles of environmental designers, similar to the way that advocates of HCI often have trouble seeing beyond the traditional model of human-computer interaction centered around desktop computing (Norman, 2010). For example, interaction design consultant Donald Norman recently spoke out against natural user interfaces[32] (NUIs). Norman considers NUIs unnatural. As implemented today, NUIs often require users to learn complex sequences of movements. Like graphical user interfaces, they have to be learned (Norman, 2010). These are valid complaints, but Norman's objections arise from his persistence in thinking of interaction design in the context of its historical focus on personal desktop computing. Norman's anxiety concerning the coming of NUIs cannot be viewed alongside of traditional ideas concerning computation, or our experiences and interactions with personal computing.

Likewise, McCullough's emphasis on the importance of the built environment as a guiding presence for interactions in space deemphasizes the ability spontaneous human-computer interactions present in the democratization of space. As discussed earlier in the thesis, the emergence of a reconfigurable digital layer that sits atop the built environment offers the potential for users to design their own environments, and marginalize to an extent the role of

[32] Natural user interfaces are primarily touch and gesture based. Major technology vendors including Microsoft are touting NUIs as the evolution of the graphical user interface (GUI). Microsoft's Kinect is currently a popular hardware device used to acquire input in many NUIs.

environmental designers. This possibility should not be marginalized or left unexplored out of deference to the more established practice of environmental design.

As ubiquitous computing takes hold, as the built environment, furniture, objects, and even clothing become sites for engagement with computation, designers should begin to consider how new forms of interaction can form the basis of new relationships between people, computation and place. Instead of trying to recreate experiences we achieve through interactions with mice, keyboards and GUIs, we should instead focus on the outcomes we have traditionally hoped to achieve by using them. In many instances, these outcomes will determine the ways in which we communicate, socialize and inhabit spaces in the future. We should speculate more on cultural and aesthetic aspects of interactions with technology in order to accommodate these outcomes more properly in the places we build to inhabit and promote our societal expectations (Shepard, 2011).

Examples of interaction design employed within the built environment

Microsoft's Future Vision productions provide meaningful examples of designed interactions between people and situated ubiquitous computing technology within the built environment. In an effort to understand how context provided by architectural form can influence our interactions with technology situated in the built environment, it is useful to examine one such example here.

Figure 2 depicts an interaction between a person and the ubiquitous computing technology she encounters as she enters an area of computation situated within the built environment. In the scene shown in Figure 2, the woman stops at a natural seam between the edge of the building, a walkway, and a roadway. Changes in the materials used to construct this site, and changes in architectural form including the scale and mass of the architecture indicate the presence of this transitional space.

Figure 4. A designed interaction between a person and ubiquitous computing technology embedded within the built environment ("Productivity Future Vision (2011)," 2011)

It is also apparent while watching the video that the built environment informs the ubiquitous computing devices present here of their context, and as a result, the woman’s possible interactions with the technology present are given scope and vetted for appropriateness.

The architectural type is a sidewalk, a physical transition between a building and a roadway. The ubiquitous computing devices present in this site are aware of their context, and are attuned to providing assistance to people seeking transportation options. The computation embedded here does not, for example, make non-contextually informed offers of help, such as offering to compose an email, or providing reports on world news events.

An environmental designer, when considering from a top-level perspective how to design this site, should feel empowered to consider the interactions between the site's users and the site's embedded computation, and to include those interactions within their design solution for the sit as a whole. Physical forms influence interactions within the site, and interactions and inform a visitor's perception of the place. It is a deeply reciprocal relationship and I believe that it falls entirely within the area of expertise environmental designers practice when envisioning design solutions for places in our built environment.

Reflection on What Ubiquitous Computing and Interaction Design are, and are not

Mark Weiser died in 1999, far too soon after establishing the idea of ubiquitous computing. He could not foresee all of the complex ways in which the Internet, online social networks, and highly portable computers such as smartphones would interface with his vision of a radically new, ubiquitous computing. It is useful to pause for a moment and consider, in light of our understanding of what ubiquitous computing is, what is it *not*?

Ubiquitous computing is not virtual reality. Weiser clearly expressed his disdain for virtual realities.

> [V]irtual reality is only a map, not a territory. It […] focuses an enormous apparatus on simulating the world rather than on invisibly enhancing the world that already exists. Indeed, the opposition between the notion of virtual reality and ubiquitous, invisible computing is so strong that some of us use the term 'embodied virtuality' to refer to the process of drawing computers out of their electronic shells. The 'virtuality' of computer-readable data–all the different ways in which it can be altered, processed and analysed–is brought into the physical world […]. (Weiser, 1991, p. 94)

So what does it mean to be a map and not a territory? At the most basic level, a territory is real, while a map is only representation. A map simplifies the understanding of space, for convenience, while a territory contains all of the intricacies that a space can provide. Weiser declared, “Unlike virtual reality, ubiquitous computing endeavors to integrate information displays into the physical world. It considers the nuances of the real world to be wonderful, and aims only to augment them” (Weiser, 1991, p. 94).

So, is augmented reality ubiquitous computing? It can be, but it isn’t always. Like virtual reality, augmented reality is—in and of itself—only a map. To be more exact, it is only bits and pieces of a map, fragments pulled from the virtual world and superimposed into our reality. If these fragments are contextualized, if the augmentation reflects information about the place you are currently situated in, then it acts as a display for contextual information, and it is ubiquitous computing.

Ubiquitous computing is not a personal digital assistant, such as a smartphone. “Unlike [smartphones], ubiquitous computing envisions a world of fully connected devices, with cheap wireless networks everywhere; unlike [smartphones], it postulates that you need not carry anything with you, since information will be accessible everywhere” (Weiser, 1993 para. 4). It is not a personal or intimate computer with agents to do your bidding, such as Apple’s Siri. “Unlike the intimate agent computer that responds to one’s voice and is a personal friend and assistant, ubiquitous computing envisions computation primarily in the background where it may bot even be noticed. Whereas the intimate computer does your bidding, the ubiquitous computer leaves you feeling as though you did it yourself” (Weiser, 1993 para. 4).

Weiser’s defense of physical space, as something beautiful and complex, is a key consideration to keep in mind when comparing the idea of ubiquitous computing against new computer technologies we encounter. Technology is not clear cut or easily categorized. It is complex; it crosses boundaries; and it can be immensely distracting. Ubiquitous computing, as Weiser described it, is ultimately empowering and it celebrates the complexity of the physical world. Technology that fails to do that may surround us at times (it may seem ubiquitous) but if it distracts us, demands our full attention, or disempowers us, it is not Weiser's ubiquitous computing, and it is not the technology I've discussed at length here.

Ubiquitous technology can go either a long way toward enhancing a situation, or a long way toward obscuring it. This is the reason why it is important for environmental designers to practice interaction design. As McCullough notes, "Situated technology may help us manage the protocols, flows, ecologies, and systems that form the basis of valued places; or it may add a layer of distrust, information glut, and experiential uniformity to them" (McCullough, 2005, p. xiii). The integration of computing devices with the built environment is inevitable, and it is important that it is done well.

Human life is interactive, and the built environment has provided the situation for many of those interactions. Architectural form embodies many of the cultural protocols established to govern social interaction. The built environment can lend support to ubiquitous technology, informing it through context-centered design, directing interactions and giving input about cultural considerations of what is appropriate in a given place.

The idea that context can inform computation within the built environment, I feel, is an idea that environmental designers can readily engage with. The discipline of environmental design does not need to be concerned with the behavior of intimate agents, or with the provisioning of handheld computers. The emergence of ubiquitous computing within the built environment offers environmental designers an opportunity to design places in the real world, with all of their wonderful nuances, and, by practicing interaction design, transfer that wonderful contextual information into the digital world, where it can inform computation and then return data to users of the built environment in countless ways.

So what exactly will this look like? There are no fixed answers to that question. Ubiquitous computing is an infrastructure—a material—not content or a design. Interaction design is a practice, not a specific action. Ultimately, it remains the role of designers to imagine, experiment and formulate design solutions for all of the challenges and opportunities afforded at a site. What ubiquitous computing and interaction design offer environmental designers is the ability to take the layer of digital information overlaying the physical world and make it *part of our places*, rather than leaving it placeless, disassociated from and competing for our attention in the built environment.

In Chapter 6, I will provide a short series of case studies that characterize many real-world attempts made to engage with ideas discussed in this thesis. .

CHAPTER 6

CASE STUDIES AND EXPLORATION OF ENGAGEMENT WITH UBIQUITOUS COMPUTING AND INTERACTION DESIGN

The primary concern of this thesis is to further discussion concerning the relationship between computation and the practice of environmental design. The thesis introduces the concept of hybrid space as a framework through which environmental designers can consider the kinds of places created by engaging ubiquitous computing devices within the built environment. Finally, the thesis suggests that the discipline of interaction design is a practice that environmental designers are uniquely qualified to employ when engaging ubiquitous computing technology in the built environment. This thesis does not specifically undertake a design solution employing these ideas and methods.

In an effort to clarify the concepts introduced in the preceding chapters, Chapter 6 provides a brief series of case studies for consideration and exploration. These are real-world projects undertaken by practitioners of environmental design. In each case, I will identify concepts, ideas and methods that illustrate points discussed elsewhere in this thesis. This is not meant to be an exhaustive examination of the application of the ideas put forth in this thesis. Rather, these examples and the accompanying discussion are intended to offer a starting point for further exploration of the ideas introduced in the preceding chapters.

Case Study 1: Amphibious Architecture

Figure 5. "Amphibious Architecture" installed in the East River (Living, 2012)

Figure 6. An LCD pixel set atop a buoy within "Amphibious Architecture" (Living, 2012)

"Amphibious Architecture" is a project designed by David Benjamin and Soo-In Yang (The Living) and Natalie Jeremijenko (XDesign Environmental Health Clinic). The project's designers suggest "one way to understand the project is as a horizontal *envelope*. It might be considered an experimental building envelope, turned on its side and floated out into an underused public space of the city" (Shepard, 2011, p. 52).

The project was implemented in the Fall of 2009 as a part of the Toward the Sentient City exhibition presented by the Architectural League of New York. It was installed in the East River, and then again in the Bronx River in New York City, NY.

In reality, "Amphibious Architecture" achieves many of its stated goals on a rather limited scale. It consists of 16 buoys, placed in a grid of 10 meters by 10 meters, although its sensor network design is advanced enough that it could operate at a larger scale. The buoys are each equipped with an Arduino[33] physical computer. Each Arduino is capable of acting independently to gather, process, and distribute data. Additionally, the Arduinos are capable of communicating with each other and working collectively

Input is acquired through a variety of embedded sensors. Dissolved oxygen sensors, sonar sensors, and motion sensors all monitored the environment within the architecture of the grid. Additionally, an on-shore computer relays the installation text-messages gathered from citizen participants. The structure communicates information (output) by flashing lights located on each of its 16 buoys, treating the grid as a sort of

[33] Arduino is a tool for making computers that can sense and control more of the physical world than the typical desktop computer. It is an open-source physical computing platform based on a simple microcontroller board, and a development environment for writing software for the board. Additional information is available at http://www.arduino.cc.

ultra-low resolution LCD display panel. Unfortunately, outbound network connectivity was never established in this project.

Why was the work undertaken?

The designers of "Amphibious Architecture" believe that the city, at its most basic level, is made up of flows and envelopes. Flows might involve the movement of people, plants, animals, air, water and information. Each flow circulates through the city in its own way, according to its own agenda. Envelopes are spaces, defined by thresholds. Thresholds might be building skins, neighborhood lines, streets or microclimates (Shepard, 2011).

"Amphibious Architecture" seeks answers to the questions, "Who should control the city's envelopes? What are our individual and collective contributions to the city's flows (Shepard, 2011, p. 48)? The projects designers choose to place certain aspects of the site under its visitors' control. They accomplished this by designing opportunities for democratic interactions with the project. The architecture at the site is interactive, and people can contribute to the digital information present within the site, and affect its content and presentation. "Amphibious Architecture" exemplifies the democratization of architecture through interactions with digital information situated within the site, using computing devices embedded ubiquitously within the site.

How does the project accomplish its work? What does it seek to accomplish?

Benjamin, Yang, and Jeremijenko assert that, by re-thinking traditional landscape design as a method of designing envelopes rather than designing buildings, landscapes, or places, it becomes possible to affect the flows that permeate a city, generating change at a level deeper than physical architectural form. The designers propose the following means of rethinking envelopes in their design intervention:

- The envelopes of the building could consist of both building envelopes and non-building envelopes.
- The envelopes of the city could each be a small ecosystem
- The envelopes of the city could be networked together.
- The envelopes of the city could be public.
- The envelopes of the city could be interfaces to information.
- The envelopes of the city could go beyond raising awareness—they could engage and solve problems.
- The envelopes of the city could be more than hard boundaries—they could be porous thresholds.

"Amphibious Architecture" directly monitors many of the city's flows. It uses sensors to monitor the presence of fish, the carbon cycle of the river, the hydrodynamic motion of the river, and the degree of human attention paid to the river. Its surface acts as a low-resolution LED display.

In what ways does this project engage the material concerns of this thesis?

"Amphibious Architecture" exemplifies the use of ubiquitous computing devices, embedded within the built environment, to create a hybrid place that is understood as such by its visitors. Through the practice of interaction design, and the inclusion of interactive elements, the designers of the site provided mechanisms for social participation and reconfiguration of the site.

Interactivity

“Amphibious Architecture” accommodates two methods of citizen participation: participation from terrestrial citizens and participation from aquatic citizens. Terrestrial citizen interactions are designed to occur through primarily awareness raising. Presumably, terrestrial citizens will become aware of the project when they see the display atop the buoys, and as a result of their increased awareness, they will take action to preserve the health of the aquatic space “Amphibious Architecture” occupies and monitors. The secondary mechanism for generating interactivity, sending output to additional (remote) envelopes, for interaction with a wider audience, has not yet been implemented.

Aquatic citizen interactions occur ubiquitously, when fish interact directly with sensors installed within the built environment. As fish approached the structure, sonar sensors register their presence. Dissolved oxygen sensors and motion sensors record ambient atmospheric information and relay this to terrestrial citizens.

Hybridity

As suggested in the preceding chapter on hybrid space, the idea should be employable here as a means of understanding the unique aspects of this built environment that result from the inclusion of digital mediation and computation within the physical environment. The understood place that is “Amphibious Architecture” consists of the physical space of the grid of buoys, the physical space within viewing distance of the grid, and the virtual space of the communication networks that were intended to carry output to remote displays throughout the city. This hybrid space is somewhat compromised by the lack of a persistent outbound network connection that prevented the information from the sensors from being sent to remote locations. If the sensors in the array had been able to communicate their message to remote sites, such as displays located in Times Square, then the understood space created would have been much more elaborate and inclusive.

Reflection on the implications of this project for the practice of environmental design

Although “Amphibious Architecture” is as much a landscape art installation as it is an architectural landscape, the technology employed in its construction and operation can be easily adapted into mainstream design. Landscape architects, for example, could employ sensor networks such as the one used in this project to monitor and communicate environmental conditions in sensitive environments, such as those undergoing remediation. Consider Gas Works Park in Seattle, WA as an example of the kind of site where this approach could improve understanding of the site. As discussed earlier, real-time monitoring and communication of data at the site level is an effective mechanism for generating citizen engagement. On a larger scale, such as the scale of a city, this sort of application of ubiquitous computing technology and interaction design should be of interest in the Planning profession. This is explored in greater detail in the next case study, in which the idea of Urban Informatics is explored.

Case Study 2: Discussions in Space

Figure 7. "Discussion in Space" installed in Brisbane, Australia (Radovanovic, 2012)

Figure 8. Digital content revealed by "Discussions in Space" ("Discussions in Space," 2012)

“Discussions in Space” is a project created by The Urban Informatics Research Lab, Queensland University of Technology, Australia. The designers of the project are Ronald Schroeter, Associate Professor Marcus Foth, Professor Paul Roe and Christine Satchell. It was installed at the Royal Brisbane Hospital, QUT Gardens Point, QUT Kelvin Grove, Brisbane Square, and the State Library of Queensland. It was also used for community engagement purposes at the OZCHI 2009 conference, the Workforce Innovation conferences 2010 and 2011, at the opening of The Edge (State Library of Queensland), and at Federation Square, Melbourne.

“Discussions in Space” consists primarily of a publically accessible screen (a situated technology) installed in a public, urban plaza in Brisbane, Austrlia. The screen is accessible by the public both in terms of its digital content, and in terms of physical accessibility, which is necessary in order for participants to view the content it displays. “The goal of the architecture is to allow [Brisbane city] councils to advertise civic issues or questions related to a particular place on a situated display within that place, and furthermore provide a wide range of input and output channels in order to lower the hurdle for residents to participate in the public discourse about this topic as much as possible” (Schroeter & Foth, 2009 Architecture and Implementation, para. 1).

Why was the work undertaken?

Researchers deployed the public screen in an effort to promote civic issues in urban public space, and to encourage public feedback and discourse via mobile phones (Foth, 2011; Schroeter & Foth, 2009). “The hypothesis of this research project is that in-place digital augmentation, in the context of civic participation, where citizens collaboratively aim at making their community or city a better place, offers significant new benefits compared to conventional online forums or wikis–as used today" (Schroeter & Foth, 2009 Introduction, para. 3). The project seeks to reveal contextual digital information (i.e. online conversation) about a place, within that place, in an effort to improve the quality of citizen participation there.

How does the project accomplish its work? What does it seek to accomplish?

The project re-contextualizes digital information, previously accessible only on the Internet, by locating the digital information on a screen situated in the place the data directly concerns. This project employs visitors' mobile phones in order to allow the visitors to interact with the situated displays (Foth, 2011, p. 20). Passers-by can interact with the display using their mobile phone's SMS, Bluetooth, camera and Internet capabilities. Collaborative and distributed editing and censoring capabilities ensure that the participant generated content reflects the norms and values of the installation providers (Foth, 2011).

Of the technologies supported for citizen participation in the project, MMS (text messaging) is the lowest common denominator. More mobile phone devices are capable of MMS technology than any other technology employed in the project. In addition to MMS, a specific twitter hash-tag representing each civic topic is advertised so that twitter users can send messages to the screen by including the tag in tweets made from their smartphones or portable computers. A website, tailored to iPhone and Android browsers, is also available for interaction with the display. The website is accessible through a QR code displayed on posters near the screen. Scanning the QR code with the phone's camera opens the website for participation (Schroeter & Foth, 2009).

The mobile website acts as an input and output channel for information stored in the project's database. It not only allows users to post new messages to the screen, it also allows them to browse and view the history of previous discussions. A final technology, Bluetooth, is being investigated for use sending content between devices when passersby are within a certain range of the screen (Schroeter & Foth, 2009). Through this sort of passive interaction, the system has the potential to become much more pervasive and ubiquitous.

In what ways does this project engage the material concerns of this thesis?

This project is a prototypical example of urban informatics (in its intent), but I find it problematic in some regards, because at the scale of the site, rather than the scale of the city, I do not think it makes use of the physical infrastructure of the built environment to guide the interactions that occur with computation in the site.

The smartphones employed by users in this project are experienced in a personal computing relationship, not a ubiquitous one. In order to provide a ubiquitous computing experience, the site should be equipped with computing devices that function more as a public infrastructure. In contrast to the smartphones, the display is a good example of a situated computing technology experienced ubiquitously at the site (Weiser & Brown, 1996).

Interactivity

Because the participants are engaged in a personal computer relationship with their smartphones, the physical interaction design potential of the project is diminished (Weiser & Brown, 1996). The users still have interactive experiences, but they are not experiences mediated in any significant way by the built environment. As a result, the interactivity is less relevant to the installed architecture. This is not necessarily problematic for the urban informatics researchers in charge of "Discussions in Space," but provides an opportunity for environmental designers to provide a more ubiquitous solution at the site..

Hybridity

The space created by the installation of the interactive display is a hybrid space comprised of the space within which the displays are visible, combined with the perceived space in which the ongoing citizen driven conversation occurs. As mentioned previously in the thesis, Kabisch notes that hybrid spaces can reveal previously unseen cultural aspects of a site through digital mediation. The "Discussions in Space" project does this. It reveals an ongoing, but decontextualized, conversation concerning the site as a visible and tangible feature of the site, within the physical space of the site (Kabisch, 2008). In this way, technological mediation contextualizes conversations about the place, within the place.

This suggests that, over time, the physical space in which the display is installed will take on the characteristics of a new place, due to the availability of digitally mediated interactivity (Harrison & Dourish, 1996). People will begin to associate the place with the digitally mediated encounters they can experience there.

Reflection on the implications of this project for the practice of environmental design

I believe that this project fails to take full advantage of the built environment's ability to mediate people's interactions with technology. The mobile devices employed for communication with the situated displays are not contextually aware in any way as they are implemented in "Discussions in Space." A citizen could potentially, use the mobile phone from any physical location in the world to interact with the display.

I attribute this in part to the projects origin within the field of Urban Informatics, a field more aligned with Planning that it is with the practice of landscape architecture. As such, there is perhaps a greater emphasis placed on the information collected through the operation of the technology than on creating a built environment that facilitates engagement with situated technology, and through it, engagement with elements inherent in the site. This suggests that there an opportunity exists for practitioners of architecture and landscape architecture to work closely with planners to create projects similar to “Discussions in Space,” but more fully realized in terms of their use of the built environment and its ability to enable interaction between visitor and situated computation.

Case Study 3: The Edge

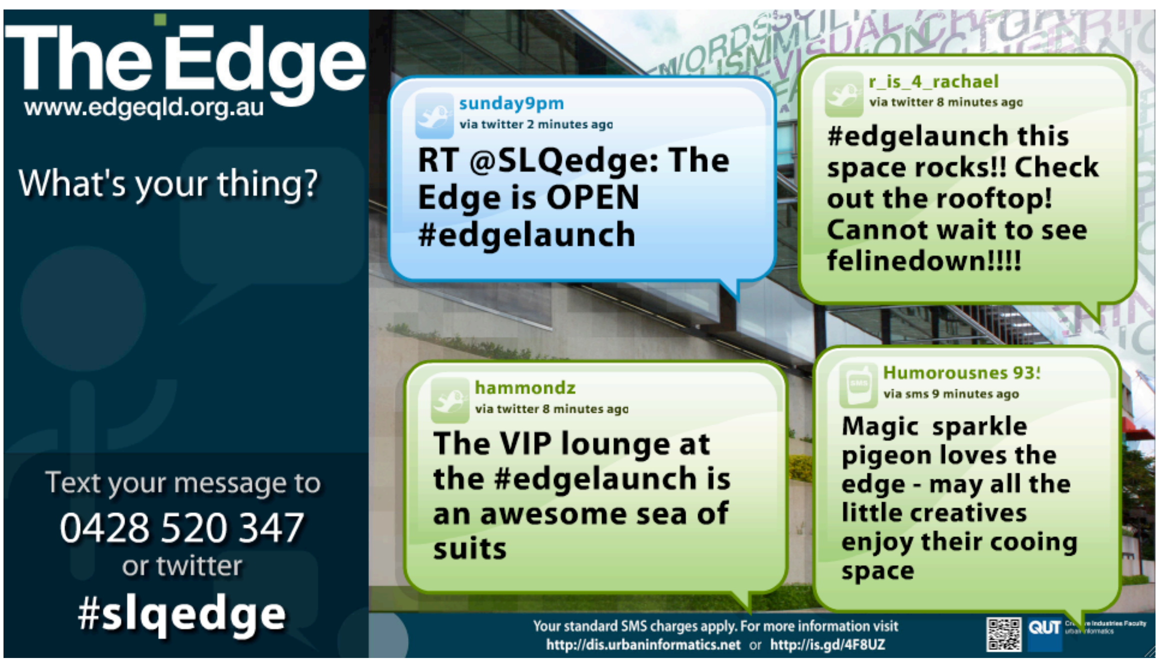

Figure 9. Digital content revealed by “Discussions in Space” installed at “The Edge” ("Discussions in Space," 2012)

"The Edge" is an initiative of the State Library of Queensland (SLQ) in Brisbane, Australia, providing an example and prototype of a new library concept as part of SLQ's evolution in the digital information age (Bilandzic et al., 2011). The project was proposed by The Urban Informatics Research Lab, Queensland University of Technology, Australia, by Mark Bilandzic, Mark Graham Jones, and Associate Professor Marcus Foth. To date, the project has not been implemented.

The aim of "The Edge" is "to explore ways how physical architecture and infrastructure of a place can be mediated towards making invisible social assets visible, thus augmenting people's situated social experience" (Bilandzic et al., 2011 Abstract, para. 2). The focus of the project is on the production of "media that materialize digital information as observable and sometimes interactive parts of the physical environment hence amplify people's real world experience, rather than substituting or moving it to virtual spaces" (Bilandzic et al., 2011 Abstract, para. 2).

How does the project accomplish its work? What does it seek to accomplish?

The goal of this project is to amplify people's perceived 'sense' of a place through the use of digital mediation. The project explores the creation of embodied media, i.e. media that materialize digital information as observable and sometimes interactive parts of the physical environment. Embodied media can enrich physical space through digital mediation, and do so in a way that is publicly accessible through direct observation, manipulation or interaction with objects in physical environment (e.g. public touch-screen or ambient information displays). Embodied media enable people to bridge spatial, temporal and social barriers and have meaningful experiences in and through physical places, which would not be possible otherwise (Bilandzic et al., 2011).

The project functions by tracking the presence of visitors, who check-in and check-out using ID cards. The Edge forms digital identities for visitors. It gathers answers to questions such as "Who are the people who currently hang out at the Edge? What are their backgrounds, interests and key areas of expertise? What projects are they working on and what questions are they currently struggling with (Bilandzic et al., 2011 Design Intervention, para. 2)? The responses are presented on nearby displays in a tag-cloud formation, where the size of keywords indicates a level of expertise these people have in a given subject (Bilandzic et al., 2011).

The embedded displays aim to help visitors make serendipitous in-situ encounters. The screens suggest " ice-break conversations and potential collaboration opportunities with fellow visitors who have similar or complementary interests, skills or knowledge" (Bilandzic et al., 2011 Design Intervention para. 2). Visitors who check-in at the Edge specify if they prefer to be approached or if they prefer to work alone. Based upon this information, ambient lights installed in the architecture will glow green or red, signaling if a person is approachable or not. The goal of these methods of interaction is to convey information in an unobtrusive, non-distracting, yet visually appealing way (Bilandzic et al., 2011).

In what ways does this project engage the material concerns of this thesis?

The Edge is an effort to reveal digital information in a physical setting, through the installation of ubiquitous, situated computing devices. The hybridity of the space, and the resulting digitally mediated understanding of place, is its defining feature.

Interactivity

The interaction design in the project appears to be quite complex. Based entirely upon where an individual places his or her body, nearby devices respond in accordance to perceived intent. If a user wants to make use of the social match-making capabilities of the place, they can move near a display or near a source of ambient lighting. By doing so, they activate the computational capabilities of the environment, triggering computation and interaction. If they do not wish to engage with the system, they can avoid opportunities for interaction by avoiding the computationally equipped spaces. The emphasis placed upon unobtrusive and non-distracting interactions shows deference to the context of the site—a library. The technology, arguably, is informed by the social and physical context of the environment.

The basic infrastructure created at the Edge could reveal additional data (e.g. wayfinding, group affiliations) that could be interacted with through modifications to the interaction design employed at the site. For example, some rooms could respond a certain way with one color scheme while another room communicated alternate information through another color scheme.

Hybridity

Hybrid space is formed at the Edge by the combination of the physical space within the structure, plus the virtual space of the digital displays plus the resultant place that is created as a result of the integration of the interactive communication devices and ubiquitous computing devices (Crabtree & Rodden, 2008; de Souza e Silva, 2006; Harrison & Dourish, 1996). It is important to understand that, when people think of the experiences they associate with the Edge, they extend their understanding of the place to all of the spaces that comprise the Edge—all of the physical spaces that are interactively connected to the Edge. For example, if a display were added to a room in a remote location, people would recognize the remote space as being of the Edge. The remote space would inherit the qualities of the Edge by association, mediated through the interactive digital display. In this way, digital mediation has the ability to spontaneously create the Edge wherever it is employed in association with the Edge (Crabtree & Rodden, 2008; de Souza e Silva, 2006).

Reflection on the implications of this project for the practice of environmental design

Perhaps more so than other case studies given here, the Edge demonstrates that a digitally mediated environment extends, in the perception of its visitors, far beyond the site boundaries normally associated with constructs created in the built environment. Environmental designers need to be aware of the implications digital mediation has on the perceived boundaries of their projects. Additionally, this project displays complex interaction design that is nonetheless well within the scope of what I believe practitioners of environmental design should undertake when considering design solutions for sites.

Case Study 4: Raise the Cloud

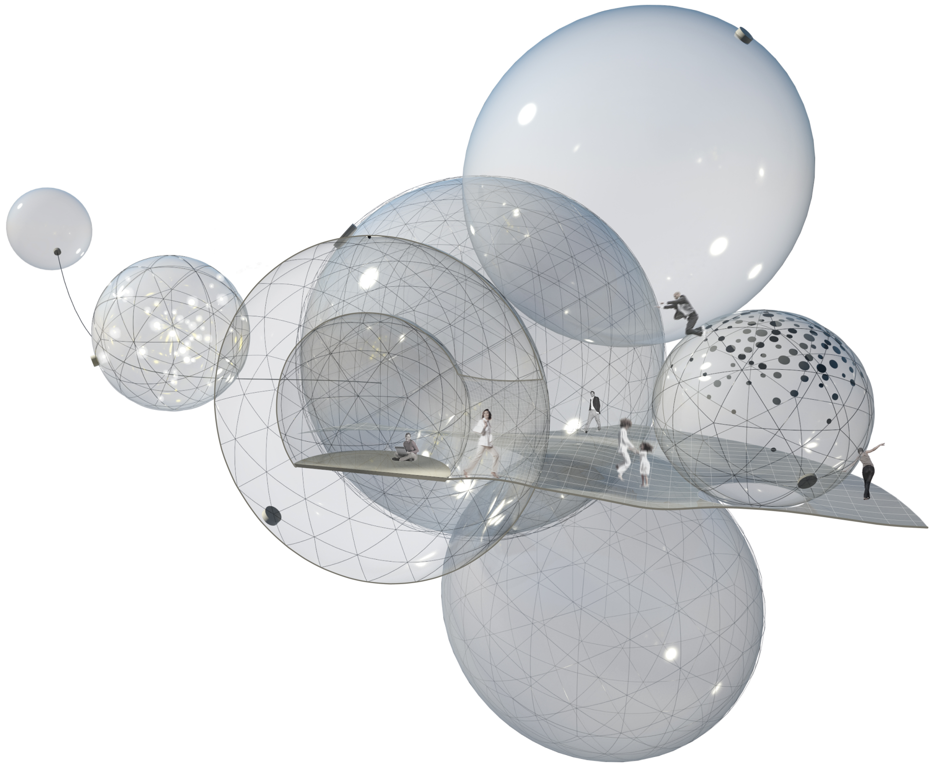

Figure 10. "Raise the Cloud" ("The Cloud," 2009)

The "Raise the Cloud"[34] project, created by the MIT SENSEable City Lab is an example of an urban-scale, digital display and interactive structure. The Cloud performs energy and data–harvesting "both from the natural ecosystem and humanity's complementary cybersphere"—the layer of digital information that overlays the modern physical environment. It collects rainwater, wind energy and sunlight. The Cloud acts as a large-scale display surface, in which its structural components are coopted to function as displays. It is designed to offer "a civic-scale interface for the delivery of real-time information to the inhabitants and visitors of the city" (Nabian & Robinson, 2011, p. 25). The Cloud was proposed in 2009, and has not yet been implemented.

[34] A press release is available at http://www.raisethecloud.org/#press

Why was the work undertaken?

Olympic and exposition structures, the project creators assert, typically display "mute mass," "ponderous monumentality" and "a conspicuous expenditure on immovable objects" ("The Cloud," 2009 The Cloud / broadcasting the climate of humanity para. 1). These, the projects designers assert, are outmoded design characteristics. The Cloud is a proposal for architecture that is "as light as air itself – a tribute to a digital age of bits and atoms beyond the antiquity of steel and glass – a structure which reveals the connected networks of a common humanity fuelling the Olympics, their 2012 host city, and the world itself" ("The Cloud," 2009 The Cloud / broadcasting the climate of humanity para. 1).

The Cloud, with a proposed situation high above London's Queen Elizabeth Olympic Park, provides visitors with a view of the whole of physical London, and also, by viewing its many structural display surfaces, a view of data sent to the Cloud's through its network connection. People on the ground, within sight of the Cloud, become participants and interact with the Cloud when they look at its display surfaces and receive the information it communicates ("The Cloud," 2009).

How does the project accomplish its work? What does it seek to accomplish?

The Cloud is a large scale embedded display. It is positioned above the city where it becomes conspicuously visible to a very large number of people. It communicates a variety of information, including (according to its proposed intentions) information about the 2012 Olympic Games. It is an interactive installation, with the ability to sense and reveal the movement of people below it or within its structure ("The Cloud," 2009).

The Cloud consists of a series of hot-air inflated spheres, connected by platforms of membranes that serve as an observation deck. These spheres are attached to a central mast, ringed with stabilizing tensioners that provides stabilization and access to the spheres and the pedestrian deck. Both the pedestrian deck and ramp leading upward through the mast harvest kinetic energy and convert it into electricity to power the structure's embedded sensors and displays.

The surfaces of the spheres act, collectively, as a large display surface. This is accomplished by attaching a series of LCD lights to the material that comprises the spheres, which act as pixels in a large, freeform digital display. This display can be seen from all directions, including from within the Cloud. Sensors within the cloud are capable of tracking movements of visitors, and those movements are capable of influencing the displays' projections. In this way, indications of activity levels within the Cloud are transmitted to viewers outside of the Cloud. Data from outside networks, specifically concerning the 2012 Olympic Games, is collected and displayed on the surface display system.

In what ways does this project engage the material concerns of this thesis?

The cloud is a large-scale architectural installation, a built environment in its own right, which transforms the majority of central London into a hybrid space. The presence of the Cloud, as an interactive digital mediator, creates a new place, with the Cloud as its defining feature. Sensors within the Cloud detect and interpret the movement of visitors within the structure and communicate those movements to observers outside of the Cloud through the embedded display in the structure's exterior skin. The Cloud communicates actions that occur within its interior to others on its exterior skin.

Interactivity

Interactions with the Cloud occur primarily through the sensors within the structure, and the displays adorning its exterior skin. These sensors detect the activity level of visitors inside of the Cloud. The Cloud is also capable of processing the input it receives from external sensors located on the ground, and returning the information to participants below on its display surface.

Although it is not specified in the project description how it can do so, the Cloud is apparently capable of gathering information inside of the Olympic Stadium. It can display relevant information such as the current Olympic medal count for each country. Arguably, this is a form of interactivity because the information is site specific and can potentially influence the behavior of the agents generating the information in a sort of feedback loop scenario.

Hybridity

The Cloud creates a large-scale hybrid space that consists of almost the entirety of London's Olympic Park, and anywhere else where the Cloud is visible. Once again based upon the research of Kabisch, over time, the entire region of physical space within view of the cloud will assume a new identity defined largely by the presence of the new interactive digital infrastructure (Kabisch, 2008). The understood place will also include any other physical spaces connected to the Cloud interactively through its sensor network, such as the interior of the Olympic Stadium, where the Cloud gathers real-time data concerning events. This is arguably the project's most significant and defining feature.

Reflection on the implications of this project for the practice of environmental design

The Cloud is an excellent example of how situated technology can invert the function of an architectural form, with surprising results. The stated goal of the Cloud is to serve as an observation platform, a traditional feature of the Olympic Games that often serves as a lasting monument to the event. Unlike traditional observation platforms, which afford an improved view only to the visitors of the platform, the Cloud, by communicating information upon its exterior surface, provides an improved viewing experience to all participants within sight of the structure, whether they are on the platform or not. I believe that this novel use of digital mediation and sensing to invert an established notion provides an exciting example of the wholesale change that the integration of computation into the built environment can offer designers in terms of the form, function and scope of their design solutions.

Case Study 5: The Digital Water Pavilion

Figure 11. “Digital Water Pavilion” (DWP) (Fortmeyer, 2010)


Figure 12. “Digital Water Pavilion” (DWP) (Vanderbeeken, 2008)

The “Digital Water Pavilion” (DWP) is a project designed by the MIT SENSEable City Lab. It was installed in 2008 at the Zaragoza World Expo in Spain. The DWP is example of interactive architecture that responds to interactions with visitors through embedded sensors. “The Pavilion of minimalist expression and small dimensions is simultaneously: a sophisticated machine of high mechanical precision; a building appearing and disappearing thanks to a 12 hydraulic pistons system; and a place where spaces are flexible, changing, and responsive due to the action of 120 meters of water walls digitally controlled by almost 3,000 electromagnetic valves. The digital water curtain had the potential of functioning as an architecturally embedded screen for delivering information, materialized as droplets of water” (Nabian & Robinson, 2011, p. 27).

The DWP explores the potential of reactive architecture. Unlike digital morphogenesis, which seeks to generate a form from within the constraints computation employed during the design of form, and then freeze it in place for construction, the DWP interprets real time digital information gathered by embedded sensors and redesigns itself spontaneously. The information gathered by its sensors is interactively returned to the site's visitors as a form of digital output. The DWP expresses architecture's evolving relationship with society's flows of digital information as a series of performances, undertaken interactively with site visitors. What matters most to the performance is not what patterns are displayed in the water curtain, but that the pavilion does a series of things instead of presenting itself as a frozen architectural form (Nicolino & Ratti, 2008).

How does the project accomplish its work? What does it seek to accomplish?

The water curtain of the DWP is a large digital display featuring individual pixels made from drops of water. Valves that open and close very quickly and operate in a synchronized manner carefully control and shape the drops of water. Proximity sensors control the operation of the valves. The water curtain can be left in a reactive mode, in which it stops the flow of water whenever an object is detected in close proximity, or it can be programmed to display a series of images, including text (Nicolino & Ratti, 2008).

The DWP employs real-time sensing to control its reactive architecture, but does not attempt to influence citizen participation in any way, or to gather information about citen response, and is therefore more in alignment with architecture than with urban informatics.

In what ways does this project engage the material concerns of this thesis?

The Digital Water Pavilion (DWP) is an example of ubiquitously sensing, reactive architecture. It reacts to changing environmental conditions based upon feedback from sensors and its own manipulation of actuators. The actuators control valves that turn water on and off at a very high rate of speed. The roof of the pavilion can be raised or lowered using hydraulic cylinders, but the position of the roof does not appear to be controlled by sensors according to the published information describing the operation of the structure.

The DWP is equipped with sensors capable of detecting the proximity of people at the envelope of the building where the water curtain is located. The DWP is also equipped with sensors that monitor wind speed.

Interactivity

Interactions with the DWP occur in two ways. The primary method of interaction is through physical proximity. When a person approaches the structure's water curtain, sensors detect the person's proximity and shut the valves controlling water in that area, thereby creating a door for the person to walk through (Nicolino & Ratti, 2008).

Interactions also occur when an operator inputs patterns for the water curtain to display. Through this mechanism, the curtain has the potential to operate as a digital display, with water droplets acting as pixels. As currently implemented, the proximity sensors cannot modify the display on the curtain based only upon spontaneously gathered sensor input, relaying on operator provided content, but sensors monitoring wind speed do have the ability to turn the water off if the wind speed increases beyond a determined threshold (Nicolino & Ratti, 2008).

Hybridity

As envisioned and constructed, the DWP does not display the characteristics of a hybrid space in any real regard. An argument can be presented that the DWP does feature some form of hybridity due to its nature as a display, and its ability to display content, but the contextually disconnected nature of the content it displays makes this argument problematic. Problematically, as currently implemented, digital mediation at the site does not meaningfully connect the site to any other space.

If the site were connected to input sensors in another space, then a new sense of place would extend to both areas. An interesting expansion of the idea would be to create a water curtain at a remote location, perhaps at MITs campus, that responded to the input of sensors in the main DWP location. In this way, information from the physical space of the DWP could be communicated to a remote location, and the perception of the place that is the DWP would be significantly altered through digital mediation.

CHAPTER 7

CONCLUSIONS

Microsoft's Future Vision productions anticipate the near-future relationship between people and computing technology. These lavishly detailed video explorations portray a ubiquitous computing environment, identifiable by the emphasis placed on portraying people's interactions with computation rather than recognizable computing devices. Although screens appear in abundance, they are rendered with an aggressive emphasis on minimalism. They exist as locations for visual and haptic information exchange, while the underlying computation occurs elsewhere, ubiquitously. Small screens are tucked into books as place-marks while others are stuffed into pockets. More elaborate computing devices are conspicuously absent. They appear to have dissolved into the ambient environment. Human-computer interaction takes place with tables, countertops, windows, walls and other architectural surfaces.

Microsoft's depiction of future ubiquitous computing technology is consistent with Weiser's vision of the fourth era in human computer relationships. Weiser predicted a massive proliferation in the number of computers situated in our environment (many computers for every person) but he rarely acknowledged the computers themselves, focusing instead on the computation and interactive opportunities they would offer instead. When he did acknowledge future computers, it was to illustrate how unimportant they should become.

Ubiquitous computing

Weiser displayed an intense interest in *computation*, but rarely showed interest in *computing devices*. Although the two ideas seem quite similar at first, they are not. The relationship described between computation and computers is not one of synonymy; it is a relationship describing the result of interacting components. Interaction between people and computers produces computation, in much the same way that interaction between people and space produces place. It is a distinction that is clear to scholars of human-computer interaction, and one that environmental designers—because of their own familiarity with embodied action—will easily understand.

By nature, ubiquitous computing devices are specialized, defying current ideas of what computers are and what they do. In a ubiquitous computing environment, many devices are embedded within the built environment. These devices are largely characterized by the presence of sensors. The primary purpose of these sensors is to collect data and communicate it to other computing devices to facilitate cooperative action. This data, as it streams from sensing devices, is aggregated through ad-hoc networks and eventually forms part of a software map defining the computational perception of what is currently happening and who is participating. This situational knowledge is analyzed against contextual information in an effort to establish a narrow range of meaningful expectations and actions that could appropriately take place within the site. Contextual information is provided in part by architectural forms and types.

Hybrid space

Harrison and Dourish made clear distinctions between space and place, based upon their own research and work conducted by William H. Whyte and Christopher

Alexander—influential architectural scholars. Their work helped to establish the basic principles and techniques employed by designers of digitally mediated, collaborative communication environments. Their work was subsequently expanded by other researchers and applied to mobile and ubiquitous computing situations. A hybrid space is a form of space capable of manifesting digital information within physical space. This manifestation of digital information, over time, results in the formation of place-centric behaviors.

These place-centric behaviors can be inspired by digital content provided from distant physical spaces, from digital social networks, or from site-specific databases such as GIS. By incorporating knowledge from the study of hybrid space, environmental designers can make well-informed decisions while working with digital information in physical settings, and better understand the implications that digital mediation has on the practice of place making. Hybrid space describes a type of space in which digital information is given equal footing with physical and cultural assets present at a site.

Interaction design

Environmental designers have yet to engage with the field of human-computer interaction. The emergence presence of ubiquitous computing will change this. The presence of computation, distributed abundantly throughout the built environment, offers environmental designers an opportunity to learn from research in human-computer interaction. The practice of interaction design is a means for engaging computation occurring in physical space. Environmental designers can use techniques and methods from the practice of interaction design to design experiences, to specify how visitors of a site will interact with digital information and computation and how digital information present in a site can change over time as a result of spontaneously emerging communication with digital assets provided by visitors to a site.

A call for future research and exploration

The field of interaction design is young; and the practice of interaction design continues to evolve. Many practitioners of interaction design are entirely unaware of the recent research in their field concerning the application of their trade in physical space. Abundant opportunity exists for cooperation between practitioners of interaction design and environmental design and opportunities for cooperation should be pursued. Work in the areas of museum studies and virtual heritage, including work pioneered by interaction design researcher Luigina Ciolfi, provides direction for environmental designers seeking engagement with interaction design. Additionally, work underway in the MIT SENSEable City Lab offers inspiration for designers who wish to engage with digbital information in physical space.

Urban informatics is an emerging field closely aligned with planning, and interaction design. The literature review conducted as part of this thesis determined that interest in the urban informatics is expanding. The Urban Informatics Research Lab, at Queensland University of Technology, Australia, offers many examples of urban informatics projects and should serve as a starting point for environmental designers and planners interested in participating in the use of digital sensing and feedback loops in urban settings.

Human-computer interaction researchers, the technology industry, researchers in computer science and countless engineers have a vested interest in bringing ubiquitous computing devices into the built environment. For some, the academic challenge is irresistible, while others find the commercial possibilities too tempting to deny. The presence of computing devices and computation within the built environment will continue to expand. There is an urgent need to environmental designers and planners to insert themselves into conversations concerning how the implementation of ubiquitous computing within the built environment will proceed.

Closing thoughts

The terms used to describe the growing presence of computation within the built environment are numerous and largely unfamiliar to environmental designers, but the idea behind interaction with ubiquitous computing is familiar. Digital assets are, in many senses, a kind of material. Ubiquitous computing devices are, in some ways, citizens and actors. At the core of the matter lies the act of place making, an act of considerable importance that has been recognized as such in the work of Harrison and Dourish, and Whyte and Alexander.

Environmental designers are uniquely qualified to understand interactions occurring within the built environment. Harrison and Dourish drew from the practices of landscape architecture and architecture, specifically from Whyte and Alexander, when they set out to understand the differences between space and place. Their research led them to conclude that human-computer interactions occurring within digital environments were based on an innate understanding of place, not space, and that place making was an important act, for both digital worlds and physical worlds alike.

Interaction design emerged from the field of human-computer interaction. A recent turn in the field of interaction design has brought the discipline closer into alignment with environmental design. Environmental designers can easily draw upon techniques and methods from this closely aligned practice and can contribute expertise in return, influencing the evolving practice of interaction design in return.

Despite reservations involving intimate association with intangible, digital information, environmental designers can focus—as Weiser did—on the *computation*, not the *computers*, involved in the emergence of ubiquitous computing within the built environment. Designers should concentrate on designing the interactions between people and computers, between people and their digital assets, that contribute to the creation of places, and not become distracted with the engineering concerns surrounding the computing devices themselves.

Ultimately, ubiquitous computing and interaction design, taken together, form the materials, methods, and techniques needed to bring digital information into the built environment, as the result of computation, made possible by the emergence of ubiquitous computing devices within the built environment. An understanding of hybrid space allows environmental designers to understand the qualities and properties of sites, to recognize the digital assets present at a site and to understand how the manipulation of those elements will contribute to the perceived sense of place they create during future design interventions.

Just as Microsoft's future vision focuses on people's interactions with computing devices, while largely ignoring the devices enabling the computation, environmental designers can look past the unfamiliar devices appearing in the environment in which they design, and engage with the resulting computation, creating meaningful interactions that reinforce, rather than diminish, the role of designers in creating computationally rich places.

REFERENCES

Alexander, C. (1977). *A pattern language: towns, buildings, construction* (Vol. 2): Oxford University Press, USA.

Applin, S. A., & Fischer, M. (2011). *A Cultural Perspective on Mixed, Dual and Blended Reality*.

Bannon, L. J. (2011). *Re-framing HCI: from human-computer interaction to human-centred interaction design*.

Beesley, P. (2012). Sculptures and Installations, from http://philipbeesleyarchitect.com/sculptures/index.php

Bilandzic, M., & Foth, M. (2011). A review of locative media, mobile and embodied spatial interaction. *International Journal of Human-Computer Studies, 69*(10), v.

Bilandzic, M., Jones, M. G., & Foth, M. (2011). *The embodied hybrid space: designing for digital encounters in physical environments*.

Bilandzic, M., & Venable, J. (2011). Towards Participatory Action Design Research: Adapting Action Research and Design Science Research Methods for Urban Informatics. *The Journal of Community Informatics, 7*(3).

Brumitt, B., Meyers, B., Krumm, J., Kern, A., & Shafer, S. (2000). *Easyliving: Technologies for intelligent environments*.

Card, S. K., Moran, T. P., & Newell, A. (1983). *The psychology of human-computer interaction*: CRC.

Ciolfi, L. (2003). Understanding spaces as places: extending interaction design paradigms.

Ciolfi, L., & Bannon, L. J. (2007). Designing hybrid places: merging interaction design, ubiquitous technologies and geographies of the museum space. *CoDesign, 3*(3), 159-180.

Ciolfi, L., Deshpande, P., & Bannon, L. (2005). Understanding place as experience: augmenting human activities in contex.

. The Cloud. (2009), from http://web.mit.edu/giodn/Public/theCLOUD_project.pdf

Cooper, A., Reimann, R., & Cronin, D. (2012). *About face 3: the essentials of interaction design*: Wiley.

Crabtree, A., & Rodden, T. (2008). Hybrid ecologies: understanding cooperative interaction in emerging physical-digital environments. *Personal and Ubiquitous Computing, 12*(7), 481-493.

de Souza e Silva, A. S. (2006). From Cyber to Hybrid. *Space and culture, 9*(3), 261-278.

. Design Machine Group. (2012) Retrieved 2012, 2012, from http://arch.be.washington.edu/programs-courses/ms-architecture/design-computing

. Discussions in Space. (2012), 2012, from http://www.urbaninformatics.net/projects/swarm/dis/

Dourish, P. (2006). *Re-space-ing place:" place" and" space" ten years on*.

Dourish, P., & Bell, G. (2007). The infrastructure of experience and the experience of infrastructure: meaning and structure in everyday encounters with space. *Environment and Planning B, 34*(3), 414.

Easterling, K. (2011). The Action is the Form. In M. Sheppard (Ed.), *Sentient City* (pp. 154 - 158): MIT Press.

Erickson, T. (1993). From interface to interplace: The spatial environment as a medium for interaction. *Spatial Information Theory A Theoretical Basis for GIS*, 391-405.

Esler, M., Hightower, J., Anderson, T., & Borriello, G. (1999). *Next century challenges: data-centric networking for invisible computing: the Portolano project at the University of Washington*.

Fortmeyer, R. (2010). Control Freaks, 2012, from http://continuingeducation.construction.com/article.php?L=5&C=653

Foth, M. (2011). *Urban informatics, ubiquitous computing and social media for healthy cities*.

Foth, M., Choi, J. H., & Satchell, C. (2011). *Urban informatics*.

Gibson, W. (1984). *Neuromancer*: ACE.

Greenfield, A. (2006). *Everyware: The dawning age of ubiquitous computing*: Peachpit Press.

Greenfield, A. (2012). Speedbird, 2012, from http://speedbird.wordpress.com/2008/01/01/new-day-rising

Greenfield, A., & Shepard, M. (2007). Urban Computing and its Discontents. In A. a. S. T. Pamphlet (Ed.). New York: The Architectural League of New York.

Grubert, J., Langlotz, T., & Grasset, R. (2011). Augmented reality browser survey: Technical report 1101, ICG, University of Technology Graz, Austria.

. *Guidance for Industry Part 11, Electronic Records; Electronic Signatures — Scope and Application*. (1999). U.S. Department of Health and Human Services

Food and Drug Administration.

Harrison, S., & Dourish, P. (1996). *Re-place-ing space: the roles of place and space in collaborative systems*.

Iaconesi, S., & Persico, O. (2012). ConnectiCity, augmented perception of the city. *Arxiv preprint arXiv:1207.4291*.

Interactions, M. (2012). Bill Verplank, from http://www.designinginteractions.com/interviews/BillVerplank

Ishii, H., & Ullmer, B. (1997). *Tangible bits: towards seamless interfaces between people, bits and atoms*.

Ishii, H., Wisneski, C., Brave, S., Dahley, A., Gorbet, M., Ullmer, B., & Yarin, P. (1998). *ambientROOM: integrating ambient media with architectural space*.

Junaio. (2012). Location Based Channels, from http://www.junaio.com/develop/docs/location-based-indooroutdoor/

Kabisch, E. (2008). Datascape: a synthesis of digital and embodied worlds. *Space and culture, 11*(3), 222-238.

Kaptelinin, V., & Bannon, L. J. (2012). Interaction Design Beyond the Product: Creating Technology-Enhanced Activity Spaces. *Human–Computer Interaction, 27*(3), 277-309.

Katz, R. H. (1999). Project Endeavour, from http://endeavour.cs.berkeley.edu/proposal/9907IIA.html

Laurel, B. (1991). Computers as theatre.

Leach, N. (2009). Digital Morphogenesis. *Architectural Design, 79*(1), 32-37.

Living, T. (2012). Amphibious Architecture, from http://www.thelivingnewyork.com/amphibiousarchitecture.htm

MacIntyre, B., Hill, A., Rouzati, H., Gandy, M., & Davidson, B. (2011). *The Argon AR Web Browser and standards-based AR application environment*.

McCullough, M. (2005). *Digital ground: Architecture, pervasive computing, and environmental knowing*.

McCullough, M. (2007). New media urbanism: grounding ambient information technology. *ENVIRONMENT AND PLANNING B PLANNING AND DESIGN, 34*(3), 383.

MEMSnet. (2012). MEMS and Nanotechnology Applications.

Meredith, M., & Sasaki, M. (2008). *From control to design: parametric/algorithmic architecture*: Actar-D.

MIT. (2012). Things That Think, from http://ttt.media.mit.edu/vision/vision.html

. MIT Project Oxygen. (2012), from http://www.oxygen.lcs.mit.edu/Overview.html

Moggridge, B. (2006). *Designing interactions*.

Molen, B. (2010). Engadget Primed: What is NFC, and why do we care? , from http://www.engadget.com/2011/06/10/engadget-primed-what-is-nfc-and-why-do-we-care/

Nabian, N., & Robinson, P. (2011). *SENSEable City Guide: The SENSEable City Lab Presents a Vision of the SENSEable City, Through an Exploration of Mechanisms of Crowd-sensing, Actuation, Data Analysis and Computation*: SA+P Press.

Neale, M. (Writer). (2000). No Maps for These Territories: Docurama.

Nicolino, W., & Ratti, C. (2008). *Dwp: Digital Water Pavilion at Zaragoza's Milla Digital and Expo 2008*: Electa.

Noble, J., Low, A. N. H. I., Rules, B. H. O., & Remix, D. M. L. T. T. V. (2011). Vague Terrain Retrieved 08/01, 2012, from http://www.vagueterrain.net/content/2011/07/collaborative-spaces-five-strategies-softening

Norman, D. A. (2010). Natural user interfaces are not natural. *interactions, 17*(3), 6-10.

. Office Vision. (2012). *Office Labs*, 2012, from http://www.youtube.com/playlist?list=PL2B8C6AB94E8259C6&feature=plcp

. Productivity Future Vision (2009). (2009). *Office Labs*, from http://www.youtube.com/watch?v=t5X2PxtvMsU&list=PL2B8C6AB94E8259C6&index=2&feature=plpp_video

. Productivity Future Vision (2011). (2011). *Office Labs*, from http://www.youtube.com/watch?v=a6cNdhOKwi0&list=PL2B8C6AB94E8259C6&index=1&feature=plpp_video

Radovanovic, D. (2012). Urban informatics and new opportunities for interdisciplinary exchange, 2012, from http://www.danicar.org/tag/internet/

Roberts, C. M. (2006). Radio frequency identification (RFID). *Computers & Security, 25*(1), 18-26.

Russell, S. J., & Norvig, P. (2006). *Artificial intelligence: a modern approach*: Tsinghua University Press.

Saha, D., & Mukherjee, A. (2003). Pervasive computing: a paradigm for the 21st century. *Computer, 36*(3), 25-31.

Sazonov, E., Li, H., Curry, D., & Pillay, P. (2009). Self-powered sensors for monitoring of highway bridges. *Sensors Journal, IEEE, 9*(11), 1422-1429.

Schroeter, R., & Foth, M. (2009). *Discussions in space*. Paper presented at the OZCHI 2009 Proceedings : Design: Open 24/7. http://eprints.qut.edu.au/29056/

Shafer, S. (1999). *Ten dimensions of ubiquitous computing*.

Shenk, D. (1998). *Data Smog: Surviving the Information Glut Revised and Updated Edition*: HarperOne.

Shepard, M. (2011). *Sentient city: ubiquitous computing, architecture, and the future of urban space*: The MIT Press.

Sousa, J. P., & Garlan, D. (2001). From computers everywhere to tasks anywhere: The Aura approach. *School of Computer Science, Carnegie Mellon University,* http://www*. cs. cmu. edu/~ aura*.

Stone, R. W. (2005). What are MEMS? , 2012, from http://eed.gsfc.nasa.gov/562/SA_MEMs.htm

Vanderbeeken, M. (2008), 2012, from http://www.core77.com/blog/object_culture/mit_digital_water_pavilion_makes_a_splash_in_spain_10171.asp

Webster, M. (2012). ubiquitous, 2012, from http://www.merriam-webster.com/dictionary/ubiquitous

Weiser, M. (1991). The computer for the 21st century. *Scientific American, 265*(3), 94-104.

Weiser, M. (1993). Hot topics-ubiquitous computing. *Computer, 26*(10), 71-72.

Weiser, M., & Brown, J. S. (1995). Designing calm technology. Xerox PARC: Citeseer.

Weiser, M., & Brown, J. S. (1996). The coming age of calm Technology [1]. *Xerox Parc, 8*, 2007.

Whyte William, H. (1988). City: Rediscovering the Center. *New York: Anchor*.