LIBERATED PIXELS

Alternative Narratives for Lighting Future Cities

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Submitted to the Program of Media Arts and Sciences,
School of Architecture and Planning,
in partial fulfillment of the requirement for the degree of
Doctor of Philosophy
at the
Massachusetts Institute of Technology
September 2010

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Abstract

Lighting and illuminated displays shape our relations to urban environments and to one another at night and increasingly during the day by transforming what Kevin Lynch referred to as the "image of the city" (1964). Today, the wide-spread availability of LEDs (light-emitting diodes) in combination with embedded, miniaturized computation offers different ways of designing ambient infrastructures. In this dissertation, I explore these alternatives by exploiting the programmable and responsive capabilities of LED-based, low-resolution systems. In short, I examine the alternative aesthetic and communications opportunities afforded by a new generation of lighting and display technologies in the city.

I investigate the origins of lighting and displays to illustrate how they have evolved through a complex interleaving of the social and the material. This grounding leads me to develop three design explorations that focus on programmability, addressability, responsiveness, mobility and ad-hoc control. The first of these explorations, Urban Pixels, presents a wireless network of individual, autonomous physical pixels that can be deployed on any surface in the city. The second, Light Bodies, reconnects with the history of lights-on-people like lanterns that travel through the city with their users. The third, Augmented-reality (AR) Street Light, provides a layer of programmability for existing infrastructural networks.

Together the historical perspective and design interventions lead to a framework of what I call "liberated pixels", a new generation of lighting and display technologies. Liberated pixels can be placed flexibly within any context and recruited in different situations for aesthetic and ambient information purposes. This vision captures the contingent and emergent nature of “sociomaterial assemblages” (Suchman 2007) to chart holistic technical, aesthetic, and social directions for future infrastructures of “imageability” (Lynch 1964) in the city.

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For Bill Mitchell

Acknowledgments

When Franco Vairani and I proposed a line of suspended lights for the city of Zaragoza's Milla Digital, I did not anticipate that the idea would inspire my dissertation research. I am indebted to my mentor and advisor Bill Mitchell for recognizing the power of these early ideas and pushing me to implement them. My dissertation committee Pattie Maes, Richard Sennett and Alex Taylor have provided unwavering support throughout the research and writing stages of the dissertation. I am especially grateful to Richard Sennett for enabling Writing Cities, a joint MIT-Harvard-LSE association of young urbanists. I developed early drafts of parts of the dissertation for our annual meetings. Alex Taylor invited me as an intern to Microsoft Research in the "other" Cambridge which was one of the most productive and enjoyable periods of this thesis work. I am so thankful to him for agreeing to spend a summer building and testing responsive lights. During the last year, I have relished the many insightful and constructive comments on my writing.

Anne Beamish has been a friend, mentor, co-investigator and editor. I am so grateful that she agreed to co-teach the course World of Night with me during the fall 2009. And I'd like to thank all the students who made it so much fun: Jim Salem, John Arroyo, Sari Rothrock, Victoria Lee, and Wayne Higgins. Thanks are also due to Iram Farooq at the City of Cambridge for enabling the implementation of full-scale installations throughout the Central and Kendall Square areas.

None of the work would have been possible without the generous time and help from Mark Feldmeier who taught me everything that I know about electronics. My undergraduate research assistant and friend, Danny Perry was instrumental in implementing Urban Pixels at a convincing scale. I also appreciate the work of Ellen Yi Chen with whom I built the earliest versions of Urban Pixels. Special thanks are due to Richard Wilson (Distance Lab, Forres, Scotland) for interfacing Urban Pixels with his SMS system. Thanks to many other supporters in Scotland: MIT Media Laboratory sponsor Highlands and Islands Enterprise in particular Douglas Yule, Laura Dingwall, and Stephanie Anderson as well as Rab Gordon (Rainnea Ltd.) and the whole team at Eden Court Theater.

Thanks to our shared obsession with lighting projects, Dan Taub supported me immensely while working on Light Bodies at Microsoft Research. I am grateful to Mo Seeger for inviting us to Electrovision and the Roxy Bar and Screen for hosting us. Our participation in Klang.Körper was made possible by Georgine Zabrana of the Wiener Musikfreunde Orchestra. I would also like to thank Eberhard Papesch of the Wiener Musikfreunde Orchestra and Martin Atzwanger of the Technical University, Vienna. I am extremely grateful to Daniela Heissl, an extraordinary choreographer and dancer who managed to integrate Light Bodies into her pieces at a distance. Finally, I'd like to express our gratitude to the performers and bystanders who engaged with light bodies at the various performances! Thanks are due to Joshua Robles for his work as an undergraduate research assistant. I enjoyed collaborating with Alexis Sanal and David Lee in developing the self-organizing lantern project for the Seoul Digital Media City.

I am thankful to the many mentors across MIT who have guided me and encouraged me on my unusual and interdisciplinary trajectory including Edith Ackermann, Wanda Orlikowski, John DeMonchaux, Bill Porter, Lucy Suchman, Dennis Frenchman, Kent Larson, Joe Paradiso, Michael Joroff, and Larry Vale. Outside MIT, Sandy Isenstadt, architectural historian and lighting design expert, and Mark Rea, director of the Lighting Research Center at RPI, pointed me to important literature on the history of lighting design and lighting research.

The research would not have been possible without the generous support from Media Lab Sponsor Consortia, the MIT Council for the Arts, Highlands and Islands Enterprise and Philips ColorKinetics. I'm especially indebted to Jim Anderson, Kevin Dowling and John Warwick for donating hardware, attending courses and providing valuable input at various moments. I'm grateful to Lorna Goulden for inviting me to introduce my work at Philips Design in Eindhoven, The Netherlands.

Cynthia Wilkes has always been there during the many crises and difficult times. I do not know where I would be without her. I am equally grateful to the many wonderful people who keep the Media Lab running including –in no particular order– Aaron Solle, Linda Peterson, Stephanie Gayle, Felice Gardner, Stacie Slotnick, Taya Leary, Amna Carreiro, Deb Widener, Lisa Lieberson, John DiFrancesco, Tom Lutz, John Ferguson, Jeannie Finks, Jonathan Williams, Kevin

Davis, and Greg Tucker. Special thanks are due to Paula Aguilera and Will Glesnes for making my defense run so smoothly.

Over the last eight years at MIT, I have gained many friends at the Media Lab and in the Dept. of Urban Studies and Planning who have accompanied me on my journey. Thanks to Lira Nikolovska for being such an ardent supporter, mentor and friend. Thanks to Amit Zoran for all the insightful conversations in the office. Adam Boulanger and Cati Vaucelle have become great friends as we have navigated the dissertation process together. Thanks to Tad Hirsch for all the provocative discussions. I am thankful to my classmates and friends Sajid Sadi, Aaron Zinman, Amon Millner, Noah Vawter, Angela Chang, and Will Lark. Other "labbers" have made my time at the Media Lab so rewarding including Karen Brennan, Kelly Dobson, Jean-Baptiste Labrune, Orkan Telhan, Joost Bonsen, Eric Rosenbaum, Jay Silver, Diana Young, Ryan Wistort, Nadya Peek, Marcelo Coehlo, Jamie Zigelbaum, and Keywon Chung. I am grateful to the Smart Cities Group for providing a home at the Media Lab. Laura Noren has been generous in sharing her knowledge of sociology. Thanks to Francisca Rojas and Andres Sevtsuk for sharing a love of urbanism and technology. Thanks to my friends Azra Aksamija, Dietmar Offenhuber, Neri Oxman, and Bruce Deffenbaugh. Katja Schechtner has brightened the lab during her visit from Austria.

My final words of thanks go to my family and partner. To my parents, Karin and Heinz Seitinger, I am thankful for encouraging me to pursue an unconventional and interdisciplinary path. I appreciate their love and support more than they know. And I am grateful to Peter Schmitt for always bringing me back to what matters.

Contents

Thesis Committee 5

Acknowledgments 9

Prologue 17

Chapter 1: Introduction 19

- Part 1: Background 20
  - Research Problems 21
  - Significance 23
- Part 2: The Research 24
- Research Question 24
- Analytical Perspective: A Sociomaterial Frame 24
  - Design Research and Practice 25
  - Role of Design and Development Artifacts 26
  - Social and Material Symmetry 26
  - Sociomaterial Assemblages 27
- Methods 28
  - HCI and Design 29
  - Precedents: Critical Technical Practice 33
  - Precedents: Cultural Probes 33
  - Other Critical Design Precedents 34
  - Guidelines for Design Explorations 34
- Part 3: Liberated Pixels, A Generative Metaphor 35
- Outline 38

Chapter 2: History and Precedents 41

- Spotting Liberated Pixels 41
- Visual Information and Perception after Dark 42
- Contrast and Affect: 44
- Controlling the Fine-grained Qualities of an Environment ... 44
- Time and Narrative 46
- Communicating with Light 47
- Early History: Fire, Torches, Lanterns 48
- Middle Ages: Lights-on-Bodies 48
- Navigation Lights: Lights on Buildings 49
- Street Lights Separate from the Walls 50
- Networks Emerge: Gaslight 51
- New Possibilities: Electricity 52
- Dappled Nighttime: Multiple Technologies Coexist 53
- Celebrating the Night 56
- Fairs 58
- Retail Lighting 59
- The Light Bulb as Pixel 59
- Lichthunger – Hunger for Light 59

Capturing the Effect of Light 60
Relationships between Substrate and Image 62
Photography and Film 63
Going 3D: Licht-Raum Modulator 64
Lines of Light – Gaseous Discharge Lamps 65
Neon/Venturi/The Strip 66
Light-Emitting Diodes (LEDs) 67
Issues with the Quality of LED Lights 68
Pervasive Computing Visions for Urban Environments 68
The Initial Ubiquitous Computing Vision 68
Interaction Principles for Ubicomp Environments 68
Expanding the Context for Ubicomp 69
Ambient Displays 70
Urban Pattern Languages 72
Media Facades 76
Social Life in the City and Urban Screens 77
Safety 77

Chapter 3: Augmented Reality Street Light 83
Converting to LED Street Lighting 85
Related Work 86
LED Luminaire Design 86
Prototype Design 87
In the Lab 89
Discussion 89
Color 89
Motion 89
Sensing 90
Reaching for Evocative Urban Infrastructure 90
Playful Infrastructure: Shadow Playground 91

Chapter 4: Urban Pixels 93
Rethinking Urban Screens 93
Design Criteria 93
Programming Urban Pixels 94
Simulations and Scenarios 95
Related Work : Sensors and Displays 97
Sensor Networks 97
Precedents 97
Early Prototypes 100
Urban Pixel Units 100
Communication Protocol 102
IR Sensors 102
Interactions 103
Urban Pixels in the Lab 103
Urban Pixels in the Wild 105
Deployment 1: Urban Pixels in Inverness, Scotland 105

Liberated Infrastructure 107
Painting with Light 107
Responsive – Interacting with Urban Pixels 108
Future Technical Requirements 109
Deployment 2: Urban Pixels on the Media Lab Facade 110
Ambient Wayfinding 110
Transparent Display 110
Outlining Images and Words: The MIT Logo 111
Reaching for a City-Scale Vision 112

Chapter 5: Light Bodies 113
Introduction 113
Design Criteria: "Excuse me, Miss, your bag is on fire!" 113
Related Work 117
Hardware 117
Casings 119
Software 119
Light Bodies in the Wild 120
Klang.Körper and Licht.Körper 120
Play Me, I'm Yours 121
Electrovision 123
Discussion 125
Unexpected Affordances 125
Reflections on Open-ended Explorations 126
Performative Space through Light 127
Reaching for an Everyday, Urban Experience 128

Chapter 6: Lessons Learned 129
Envisioning New Sociomaterial Configurations 129
AR Street Light 131
Urban Pixels 131
Light Bodies: Mobility 133
Adding It Up 135
Guidelines for Future Technologies 139
Illumination and Displays 139
Responsive Environments and Ubicomp 141
Sensor Networks 142
Guidelines for Design 142
Exploit the Programmability of LED-based Systems 143
Design Transparent Displays 143
Create More Illusions 144
Link Personal Devices and Collective Infrastructures ... 144
Create Place through Display and Illumination 144
Contributions of the Thesis 144

Chapter 7: Conclusions 147
Alternative Narratives for Lighting Future Cities 147
Blurring: A Metaphor 148
From the Artificial Sun to the Pixilated Landscape 149
A Malleable Environment 150
Shared Places for Interaction 152
Infrastructures of Imageability 154
Reiterating the Liberated Pixels Vision 156
Future Work 157

List of Images 161

References 165

Appendix 173

Prologue
Milla Digital, Zaragoza, Spain

In the fall of 2005, the city of Zaragoza, Spain asked an interdisciplinary team at MIT to develop ideas for a new neighborhood under the direction of Bill Mitchell, Dennis Frenchman, Michael Joroff and Carlo Ratti. (Frenchman & Mitchell, 2006) A large swath of land had recently been reclaimed for urban development because the city had relocated the old central train station. The area leads right into the heart of the city through residential neighborhoods historically separated by railroad tracks. The brief called for creative, digital interventions and programming for a reinvented twenty-first century environment. (Frenchman & Rojas, 2005)

21st century public realm

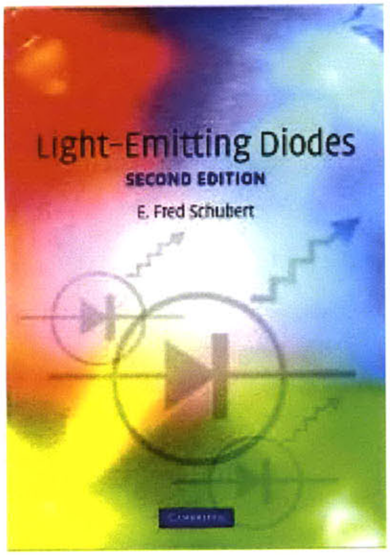
As part of the plans for the neighborhood now dubbed Milla Digital, Franco Vairani and I proposed a light-weight system of addressable lights that would simply call attention to the mile-long stretch of city that had been won for future development. This interim measure would require very little investment and no significant infrastructural improvements thus providing a simple and powerful urban gesture. Though the proposal was not implemented, the ideas germinated into a much broader project to explore the dynamic relationship between urban spaces and strategically placed light. This dissertation describes the investigations which were inspired by this initial proposal.

Fig. 0.1. Illustration showing a line of light as a datum spreading along the Milla Digital zone proposed for Zaragoza, Spain. Visualization by Franco Vairani. (Frenchman & Mitchell, 2006)

Chapter 1
Introduction

City dwellers interpret the physical, social and aesthetic nature of urban environments in the nighttime and increasingly in the daytime through a reading of illuminating and illuminated displays, signs and lights. Collectively, I refer to these systems as "infrastructures of imageability" expanding upon Kevin Lynch's concept of "imageability" (1960, 1964). The term refers to those characteristics of urban spaces that leave lasting impressions and assist people in deriving personally meaningful connections with place. Though symbolic light and illumination have always played an important role in human society, the last two hundred years of technological development have been particularly significant for the co-evolution of urban form, social practices with display and lighting technologies which leads me to refer to these technologies as infrastructures of imageability. The dissertation operates on two levels. On a conceptual level, it describes historical facts to make a leap forward towards new directions for envisioning new figurations of light, culture and urbanism. On a practical level, a series of design explorations model how to intervene in the status-quo given the revolutionizing nature of contemporary solid-state lighting coupled with miniaturized, embedded computation.

The introduction is divided into three main sections. Part 1 contextualizes the research by describing some background and explaining the significance of the project at the current moment. Part 2 summarizes the research agenda by describing the research question, outlining an analytical perspective and situating the design method used within the context of contemporary human-computer interaction (HCI) research. Part 3 explains how the specific case studies were selected in order to cover different parts of the provocative metaphor which is also the title of this dissertation, liberated pixels. The chapter concludes with an outline of the subsequent chapters.



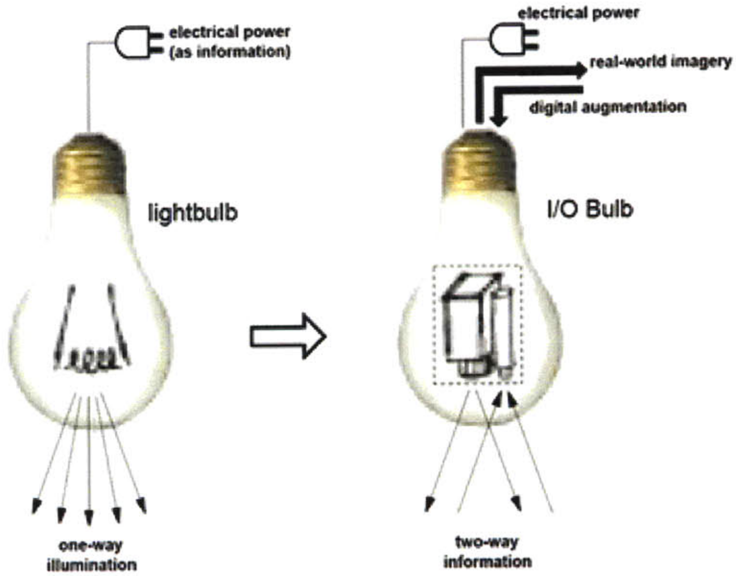


Fig. 1.1. (left) Definitive publication on LED technology by E. Fred Schubert (2006).

Fig. 1.2. (right) I/O Bulb diagram by John Underkoffler (1999).

Part 1: Background

Silicon revolution for solid-state lighting and microprocessing power

The advent of solid-state lighting (light-emitting diodes or LEDs) (Schubert, 2006) has revolutionized our ability to conceptualize and build dynamic and programmable lighting that would enable more responsive and interactive experiences. Approximately ten years ago, Underkoffler (1999) envisioned a world of programmable elements called IO bulbs, points of light combined with communication elements. While traditional lighting indoors and especially gaseous-pressure lamps in city streets do not lend themselves to easy programmability, LED-based technologies enable a highly dynamic use of small, point-sources of light. This technological revolution demands new social and aesthetic framings and implementations that hold great potential for urban design and human-computer interaction in an urban context.

Efficacious: lumens/watt, technical term in lighting industry used to compare different light sources with each other

LEDs are much more efficacious than other sources of light. And they can easily be switched between states with no detriment to the lighting element if properly conditioned. Thus, LEDs are gradually penetrating every niche of the lighting industry from digital displays to street lighting. Competitive cost factors and increasing brightness make them viable for daytime and nighttime applications. Though uses differ vastly, the underlying lighting element has a common denominator, the LED. Thinking of the city as a continuum of programmable elements no longer exists in the realm of imagination and simulation, but it is being implemented all around us with both explicit design intentions and unplanned consequences. There are many factors which have not been established concerning LED lighting. Though energy-savings can be significant, there are still many unsolved questions, particularly regarding large-scale urban installations to replace street-lighting. While almost all traffic signals and display technologies use LEDs, regular street-lighting and indoor lighting has been slow to follow due to issues of glare, cost and the general unfamiliarity with the quality of light emitted by LEDs.

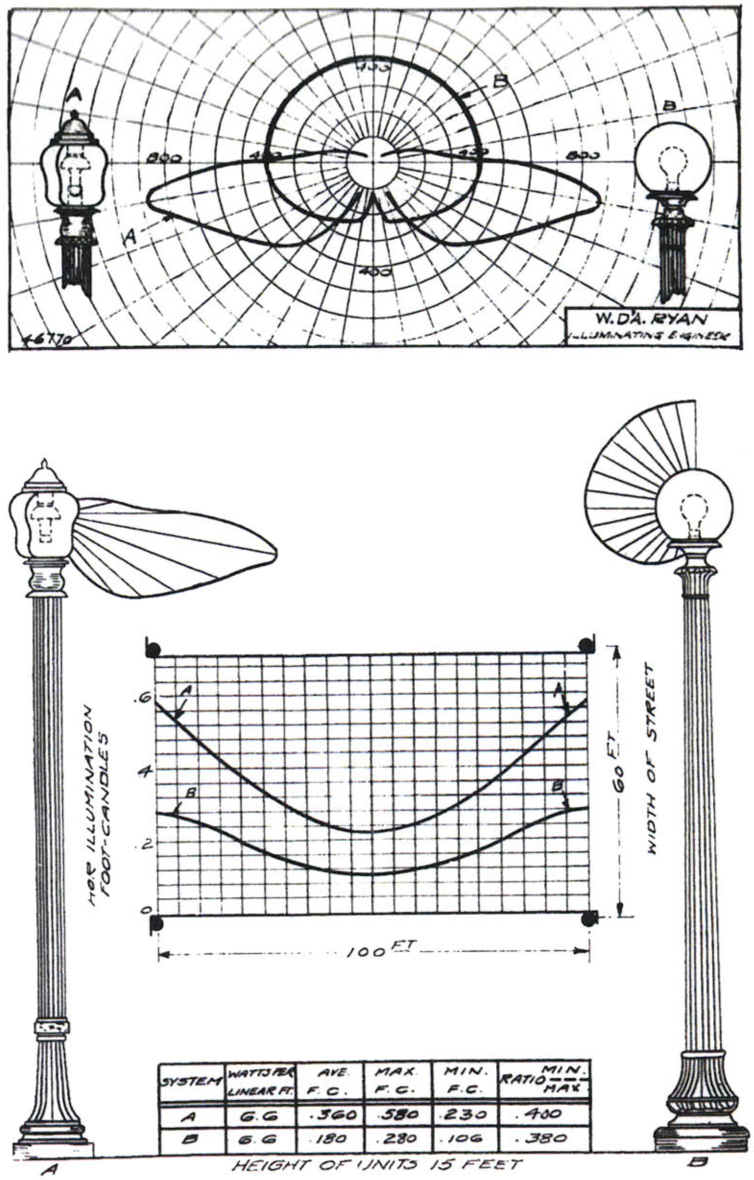
Research Problems

Even though digital displays have become increasingly sophisticated, the predominant designs are inflexible, flat and bounded. There are public and private displays throughout the urban environment that are not integrated with existing architecture and often overlap awkwardly with existing built conditions. These screens usually support high-resolution content that requires a user's undivided attention. Further, the display's impact is limited by its size, location, orientation, and placement. In most cases, the user cannot influence the content shown on the screen or have a direct impact on its representation. The result is often a disconnect between content, interaction and physical context of the user. In other words, place does not play a central role in the user's experience making the experience more generic than it might otherwise be.

There are commercial examples of environments with sophisticated public display and lighting systems such as Freemont Street in Las Vegas or parts of Times Square in New York and more recently a shopping district in Beijing, China where the world's largest ceiling display was unveiled. More architects are also experimenting with sophisticated programmable building skins that overcome some of the limitations of typical display technologies described above. However, these systems are expensive, custom-built and do not extend beyond a specific building. In fact, they are typically intended to highlight a particular architectural statement rather than blend with the urban setting. This disparity has led to debates in some cities where residents have contested the use of programmable billboards and other large-scale animated surfaces.

Lighting technologies, in contrast to display technologies, provide ambient lighting for comfortable, safe nighttime settings through a networked system of individual points of light. For public illumination purposes, they are typically built and maintained by local governments though private developers often accept the responsibility for them as well. While urban lighting systems have become increasingly sophisticated and robust, these systems do not enable communication or interactivity nor do they convey information. In fact, they are designed to inhibit tampering

Fig. 1.3. Engineering specification from the early 20th century for a proposed luminaire. General Electric Review 22 (December 1919), p. 1044. (Jakle, 2001, Figure 5.3).



and manipulation for safety reasons. With few exceptions (Dial4light), controls are centralized and rarely accessible by citizens.

The vision for ambient and ubiquitous information delivery anywhere and everywhere has been circulating for almost thirty years now (Weiser, 1991). In this world, every artifact is addressable and programmable via wireless communication embedded in tiny ubiquitous devices (Greenfield, 2006). These systems respond dynamically and should not depend on centralized computing infrastructures. Urban lighting and display is a particularly rich domain for exploring the potential of these new infrastructures. Urban computing research, in general, has also become increasingly prominent within HCI. However, these investigations seem to focus more on mobile devices rather than on infrastructural systems. And they overemphasize the communicative, informative aspects of ubiquitous technologies as opposed to new (aesthetic) design opportunities that will improve the quality of urban nighttime environments.

Significance

Significant technological shifts taking place in the LED-lighting industry and the urban lighting field more generally make the topics addressed in this dissertation especially salient today. These technical developments have opened a window of opportunity for creating new types of configurations of light and urban spaces for citizens, especially ones that are dynamic.

Like urban design, urban lighting guidelines have steadily integrated functional requirements with aesthetic ones. In the past, urban design was often dominated by engineering specifications for vehicular traffic. For example, exaggerated parking requirements for malls within some existing code structures often led to oversized parking lots that did not create inviting, street-level environments. In contrast, urban design approaches, such as developing street-level retail, hiding parking within malls rather than surrounding the entire periphery, considering the importance of landscaping and providing alternative access routes for pedestrians and bicycles have improved urban spaces, quality of life while still accommodating mobility needs. A similar convergence is taking place among (urban) lighting designers and lighting engineers in cities who typically focus on safety, base lighting requirements or signal lighting (see Fig. 1.3.). Through approaches such as lighting masterplans (Brandi & Geissmar-Brandi, 2007), more holistic responses are being developed that consider both aesthetics and function together.

Meanwhile increased demand for dynamic signage, media facades and other LED-based, programmable systems is increasingly attracting other engineers like computer scientists, ubiquitous and pervasive computing experts into the field. Though active in the same realm, researchers in display technology and urban lighting designers are only beginning to exchange ideas. In order to build bridges across disparate domains, this thesis proposes alternative narratives that enable shared meanings and ultimately engender new approaches to lighting future cities. One common narrative in the field relates to energy conservation and sustainability (see for example the Lightsavers project by The Climate Group). Other narratives exist around user-generated content and increased personalization and customization around technologies. In this dissertation, I focus on alternative narratives of figurations (Haraway, 1991) related to the connections among aesthetics, design and

bringing HCI, ubicomp and urban lighting design together around...

...infrastructures of imageability

communications that can inspire theory and practice alike and enable more multifaceted approaches to a series of technical systems that are increasingly present in our cities.

Part 2: The Research

The aim of this research is to develop a new approach that differs from the status-quo and retrofit mentality of existing display and especially lighting technologies in the city. Though many interesting contemporary projects (Fig. 2.22.) hint at exciting possibilities, they are disparate and not linked in a common conversation about infrastructures of imageability that are presented here as having powerful roles in the construction and interpretation of urban public space.

Research Question

Clearly LEDs will continue to co-exist with other lighting systems and it is not the focus of this thesis to predict the future of a particular technology. Instead, this dissertation aims to derive a framework for approaching future developments by taking advantage of the fundamentally different qualities of LEDs, their miniaturization such as their addressability, and their abundance. This framework informs a series of alternative narratives that will inspire designers, technologists and urbanists alike. The underlying research question for this project is: What technical, aesthetic and social potentials will programmability, addressability, responsiveness, mobility and ad-hoc control unlock in urban environments? In order to answer this research question, I combine a sociomaterial analytical perspective with design investigations. I use the analytical perspective to examine the contingent and connected nature of people, urban environments and proliferating lighting and display infrastructures. And design provides a way of introducing new elements into the complex existing urban condition to create new directions and potentially alternative directions for the future. The approach (sociomaterial frame) and the method (design) are described in the following sections.

Analytical Perspective: A Sociomaterial Frame

As illustrated by the research question, the focus in this dissertation is not on resolving specific technological issues related to LED lighting or display systems, which are already being addressed by a burgeoning industry. The emphasis is on proposing alternative usage scenarios in urban environments that will expand the application space and ways of thinking about these emergent technologies that do not replicate existing patterns of light and display in the city. The goal is to exploit the dynamic and flexible form factors enabled by LED systems in combination with embedded, miniaturized computation to inform theory and practice in urban design and HCI through a sociomaterial lens. For now and for the basic purposes of the dissertation, I propose a simple definition of sociomaterial to mean the joint and enmeshed importance of material affordances and social practices. Rather than studying the two separately, this perspective captures the full extent of the impact which I claim this new generation of systems has on cities. The following section describes the analytical frame in more detail within the context of a design thesis.

Design Research and Practice

Design research and practice raise important questions about the nature of the artifacts we study within HCI. These ontological considerations are rarely mentioned because researchers often take an a-theoretical stance and deserve further attention. Writing in the context of Computer-Supported Collaborative Work (CSCW), Ackerman describes the separation between the social and the technical: "The social-technical gap is the divide between what we know we must support socially and what we can support technically." (2006, abstract) According to Ackerman, this gulf haunts the entire field of CSCW and can be extended to HCI in general. It presents researchers with a limited view of the world that does not accurately reflect how the technical and the social co-exist and co-evolve. Dourish (2006) also presents this argument in his reflections on the role of ethnography in HCI. Rather than seeing a division between people and technologies he understands technologies as the very places of social and cultural production. In other words, there is no gap between the social and the technical. Instead, people – users – experience the artifacts and technologies in different social and cultural contexts.

A similar divide exists between design and technical development. Design takes place before, after and around technical development, but it is rarely considered a constitutive part of that development. Designers provide inspiration, meaning, holistic visions for technology, but they are not the creators of technology. They produce housing, casing, interaction modes and other aspects of a whole, but they are not responsible for functionality or feasibility. As Zimmerman et al. (2007) write in their study of interaction design, designers frequently face engineers' head-shaking because "that's just not feasible at this stage". While their study of interaction designers shows an increased collaboration among them and researchers in HCI the implicit gap-thinking holds back true co-creation.

Role of Design and Development Artifacts

At the nexus of design and technical development lies the artifact whether it is a prototype or a completed system. These are the material components of the research endeavor that provide common ground among interdisciplinary teams. They are "boundary objects" (Star & Griesemer, 1989 in Bechky, 2003) which facilitate a conversation about the research trajectory. In some cases prototypes are sufficient because they embody all aspects of the project.

If the gaps between technical-design and technical-social are artificial distinctions the nature of the artifacts created in HCI shifts in important ways. We are not studying the artifacts in and of themselves, but their use by real people in context. This growing interest leads to a different division between research in practice and research as it is reported in papers where the separations between technical and design processes as well as social context is reinstated. As a result, we risk losing a project's richness.

The risk is particularly great when context increases in size and complexity. In the past, many technologies were tested in a lab setting or addressed work-place environments. Today, HCI is taken into new settings such as the city, the home, the school, transitory spaces, and more. Mobile applications have also increased the need to consider the technical and the social together in order to produce meaningful technologies. (Paulos & Jenkins, 2005)

Urban Pixels, one of the design explorations subsequently described in detail, is an example of a project that requires a setting "in the wild" in order to take on significant meaning. They are individual points of light that do not convey meaning until they are configured in a network of units and placed in a context. Both the architectural context and the social context provide important pieces of the puzzle. For example, a single line of lights along a façade can convey direction towards a destination. But this simple animation depends on the placement of the lights, the existence of some destination at either end and users who are attempting to reach that destination. In order to understand the benefits and meanings behind an ambient information system in the city these contextual and social cues are indispensable.

Social and Material Symmetry

The preceding considerations raise a very important question about the nature of the artifacts we design, build and study within HCI. A dumb pixel by itself is meaningless, but in situ it takes on many meanings. Does this fact imply that context instills meaning in the technology? Or does the material direct the behavior of users? These are difficult questions that have been debated in the social sciences for years. Under different social science research paradigms, technologies (and the material in general) play very different roles. (Burrell & Morgan, 1979) In functionalist studies, specific technological systems engender predictable organizational outcomes by definition. In process-based interpretive studies, agency resides primarily with human actors rather than deterministic technological and organizational structures. (Barley, 1986; Schultze & Orlikowski, 2004)

Interpretive approaches (that take a more open-ended, qualitative position to explaining social phenomena) tend to privilege human actors while HCI privileges the machine. (Suchman, 2007, pp. 269-270) In practice, material and technical concerns do not trump social and contextual preoccupations as explained above. Design projects especially blur the boundaries between challenges grounded in social contexts and their material responses. For example, Urban Pixels presents a lighting system that combines certain technical capabilities of wireless networks with the communicative aspects of urban lighting. The system cannot be evaluated in the absence of an urban context or people. It only becomes interesting when it blends with and becomes a mesh of people, lights and the city. In this example, the social, technical and spatial components of a project are "constitutively entangled" (Orlikowski, 2007) to produce an entity that becomes my focus of study and which does not categorically distinguish physical artifacts from social experiences.

This perceived duality leads me to another category of social science studies which places technologies on par with humans in networks of actors. Humans and machines are equal players in different assemblages of human, non-human and hybrid actors. While these post-humanist approaches such as actor-network theory (ANT) reflect many of the complex interactions among people and machines that my research addresses, unqualified symmetry does not account for complex assemblages of actors with different degrees of accountability. (Latour, 1992) Suchman addresses these concerns by introducing the term "sociomaterial assemblage" which is explained in more detail in the next section.

Sociomaterial Assemblages

For the purposes of this study, I use sociomaterial to mean the joint and enmeshed importance of material affordances and social practices with no categorical position on symmetry or asymmetry of actors. To further deepen this definition, I draw on Suchman (2007). She addresses the concern with symmetry by outlining an approach to sociomaterial assemblages that also captures the role of technology in my research. There is a host of projects that are not inherently linked to a functionality or self-contained capacity of an artifact but rather to the enacted experiences among people, objects and spaces: "The effects are created through the particular possibilities provided by an artful integration of persons, objects, spaces, fantasies, remembered experiences, and technologies to evoke and explore an emblematically human encounter but not to replicate it" (Suchman, 2007, pp. 280-281). They are not interacting over the course of discrete encounters rather assemblages of actors are emerging together.

sociomaterial assemblages

Other examples of sociomaterial assemblages abound. For example, Boehner, Sengers and Warner (2008) have argued that embedded ambient information displays to be used in intimate social contexts cannot be studied as technical artifacts independent from human actors or aesthetic experiences. In this case, "the medium is not the message" (McLuhan, 1964) because the message arises from a specific assemblage of human interactions, social norms, and artifacts. These displays operate under the same principles Suchman (2007) describes in a series of new media installations. They are emergent through ongoing interactions among a range of human, non-human and hybrid actors.

Studying the sociomaterial assemblages may resolve tensions between the technical/material and social as well as design and science which can lead to a project's evaluation on its own terms. (Boehner et al., 2008; Wolf, Rode, Sussman & Kellogg, 2006) Prototypes and designed artifacts should serve as evocative objects or "companions to our emotional lives or as provocations to thought" (Turkle, 2007, p. 5) for particular sociomaterial conditions. Without their relational component they are not meaningful.

Methods

The preceding section described the importance of taking an analytical perspective that does not privilege technologies over human actors or vice versa. The following section moves from this fundamental (ontological) level to the operational, process (epistemological) level in order to describe my approach to design in the dissertation. Though addressing practitioners across fields, this thesis is situated within the Media Laboratory and a computing, technology-oriented community. As discussed above, holistic urban lighting design for dynamic environments is in its early stages and there have not been many comprehensive studies. And technologists are among those professionals who are increasingly becoming part of urban design debates related to cityscapes at night. Thus, the following discussion on method draws on current discourses around design HCI.

HCI and Design

HCI and ubiquitous computing researchers embrace design methods as valid and fruitful approaches to envisioning, prototyping and evaluating innovative technologies. The word design can mean many different things. I use Zimmerman et al.'s (2007) term "creative design" which encompasses a broad definition of the domain as it is taught and practiced in architecture or industrial design. In all these fields, design unfolds over time, Suchman (2007, p. 278) writes that: "(...) design is an ongoing process of (re-)production over time and across sites." This iterative vision of design parallels the dynamic nature of sociomaterial assemblages described above. Rather than studying the social and the material separately or as causally related, designers intervene in given sociomaterial assemblages to produce new ones. Unlike purely technical endeavors, design becomes meaningful when it fulfills the needs of users in the wild as well as in the lab. The importance of going into the field or creating new immersive experiences (rather than controlled lab experiments) has been recognized by HCI researchers who are increasingly concerned with technologies in everyday contexts. Before turning to these precedents, I review some of the issues facing design in computing research.

In an effort to demonstrate the rigor of design investigations to the research community, the entangled nature of the design process is often neglected. Design as an iterative practice has led to design as a step-by-step process that can be reenacted like a recipe. Frequently design is also presented as component part of a much larger development process. In this view, researchers study a phenomenon, design or construct some technologies and then theorize about their meaning. These cyclical diagrams limit how design can contribute to the research and development process. Zimmerman et al. (2007, p. 496) interviewed interaction designers and HCI researchers to ask them how design contributes to the research agenda. Three areas were noted by interviewees:

- "interaction designers brought a process for engaging massively under-constrained problems..."
- "designers brought a process of integrating ideas from art, design, science, and engineering, in an attempt to make aesthetically functional interfaces."
- "empathy for users"

The contributions of interaction designers identified by Zimmerman et al. (2007) above often take place prior to or following technical development. The study also found that many designers were asked to shape the aesthetic appearance of the artifact after technical specifications had been set. These limited views underestimate the theoretical and holistic implications of design and thus its potential to inform the overall project.

In contrast, design can be seen as something dynamically enacted that can infuse the entire research process. Design contributes to the blurring between social and material because the practice itself is grounded in social settings and produces material solutions. This philosophy has become an important component of HCI research as well which is increasingly concerned with technologies in everyday contexts. Suchman (2007, p. 278) captures how these practices unfold: "(...) design is an ongoing process of (re-)production over time and across sites." This iterative vision of design parallels the dynamic nature of sociomaterial assemblages described above.

Enacting this iterative process as an individual researcher poses many challenges. In her essay in the essay collection Managing as Designing, Orlikowski (Boland & Collopy, 2004) describes two features of design practice: a reflexive vocabulary; an enacted design practice. A reflexive vocabulary refers to every designer's ability to reflect upon her work during its creation. (Schön, 1991) The enactment of design refers to a dynamic practice or as Orlikowski (Boland & Collopy, 2004, p. 93) describes it: "Good design in this view is not an intrinsic feature, stable property, or static quality of the representation (the design artifact, building, program, organization), but a recurrently enacted accomplishment provisionally and ongoingly achieved by human actors trying to use the design to get something useful done." The co-creation of the world among designers and users thus becomes an essential aspect of design. Under these criteria, design becomes increasingly entangled with the social world. The material/technical artifacts are thus always produced in relation to an enacted social experience. It becomes increasingly difficult to distinguish artistic/aesthetic choices from particular observations about the social or any technical specifications.

The entanglement of research and design more generally raises issues about which knowledge counts. HCI stresses evaluation of technologies against stringent system performance requirements. If the evaluation process becomes entangled with the design process then the boundaries between development and evaluation are blurred which jeopardizes a researcher's ability to objectively assess the project. Boehner et al. (2008) also describe their struggles to fit aesthetic experiences for affective communication into this model of evaluation instead of meeting new experiences on their own terms.

The clash results from a scientific, functionalist paradigm that does not acknowledge the synthetic and holistic nature of any design practice (Simon, 1996; Mackay & Fayard, 1997) In addition, the full sociomaterial reality of the artifact may be difficult to capture. For example, an evaluation study about the technical capabilities of an artifact cannot capture its emergent nature nor the full extent of its impact in a social setting. If the desired outcome must be fully ascribed to the technical capabilities of the machine, then the user's interpretive role in the interaction cannot be counted. Conversely, a person's well-being cannot be measured independently of her interactions with the machine because her feelings are constantly mediated. These two avenues exacerbate tensions between technically oriented and socially oriented research agendas because neither can prove how a project impacted key indicator variables. Instead of reading them in the context of a particular sociomaterial assemblage they are studied under separate conditions imposed by scientific methods.

Remolding design after the fact relates to Law and Urry's (2004) critique that social science often creates the world in its image rather than vice versa. As a result, certain phenomena such as "fleeting, distributed, multiple, sensory, emotional, kinesthetic" (Law & Urry, 2004) are difficult to study with traditional social scientific methods. New schools of thought have responded to these shifts, but they have not openly assumed their role in co-creating those new worlds. Similarly, design and its relationship to HCI remains a passive one where the performative nature of design research does not play a central role. If research and design share a common reality then they should assume their role in shaping that reality: "The move here is to say that reality is a relational effect. It is produced and stabilized in interaction that is simultaneously material and social." (Law & Urry, 2004, p. 395)

Laurel (2003) attempts to address this complexity in her edited book Design Research by outlining the diversity of approaches in design: "(...) designers today are employing a panoply of research methods to strengthen their work. This 21st century hodge-podge is beginning to coalesce into a coherent discourse." (Laurel, 2003, p. 19) I share Laurel's desire to bring design research methods under a coherent umbrella, but I do not think we are witnessing a growing coherence. Rather I think we confuse design practice with ontological questions about the nature of the phenomena we are studying.

I argued above that the theoretical and analytical contributions of design to HCI are underestimated. Dourish (2006) identifies a similar role for ethnography within HCI because it is merely used to supply "design criteria" when more important lessons could be learned from the analytical findings made by ethnographers.

Zimmerman et al. (2007, p. 498) identified much more far-reaching contributions which included finding new opportunities for technologies, giving form to theoretical and technical proposals, and making overall contributions to the research questions and framing. These results indicate that design delivers a kind of glue between the technical possibilities and behavioral models. And I would go even further to claim that design is not just bridging the gap between technical and social or instilling meaning, but rather drawing attention to the entangled sociomaterial nature of the conditions we increasingly encounter in HCI investigations.

By nature, design is a reflexive practice that has a built-in cycle of personal reflection on an artifact or project. In an interview, Schön captures the balance between this reflexivity and a rigorous process: "Designers need to be able to bridge this gap between the personal and the technical-to be able to work with the medium and to reflect on the surprises, and in the end to produce a design that works both for the designer and for the audience. Not every designer can produce a design that evokes love, but that's not a bad description of what good design is trying to achieve." (Schön in Winograd, 1996) Schön's gap is very different from the gap between social and technical/material discussed earlier. It acknowledges the agency of the designer and researcher in her role as shaping new sociomaterial conditions. More coherent discourses or unified approaches to design will not capture this richness, but further obfuscate the theoretical contributions of design to HCI in bringing the social and the material closer together. We should strive for more explicit accounts of the nature of specific artifacts or technologies and their relationship to new findings in HCI. To achieve a similar goal in this dissertation, I needed to go beyond social-scientific methods that incorporate design components and identify a more interventionist point-of-view where design of new technologies changes the basic conditions which can be studied.

There is a trend within HCI and ubiquitous computing to engage more with design as a critical tool for open-ended explorations. As mentioned above, technologies are increasingly designed for use in multiple contexts that researchers cannot fully anticipate. Rather than being a discrete part of the research process, design has proven to be a useful tool in bringing about situations that push the boundaries of expected scenarios for technology thus creating entirely new application spaces. I give a brief overview of critical design practices in general and specific interventionist methods such as "cultural probes" (see section below). This background leads to the stance employed in investigating the liberated pixels vision.

Precedents: Critical Technical Practice

In order to recast the outcomes of technical work within the artificial intelligence domain, Phil Agre coined the term "critical technical practice." His approach melds technical research with reflexive considerations about technology's role in emerging practices. Agre writes: "A critical technical practice rethinks its own premises, revalues its own methods, and reconsiders its own concepts as a routine part of its daily work. It is concerned not with destruction but with reinvention. Its critical tools must be refined and focused: not hammers but scalpels, not a rubbishing of someone else but a hermeneutics and a dialectics of ourselves." (1997,

p. 24) Critical technical practice incorporates a critical loop within the process of research.

Under this view, research operates on two levels – reflexively and substantively – that both produce important contributions to academic knowledge. In the reflexive mode, the researcher has "A primary goal of critical technical work, then, is to cultivate awareness of the assumptions that lie implicit in inherited technical practices." (Agre, 1997, p. 105) On a substantive level, the research should value "....what happens in the course of designing a device that interacts with its surroundings. (...) the focus is not on complex new machinery but on the dynamics of a relatively simple architecture's engagement with an environment. (...) Instead, the principal substantive contribution is a way of thinking about the relationship between machinery and dynamics for certain purposes." (Agre, 1997, p. 106) The outcome of a research project thus consists in making meaning through the new configuration of technologies in context much like Suchman's sociomaterial assemblages described above.

critical technical practices

Precedents: Cultural Probes

Pioneering interaction designers developed the notion of "cultural probes" to engage with new communities through collecting various qualitative feedback (postcards, images, diaries) and excavate unexpected requirements. Inspired by Situationist art practices from the turn of the 20th century, Gaver, Dunne & Pacenti (1999) write that they "concentrate on aesthetic control, the cultural implication of [their] designs, and ways to open new spaces for design." (p. 24) They used this approach to learn about elderly communities across Europe rather than expecting specific design recommendations. The outcomes and rich data arise from the specificity of the communication among designers and users through physical artifacts generated to elicit responses and spark a dialogue.

The probes method has been adopted widely under many guises such as urban probes, technology probes and domestic probes. Some researchers are more explicit about the desired outcomes for their probes. Hutchinson et al. (2003), for example, divide the possible outcomes of their "technology probes" into social science, engineering and design goals. They write: "Technology probes are a particular type of probe that combine the social science goal of collecting information about the use and the users of the technology in a real-world setting, the engineering goal of field-testing the technology, and the design goal of inspiring users and designers to think of new kinds of technology to support their needs and desires." (Hutchinson et al., 2003, p. 18)

Paulos and Jenkins (2005) have adapted the cultural probes methodology to urban settings. Urban probes are a "fail-fast approach" that consists of a technical intervention in the public realm. The goal is to quickly evaluate the potential of application ideas and future evaluation metrics. To study the impact of emerging wireless and mobile technologies on urban spaces, they themed a series of interventions around the title Urban Atmospheres. They were interested in trash as a physical challenge for urban infrastructure as well as a metaphor for layers of communication in space. Their urban probes consisted of observation, intervention, artifact production and deployment and reaction.

Boehner et al. (2007) perform a meta-analysis of the uptake of probes within HCI which reveals some underlying rifts within the field. The first aspect deals with "handling interpretation" as something in process and open-ended or convergent on a single solution. The second aspect addresses the difficulty in generalizing the cultural probes approach as a fully-fledged methodology versus a method that brings with it a very particular stance that invites ambiguity rather than recipe-book approaches.

Other Critical Design Precedents

Designers Dunne and Raby have developed an entire critical design practice epitomized in their book Design Noir (Dunne & Raby, 2001). They develop prototypes of future technologies that come alive through a proposed usage scenario. Unlike explorations with non-functional prototypes such as Wizard-of-Oz-type studies (where HCI researchers simulate interactivity), their devices enact a future scenario of technology (such as new types of technologies adapted to a post-carbon fuel world) use through a series of intricately designed materials. They often come alive in connection with performers.

Guidelines for Design Explorations

Based on the precedents described above, I have elected to adopt an interventionist position that is guided by the following principles: First, the focus of the study is always framed by interaction scenarios and specific contexts beyond the lab and in the city. Second, along the lines of Gaver, Beaver, and Benford (2003) I embrace the ambiguity of the technologies and contexts studied in the work. Third, I consider the social and the material together in order to make prepare for alternative future configurations of lighting and display. Fourth, the lessons learned address very specific technical questions, but also go beyond HCI to address researchers and practitioners in urban design, planning, lighting design, sociology and technology studies.

The design explorations (Fig. 1.5.) do not seek to provide an exhaustive view on the field of urban lighting and displays. Rather, they seek to be evocative examples and demonstrations of what might be possible in the future given certain sociomaterial readings of past and contemporary practices. The aim is to illustrate the contingent and entangled nature of these technologies in an urban context to enrich the repertoire of possibilities practitioners might imagine in the future.

Part 3: Liberated Pixels, A Generative Metaphor

Liberated pixels serves as a "generative metaphor" (Schön, 1983, pp. 184-187) for considering intertwined situations of people, lights and urban spaces. Typically, contemporary cities are illuminated by a variety of systems: electronic/digital display systems, light from building interiors, street lighting systems and perhaps also mobile lights from vehicles, bikers and other vehicles. These infrastructures are designed, built and controlled by separate entities that rarely collaborate on holistic illumination schemes. Though more cities are developing detailed lighting design plans that include functional as well as aesthetic components (Brandi & Geissmar-Brandi 2007) the theoretical and broader design possibilities have not been fully considered. Through new framings and additional technical systems, we can start to imagine every point of light as participating in an animated nighttime cityscape that provides light and information together as needed by people.

The liberated pixels metaphor is intended to support new narratives and open new design opportunities for deploying light in urban environments. It is in this sense that I use the term liberated rather than in an outright political sense implying liberation or freedom. Though there are political dimensions related to increased freedom it is beyond the scope of this dissertation to address all the complex political dimensions related to current discourses around technology and personal freedom and individual control. Future work will delve more into these questions.

The second half of the metaphor consists of the term pixel or picture element which stems from computer graphics where it is used to refer to the points arrayed on a two-dimensional screen. Every digital image can be deconstructed into its component-pixels, the smallest physical unit of analysis for screen representations of graphics. In some cases, pixels can assume different colors in other cases they may simply be black and white. These parameters differ across screen technologies.

In a nighttime scene, we rely heavily on illuminated points to make sense of the underlying spaces and dynamic events. Each of these points functions like a pixel in a digital image only with very different additional characteristics derived from its location in context. Unlike on a two-dimensional screen, meaningful information or impressions arise from an interaction among pixels and their placement in an urban setting. The following five dimensions seek to highlight the key features of liberated pixels that will be exploited in the design explorations (see Fig. 1.4.):

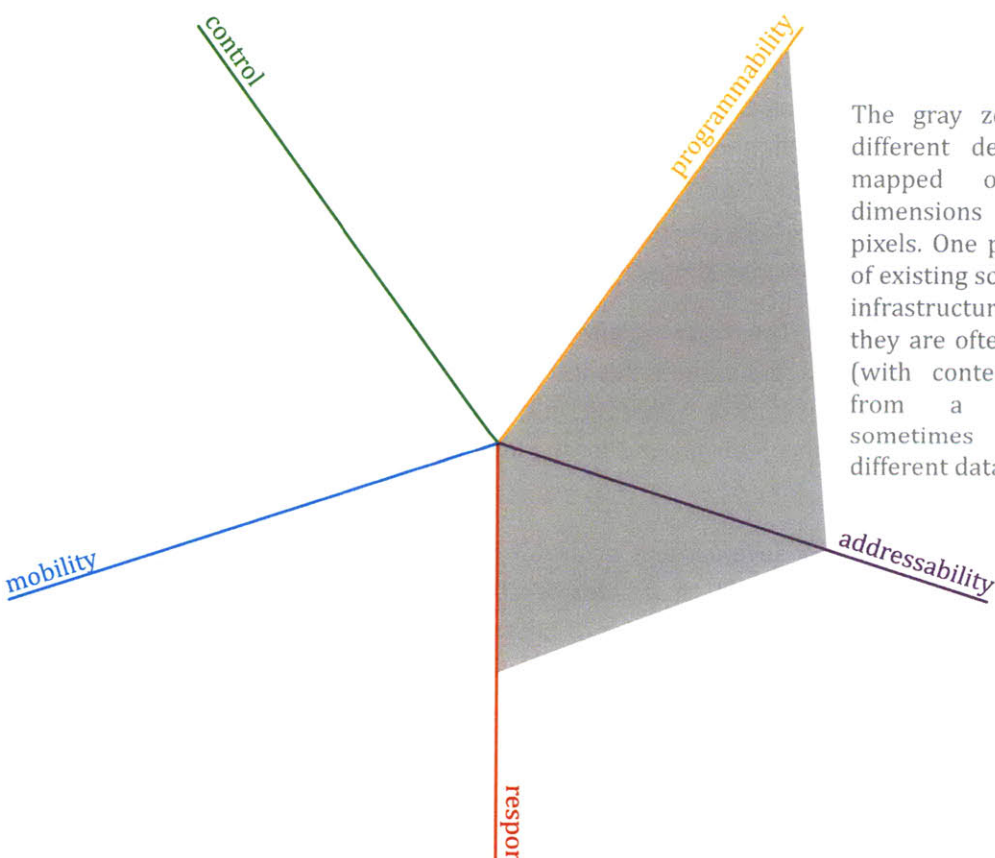
liberated pixels (LPs)

1. Programmability: Like screen-based pixels, LPs can be associated with content such as color and brightness. In addition, they can be physically rearranged. This feature allows content designers to assume areas of high- and low-resolution (as a function of the density of LPs) and reorganization of LPs over time (either in a curated or an ad-hoc fashion, see dimension three, "mobility").
2. Addressability: LPs can be programmed from a distance via wired and wireless communications networks.
3. Responsiveness: LPs can be directly integrated with sensing devices that connect the behavior of displays and lights to the activities of people and ambient, environmental information.
4. Mobility: LPs can be placed on any surface and in any location in the city thus enabling a display of variable resolution in three dimensions. LPs can be moved from place to place either by citizens on an ad-hoc basis or in more structured ways (e.g. municipal organizations or event organizers) to adapt to different occasions taking place in the city.
5. Control: LPs can be centrally or individually controlled. Unlike most municipal systems such as street lighting, LPs can be owned by individual citizens or by other public and private institutions. More than existing infrastructures, they should support explorations around control and ownership of urban infrastructure. In the diagram in Fig. 1.4., more control means greater flexibility in this respect.

Three design explorations –Augmented Reality (AR) Street Light, Urban Pixels, Light Bodies– were selected to explore these dimensions (see Fig. 1.5.). Though each of the design explorations is primarily targeted to one of the LP principles, the latter are not mutually exclusive and the overall vision assumes that all aspects together will have the greatest impact on future applications. The design interventions were developed between 2007 and 2009 with various partners who are mentioned and credited throughout as well as reflected in the publication references. The shift between I and we pronoun in the text distinguishes the collaborative aspects of some projects from the overall dissertation. The acknowledgements and research paper references describe the team composition and give credit to my partners. Each of the design explorations includes a motivation section with relevant technical references and precedents, distilled design principles for the specific application scenario, an interaction scenario (and in some cases simulations), description of the design iterations, qualitative observations from various implementations, and a discussion.

The selected in-depth design explorations arose from the questions prompted through iterations, contemporary precedent studies and historical research on light and display. For example, early versions of Urban Pixels made it clear that fixed infrastructures will continue to play an important role in urban illumination. This finding led to the notion of the AR Street Light. Attempts to place pixels in the hands of users led to the explorations with Light Bodies. The ultimately selected examples describe in detail in the dissertation cover a significant design space which ranges from centralized control to user controlled, from municipal ownership to individual ownership, from large to small, and from the infrastructural level to the personal level. The systems could be seen as overlapping with dominant which echo the five dimensions of liberated pixels listed above.

Fig. 1.4. Diagram illustrating the five dimensions of liberated pixels. This representation is used in subsequent chapters to map the design explorations.



The gray zone shows how different devices might be mapped onto the five dimensions of liberated pixels. One possible mapping of existing screen and lighting infrastructures shows that they are often programmable (with content), addressable from a distance and sometimes responsive to different data sources.

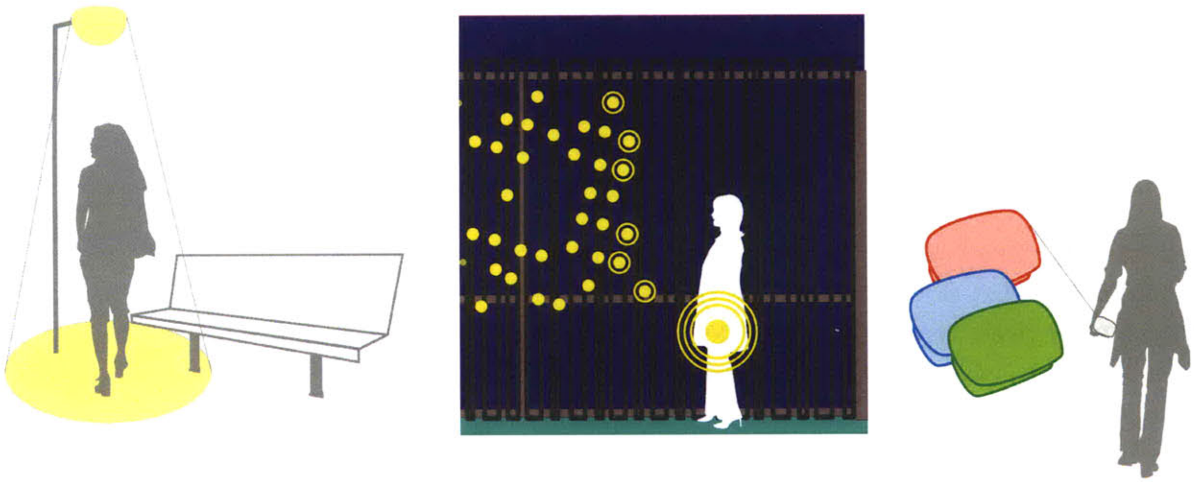


Fig. 1.5. Three design explorations. From left to right: AR Street Light, Urban Pixels, Light Bodies.

Outline

The dissertation can be divided into three parts that combine theory and practice. The literature and references span urban design, urban history, lighting research, human-computer interaction, and ubiquitous computing research. The research challenge is fundamentally interdisciplinary and is located on the boundary between theory and practice, sociomaterial framings and technological implementations. As mentioned at the outset, the dissertation can be divided into these two levels. However, the true benefit of the approach lies in their interweaving. I invite the reader to tread this line with me to reap the benefits of both aspects of the work.

The following offers a brief guide to the text. Part one includes one chapter besides this introduction. Chapter 2 provides an overview of a selected sociomaterial history of urban form and lighting to provide a conceptual ground for the interventionist projects.

Part two consists of three design explorations which include both the development of prototypical lighting and ambient display systems as well as their interpretation under different conditions. Chapter 3 reinterprets notions of programmability in everyday infrastructure such as light-poles through the AR Street Light which includes color-changing LEDs and motors to move the beam of light. Chapter 4 describes Urban Pixels, a network of physical pixels that can be used to create boundless "screens" of illuminated points of light on any surface in the city. Chapter 5 offers a reinterpretation of age-old lanterns called Light Bodies that link people to their environment not just by illuminating it, but by reflecting the soundscape of a place.

Part three knits together the conceptual and design aspects of the dissertation in an attempt to envision alternative narratives for lighting future cities. Chapter 6 interprets each exploration through the sociomaterial lens proposed at the outset and reviews a series of lessons learned and design guidelines related to specific application spaces that are linked to the specific design interventions. Chapter 7 then provides a meta-narrative and manifesto-like summary of the liberated pixels vision which has significance for theory and practice.

Analytical Perspective,
Design Method,
chapter 1

Historical and
Contemporary Precedents
and Context, chapter 2

Design Explorations,
chapters 3-5

Lessons Learned,
chapter 6

Alternative Figurations
on the Future of Light
in the City, chapter 7

Chapter 2
History and Precedents

Spotting Liberated Pixels

On my university campus, there are several graduate student residences. For better or worse, the brutalist architectural tradition of the late seventies and eighties left its mark on the neighborhood and characterizes several buildings in the area including MIT building E55 or Eastgate. Still one of the tallest buildings in Kendall Square almost all the apartments afford beautiful 180 degree views of Cambridge and Boston. I live on the 11th floor–just high enough to have a full view of other surrounding high-rise structures and the Boston skyline in the background.

Unlike Eastgate most of the surrounding buildings house offices. And one in particular directly across from my window has been under renovation for quite some time. At least five floors of the glass and stone building are being reconfigured presumably in the building management's hope to accommodate new tenants. Throughout this process on several occasions, the building's emergency lights have activated at night. The emergency lights are placed in regular intervals on every floor and blink frenetically to signal the need to evacuate. Especially in the absence of regular office lighting which seems to be deactivated during renovations the lights transformed the appearance of the building. From a distance, they animated the building in an involuntary, coordinated display of liberated pixels.

Several aspects of the emergency lights caught my attention: The lights are flexibly placed within the context of an existing building. There are no predetermined boundaries for their placement, in theory they could be placed anywhere in the building and in varying densities. Each light is addressable via the emergency communications system in the building. And finally, they are responsive and communicative because they trigger in connection with certain emergency events.

The emergency lights are just an example of how we might be able to recast familiar aspects of the nighttime environment through a specific reading of the relationship between architecture and light, observed and observer. The material qualities of the technology cannot be understood without considering their social meaning and their impact on the appearance of the city overall. My goal is to describe together the social and material characteristics of lighting and display technologies from different perspectives. Up close the emergency lights communicate the need to leave the building. From afar an observer is afforded a three-dimensional programmable display. By describing other revealing moments in time, this chapter recaps a selective history of humans' use of artificial illumination in the built environment to ground the decisions made in the later design explorations. I draw inspiration from earlier uses of light and reknit them with the possibilities enabled by current technologies to achieve alternative and hopefully surprising/provocative scenarios and designs. The following materials are drawn from biology, history, and design. Though somewhat linear, the aim is not to provide a complete overview of the history of lighting as a historian, but rather to tease out specific themes that can inform our current practice as technologists, designers and urbanists in the face of rapid transformations of our urban landscapes.

Visual Information and Perception after Dark

Though the emphasis throughout this work is on the social and cultural context of light and display, I briefly review how we parse visual information especially insofar as it changes our perception in dark environments. I focus on vision as opposed to other senses because of its relationship to light. However, nighttime or dark environments and our ability to understand them through our other senses is also a very exciting topic that goes beyond this work. Fundamentally, our dependence on light sources in order to see in dark settings makes it possible to edit our perception of spaces through light. At this fundamental level, it presents the basis for some of the aesthetic proposals made in the design explorations though I do not explore specific ways to trigger narrow effects related to the biology of our visual apparatus.

The human eye "sees" the reflection of light sources from the surfaces of artifacts around us. Without a light source we cannot perceive anything at all. The type of surface light hits determines the image our eye captures. A matte surface is very uneven and returns a multitude of diffuse reflections while a shiny surface returns one perfect ray to mirror the reflected object. No matter what the surface, though, an existing light source is central to our ability to see. With the help of this light source then, people are able to glean information from their surroundings. In the words of RPI Lighting Research Center Director Mark Rea, "People don't see light, they see information" (2010) about their context and in relation to their activities and goals.

Lighting designers are very adept at capturing and controlling the types of effects generated by artificial light. Famous lighting designer Eddie Effron writes: "While natural light fosters sight, it's artificial light that fosters insight and provides that whisper telling you what you see and influencing the experience of what you see. (...) Even though the presence of light enables us to see things, people usually do not (consciously) see the light itself. It is part of the context, the background, and has an ephemeral quality. It is hardly ever the direct focus of our attention. This makes it difficult to describe qualities of light in an aesthetic and emotional manner." (Strijp-S, 2009) Even though we may not be attuned to the specific qualities of light we feel the effects subliminally and we rely predominantly on our sight to guide us through the world.

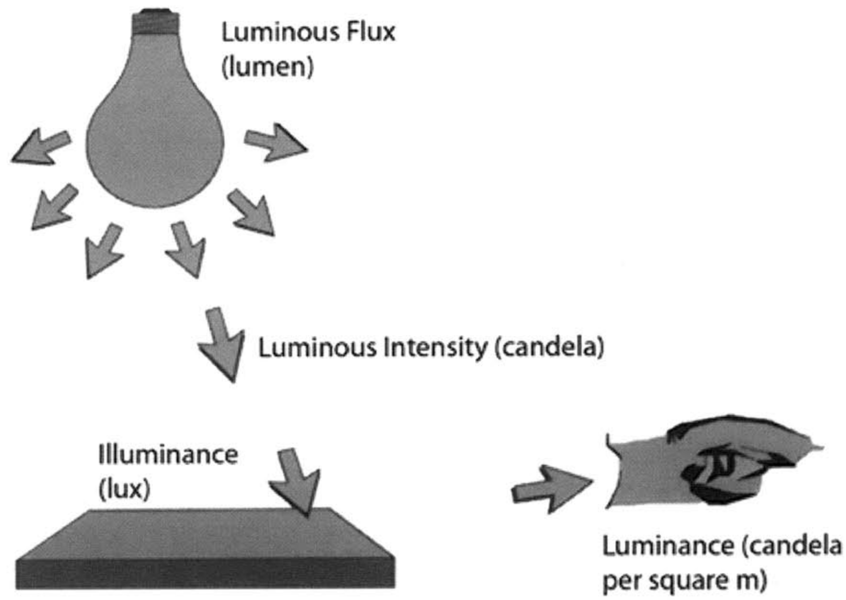
photopic and scotopic vision

Even at night, vision is central to our ability to navigate the world. As light levels decrease our ability to see color (photopic vision) using the cone photoreceptors on the retina also decreases until we only see in black and white (scotopic vision) using the rod photoreceptors. Because our rods are spread more broadly throughout the eye (while the cones are concentrated in the central part of the retina, the fovea) our peripheral vision improves at night and we lose color differentiation. Most of the time in dimmer outdoor spaces we find ourselves in the mesopic range between full color vision and black and white vision. Under these circumstances color becomes somewhat detectable but we are more sensitive to reds than blues.

Another consequence of moving through spaces with different light levels is the need for adaptation. We are much faster at adapting from dark to light than from light to dark. The reason is related to the speed with which the iris can contract and bleach or suppress the photochemicals in the rods. In order to increase the amount of light reaching the retina the iris must expand and the photochemicals in the rods must be regenerated to make use of every last bit of light. (Bean, 2005, Chapter 1; see also www.eye-therapy.com/Night-Vision) In terms of navigating spaces, it becomes important to consider the degree of adaptation a person is required to make to ensure safety and the ability to make out obstacles.

All these factors contribute to an overall point about our sensory apparatus that plays a central role in understanding the strategic deployment of artificial light in cities after dark. Though adapted for partial visual acuity at night, low light levels and variegated light levels can confound our perception. During the day we expect to see all there is to

Fig. 2.1. Adapted from the Outdoor Lighting Guide (2005).



see with our visual apparatus (even though it is still easy to play tricks on the eye-brain-mind). This congruence is considered the "normal" state. In the dark, however, we know that our eyes are limited to those parts of the environment which are illuminated and only provide a partial image of the world. Even though we recruit our other senses in addition to sight our primary source of information about the world shifts significantly.

Contrast and Affect:
Controlling the Fine-grained Qualities of an Environment

Implicit in our ability to see anything is also the need for contrast. Without a difference in light-dark our eyes cannot tell the difference between two surfaces. In terms of light and lighting design, this task becomes the design for shadow which impacts our ability to perceive three-dimensionality: "Modeling is the term used to describe the ability of light to emphasize the three-dimensional nature of objects. Modeling is an interpretation of perceived contrasts." (Philips, 2004, p. 20) When considering any built space the strategic use of light can thus shape people's perception of depth, the relationship between foreground and background and the volumetric characteristics of the forms.

The desire for more and brighter light often trumps the design for shadow and darkness. This trend lifts some of the ambiguity described in our approach to dark spaces and according to some designers also removes some of the environment's quality. For example in his book "In Praise of Shadows", Tanizaki (1977) describes how the Japanese culture's sense of beauty is linked to the interplay between shadows and light: "The quality that we call beauty, however, must always grow from the realities of life, and our ancestors, forced to live in dark rooms, presently

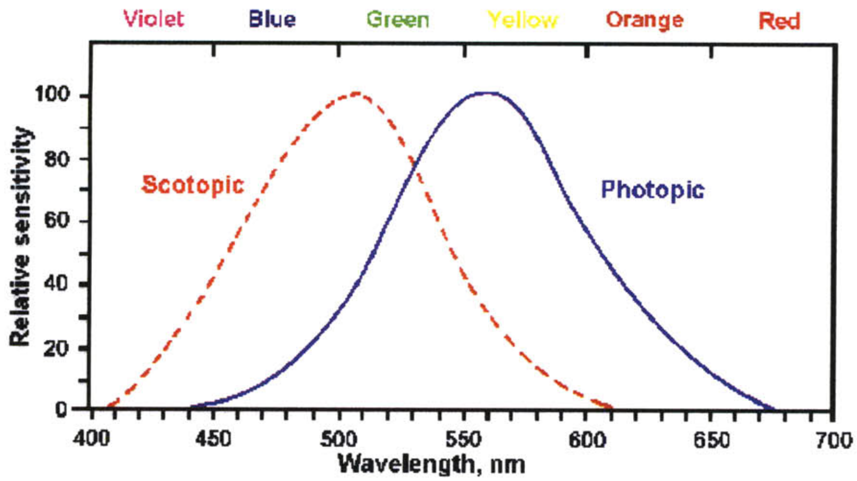


Fig. 2.2. Photopic and scotopic visibility curves. (Mann, M. D. (1997-2010). The nervous system in action. Chapter 7. Fig. 7-9. Winton FR, Bayliss LE: Human Physiology, 5th ed. Boston, Little, Brown, 1962. www.unmc.edu/physiology/Mann/mann7.html)

came to discover beauty in shadows, ultimately to guide shadows towards beauty's ends. And so it has come to be that the beauty of a Japanese room depends on a variation of shadows, heavy shadows against light shadows-it has nothing else." (Tanizaki, 1977, p. 18) The poet is particularly attuned to the affective impact of different lighting conditions and reflective surfaces such as gold dust.

For millennia architects have sought to capture the importance of the features Tanizaki describes. In particular, the dramatic effects achievable through the strategic use of contrast enhance the three-dimensional appearance of spaces. Early examples of sacred architecture like the Hagia Sophia were designed to target light at specific icons. The mosaics reflected the light and allowed the icon to glow resplendently. Gothic architecture similarly was an architecture composed to visualize dematerialization through light.

Architects and designers have perfected their ability to control the appearance of their designs at night through strategic occlusion and highlighting of architectural elements. Imagine an incineration plant which actually looks attractive in the evening because only reflective metal piping is visible. Neumann (2002) has written extensively about the evolution of this design tradition, which reached its pinnacle in the "recognition of light as a building material, which can form space directly" (Feder in Neumann, 2002, p. 80).

When designing for outdoor contexts, designers and planners rarely have the luxury (or the budget) to take affective qualities of light into consideration. With increasing programmability and fine-grained lighting systems, however, more experiential considerations are becoming more pressing. In the context of safety and public base lighting (or the minimum required light levels for vehicular and pedestrian zones in the absence of any other ambient light sources) shadows have a negative connotation. For highlighting architectural features of the city, however, designers exploit these qualities of light to the fullest. They have mastered many techniques using traditional light sources (incandescent, halogen, fluorescent, gaseous-discharge lamps) and are now experimenting with the potential of new light sources offered by solid-state lighting (LED) and organic LED lighting. The question remains how fine-grained programmability might lead to a blurring between the important functional limitations on contrast for ensuring perceived safety and the dramatic design opportunities which arise from the ability of light to model three-dimensional spaces.

In addition to spatial modeling, light introduces a temporal element to environments through several means: natural shifts in illumination through transitions from day to night, artificially programmed effects, our own movements which shift our point-of-view and thus how we perceive illuminated spaces. The natural dynamism of illumination thus already brings with it the accompanying theme of programmability which is not just a function of computation, but a built-in aspect of any display or lighting system. A person's point of view, flickering of a light source, moving a device, or repositioning a substrate (see later section in this chapter about the relationship between content and substrate or display surface) are all examples of the dynamic programmability which plays a role in shaping environment through light.

Time and Narrative

In "What time is this place?" Lynch investigates the role of change over time in urban environments. Many incremental man-made and natural processes amount to the ongoing transformation of places over time. For Lynch, these processes are a rich source of learning and information about the environment. Light introduces a similar narrative of change into the urban environment because of its temporal dimension. Finnish architect Alvar Aalto said (in Armengaud, 2009, p. 25): "At night the buildings must sleep." Armengaud describes the concept of chronotopos or the city as a reflection of the evolving movement of its citizens (2009, p. 18). These incremental, small-scale changes are not as noticeable as big changes through disaster and large-scale development. Lynch speculates on how the urban environment becomes a repository of history and thus can serve as a source of learning for citizens. Historic preservation for Lynch should support how people learn about the city and their collective memory. Rather than hiding change, he proposes celebrating it in various ways to prevent the stultifying results of some historic preservation as well as rapid change. Instead, he argues for "change management" that takes into account the dynamic aspects of environmental transformation. (Lynch, 1972, p. 238)

Lynch (1972) also proposes creating prototypes of future conditions that can be studied at full scale. The potential for ambient media and dynamic lighting in this domain are considerable. Traces in our environment provide cues for past events and give hints about the future. If the entire city can be transformed at nighttime then it could be considered a type of laboratory for future states. As the dynamic nature of nighttime becomes extended into daytime through increasingly bright media façades, these prototypical explorations will only increase in importance. These shifts transform what Lynch referred to as the "image" of the city –its iconic recognizability and appearance– into a dynamic and programmable element of place.

environment as a source of information about place and people

Communicating with Light

The communicative quality of light sources in the city has become obscured over time. Though street lighting and media displays convey information either indirectly (street lighting or illumination) or directly (displays or luminance) we do not necessarily think of them as mediators for communication among people in public space. They enable certain movements (wayfinding signage) or support certain types of conversations, but they are primarily one-way outlets. The following sociomaterial history of illuminated elements (lights and signage or symbols) takes a look backwards in order to envision alternative future figurations later in the dissertation because the seemingly anachronistic technical systems presage very sophisticated and cutting-edge devices that we can implement today.

Urban street lighting today is a networked, fixed infrastructure that relies on the electrical grid. In many places, residents take this system for granted and expect it to function reliably and automatically. However, street lighting originated as a personal, mobile technology for self-identification during the night in cities. In revisiting the evolution of street lighting from a hand-held device –the lantern– to a large-scale fixed infrastructure dependent on a centralized power source such as gas or electricity –public street lights– the communicative qualities of these systems become apparent. The words "communicative" and "communication" are used in the broadest sense throughout this section to mean an exchange among people as enabled by different technical systems. These exchanges can be very explicit or they can be very subtle, ambient signals.

Almost every technological shift brought with it an immense increase in brightness. We started with a simple open flame and have reached a point where lighting designers can precisely determine the number of lumens they need with very few upward limits. It is important to note that new systems were not driven by demand for more lighting, but rather by a complex interplay of social and political forces in conjunction with technical advances. Together, evolving practices of celebration, work and movement in public space generated the types of non-uniformly lit environments that exist in cities today.

The tension between street lighting for safety and other forms of lighting such as shop-front illumination for commerce and festivals characterizes the history of lighting. Rather than present these systems in a dialectical relationship, this thesis presents the tension between small and large sources of light, illuminating and light-emitting functions. All systems together constitute the urban lightscape and it is impossible to attribute the character of an urban neighborhood to one system or the other.

Early History: Fire, Torches, Lanterns

For most of history, human settlements have been plunged into darkness in the absence of natural sunlight or moonlight. The first lighting infrastructures for use outdoors developed as an extension of the cooking fire or hearth. Torches dipped in tar or other oils were used to light the way. Viking reenactments in the Shetland Isles, Scotland faithfully recreate the type of environment our ancestors would have experiences. Most other cultures of course also used torches for practical purposes and ritual.

Middle Ages: Lights-on-Bodies

Following on from the torch, the most universal lighting device across time and cultures was the lantern. O'Dea's (1958) drawings (part of his comprehensive study of the history of illumination) demonstrate some of the earliest Western examples using diffusers that were more affordable than glass like horn.

In medieval times, people were required by law to carry lanterns after curfew in European cities to mark their presence and signal that they were not engaging in nefarious activities. In addition, curfew marked the separation between the city and its surrounding territory reinforced by city walls. The "legal" night began with the Church tower bells sounding the last Angelus. (Armengaud, 2009, p. 49)

curfew rules

> "And no man walke after IX of the belle streken in the nyght without light or without cause reasonable in payne of empresonment" (English decree 1467) (Schivelbusch, 1988, p. 82)

> "Anyone who is found at an unusual hour in an unusual place without a light must submit to the strictest investigation." (Lehrbuch der Staats-Polizey-Wissenschaft, Johann Heinrich Jung, 1788) (Schivelbusch, 1988, p. 82)

The decree clearly demonstrates the policing and safety function lighting was intended to fulfill even in these early days. Urban historian Bouman (1987) describes the rapid increase in lighting as a result of increasing demand resulting from the resurgence of urbanism in the Middle Ages. Rapid population growth, the advent of a wealthier merchant class, increasing numbers of "nocturnal wanderers", and the first small-scale industrial production all increased the activity in the city.

Schivelbusch also makes a strong case for the interpersonal communication function of early street lighting: "Torches served to light the way, but their main function was to make their bearers, the forces of order, visible." (1988, p. 82) Indeed, the lights must have been so dim that they could not have served to illuminate more than the ground or objects within a person's immediate proximity. This fact again strengthens the argument that the light's primary purpose was to communicate presence in a dark urban context.

Navigation Lights: Lights on Buildings

The "mobile" systems lost some of their early communicative function as they evolved into the fixed infrastructure that we use today. As a first step in the move away from handheld lighting, city governments required citizens to affix lanterns on their buildings. By the sixteenth century building owners were required by Parliament to place a lantern on their building facade in London: "...during the months of November, December and January a lantern is to be hung out under the level of the first floor window sills before 6 o'clock every night. It is to be placed in such a prominent position that the street receives sufficient light." These elevated lanterns served as " 'navigation' lights (...) imposing a structure and order on the city at night." (Schivelbusch, 1988, p. 82)

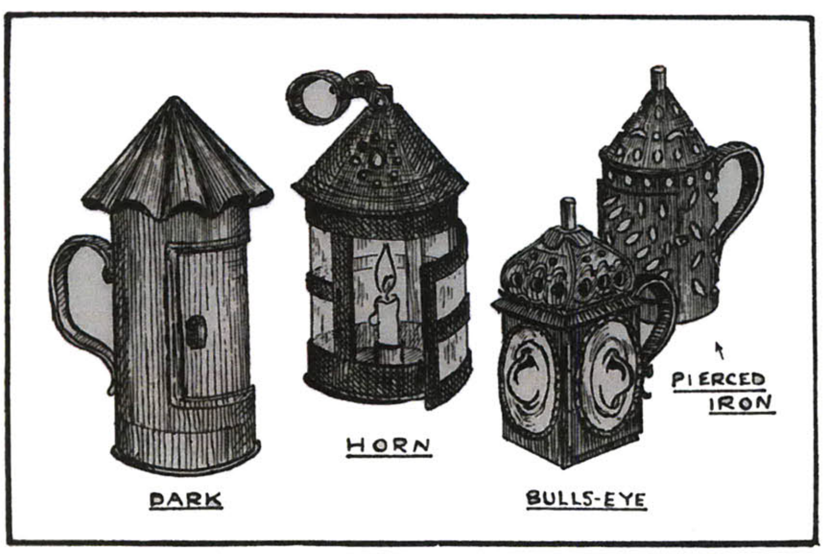


Fig. 2.3. Drawings of different types of lanterns. (O'Dea, 1958, Fig. 21. Lanterns)

Fig. 2.4. Watchman (1820), New York Public Library ID#1168473.

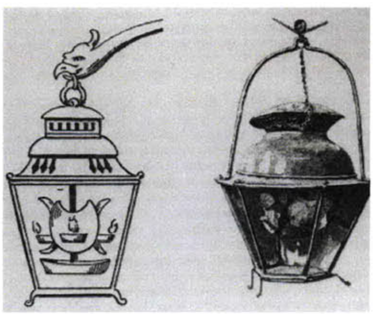


Fig. 2.5. Reflector lantern from Paris. (Schivelbusch, 1995, p. 92)

The decree's central intention was certainly to provide order and consequently it was believed to ensure safety. However, the lights also served to define the physical structure of the city. Considering that most of the environment was dark these small point sources of light must have created dramatic effects on existing streetscapes. Lynch describes the notion of "imageability" (Lynch, 1960) to explain how people recognize place. These navigation lights served to increase the imageability of the city at night by serving as highly recognizable landmarks in the otherwise uniformly dark environment.

Street Lights Separate from the Walls

Eventually, the beacons separated from the wall and evolved into lighting poles maintained by the state rather than individual property owners. Though the very first public street lighting may date back to the 4th century AD in Antioch and Alexandria (Bouman, 1987, p. 9) these public oil lamps were limited in their reach and quite dim. In Western Europe, the first public poles and cable systems for lanterns were introduced in the seventeenth century. Louis the XIV introduced lanterns suspended above the street in Paris. These later developed into the "réverbère" or reflector lantern (1763) which increased illumination levels significantly. (Schilvelbusch, 1988, p. 93) The reflector lantern won first prize in a competition to increase the efficiency of existing lanterns. It was so much brighter than previous lights that people could not imagine anything brighter. As with all advances in lighting technology each new generation of technology awed people with never-before-imagined brightness.

Even under Louis the XIV's improved lighting system, brightness levels were still insufficient to guide pedestrians at night and forced people to rely on the services of lantern bearers. In Paris, these mobile way-finders worked in collaboration with police and state surveillance. They would immediately report any suspicious activity. In London, they often colluded with the underworld to organize robberies or hold-ups. (Schivelbusch, 1988) Gradual technical improvements for lanterns such as multiple wicks, oil lamps and reflectors made these mobile torch bearers less important during the eighteenth century.

These innovations led to a gradual shift from lighting for identification and communication to lighting for illumination. Rather than relying on self-identification the state increased its control over the environment. Indeed, lanterns' association with the state often made them targets for revolutionaries in Europe from the end of the 18th century throughout the 19th century.

	...
400	Oil lamps in Antioch, Alexandria
1400	Gaslighting, Cordoba, Spain
1667	Public candle lanterns, Colbert, Paris, France
1669	Improved lantern design, Jan van Heyden, Amsterdam, The Netherlands
1673	Hamburg
1675	Turin
1682	Berlin
1683	Copenhagen
1684-1694	London
1688	Vienna
1690-96	Hanover
1697	Dublin
1701	Leipzig
	...

The adjacent timeline shows a partial history of the introduction of street lighting (mostly candle lanterns) in various cities. The history described here is mostly from a Western perspective due to the availability of sources.

(Koslofsky, 2002, p. 749; Schivelbusch, 1988; Gimpel 1977, p. 7 in Scotchmer, Innovation and Incentives, 2006; Bouman, 1987, p. 9)

Networks Emerge: Gaslight

At the dawn of the industrial revolution in the early nineteenth century in England, gaslight emerged in conjunction with industry. Streamlined processes demanded shift work which required lighting within factories. Thanks to the ready availability of coal, English industry could produce gas also known as "inflammable air" (Schivelbusch, 1988, p. 16) which was stored locally in gasometers and distributed within a complex through pipelines. The first gas lighting was installed at Watt & Boulton of Soho near Birmingham in 1802. In 1805, Phillips & Lee Cotton Mill in Manchester built the first fully-fledged system consisting of "retorts, gasometer, pipelines, valves, (...) mechanism for purifying the gas" (Otter, 2008, p. 19) Albert Winsor secured the first charter to distribute gas from a central location. He conducted huge outreach campaigns to extend the use of gaslight into homes. He touted the many advantages of gaslight: it could shine in any direction, it was uniform, required less maintenance, it was the first truly dimmable light, and for the first time the brightness of the light source justified a diffuser. The quality of gaslights differed significantly from the eighteenth century reflector lanterns. In Paris, one observer proclaimed, "Le gaz a remplacé le soleil." (Jules Janin, 1839 in Schivelbusch, 1988, p. 15) Gaslights elsewhere were described as "dazzingly white", "as bright as day", "an artificial sun" (Schivelbusch, 1988, p. 40).

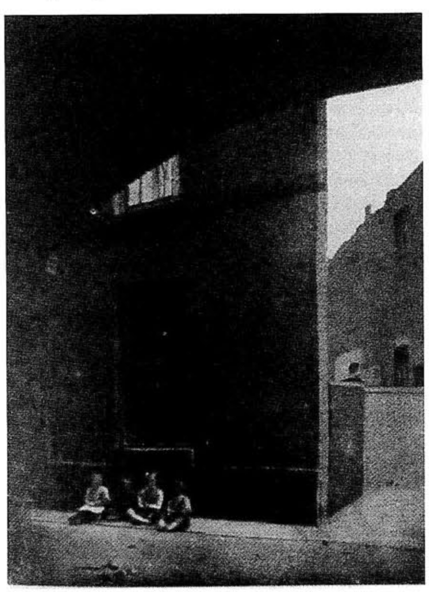
Gas light also brought many new dangers with it including poisoning, explosions, and serious pollution issues like the contamination of water reservoirs. In London, the most notorious gas explosion took place at the Nine Elms Gasworks in southeast London on October 31, 1865: "We now find ourselves encircled by about twenty of these dreadful magazines of discomfort, sickness and peril; converting thousands of tons of coal into coke and gas every day, necessarily accompanied by poisonous emanations, and an 'unavoidable accident,' at any one of which may, in the busy hours of day, or in the stillness of night, lay a neighborhood in ruins, and bury its inhabitants beneath them." (Thomas Bartlett Simpson, Cremorne Gardens owners, 1865 in Otter, 2008, p. 238)

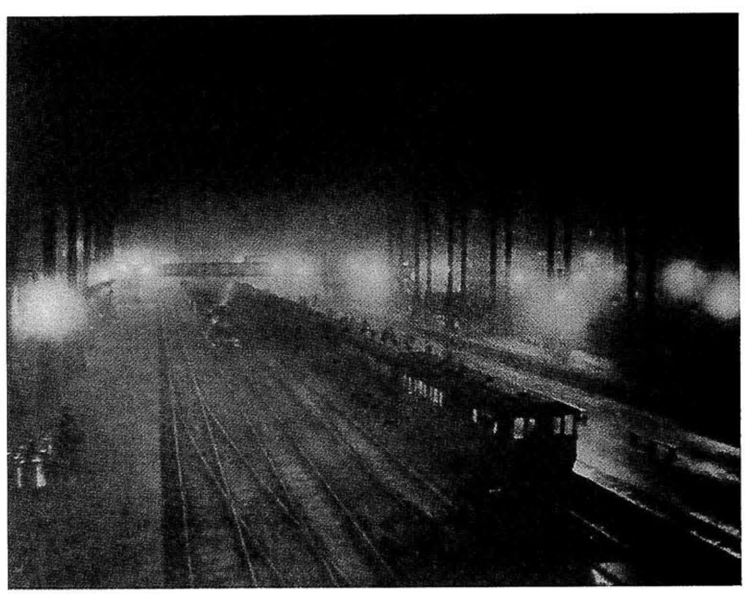
New Possibilities: Electricity

The first arc lights were installed in European capitals in the 1870s-80s. Jablochkoff lamps were the first electric lights installed in London in 1878 (on a viaduct, at the Gaiety Theater, and at the Sheffield sports stadium). In Paris, the Place and Avenue de l'Opera were illuminated with arc lights. In the United States the first arc lighting was demonstrated at the Philadelphia Centennial Exhibition in 1876 and the first public system was installed in Wabash, Indiana. (Jakle, 2001)

Fig. 2.6. (left) Otter shows that neighborhoods did not become uniformly lit during the nineteenth century despite the proliferation of illumination technologies. This image shows homes under a railway bridge in Ardwick, Manchester, 1904. (Otter, 2008, Fig. 2.7)

Fig. 2.7. (right) Early arc lights were extremely bright, but caused excessive glare and patchy illumination. Liverpool Street Station, London, 1909. (Otter, 2008, Fig. 5.4)





The difference of electric light to gaslight –which had only recently been introduced as well– was so significant that electric lighting was used as additional lighting for main streets and billboards rather than regular street lighting. Some critics did not approve of this trend because they considered electric light too bright and garish for the urban realm at night (Schivelbusch, 1988; Jakle, 2001). Electric lighting was also used to showcase the advances of industrial society such as skyscrapers and bridges and hide any disturbing side-effects of industrialization such as poverty, poor living conditions or bad sanitation (Nye, 1990).

Dappled Nighttime: Multiple Technologies Coexist

By the advent of gaslight and electric light, urban nights were no longer uniformly dark at night, but rather started to be characterized by very disparate lighting conditions which persist to some extent until today. Otter, a historian of lighting technology, refutes that gaslight led to an even glow across whole cities. Instead some areas became very bright and others remained dark. Throughout the nineteenth century darkness persisted in poorer neighborhoods as Otter documents in Manchester for example.

Gaslight and electric light coexisted until improvements to electric lighting and electricity distribution systems could be made. Electricity and subsequently electric light were still seen as a type of experiment. The first electric light installations emitted extremely bright light that

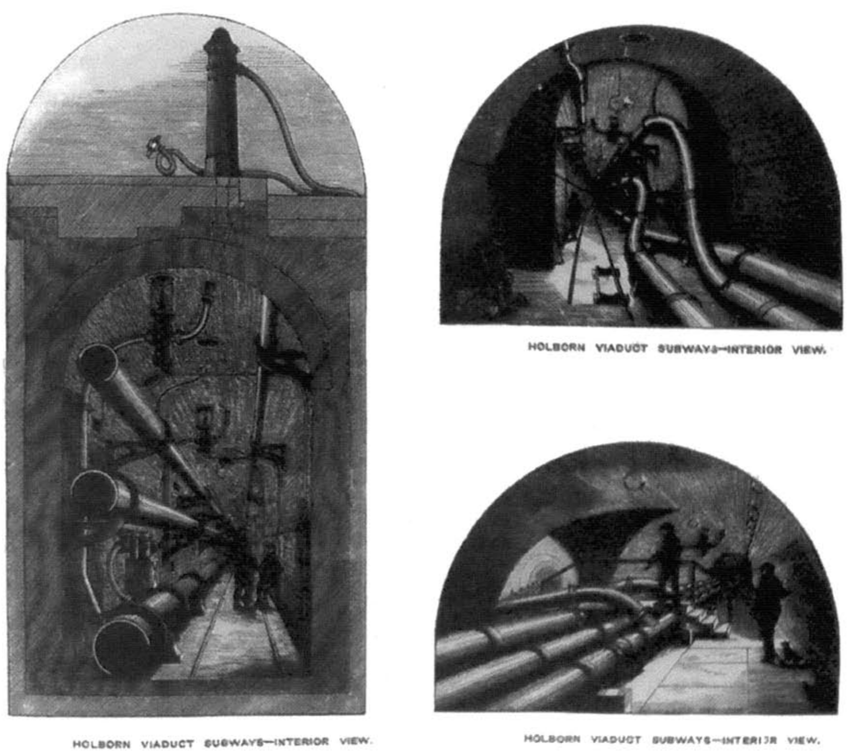


Fig. 2.8. Building new gas infrastructure in London, 1878-82. Holborn viaduct subways. (Otter, 2008, Figure 6.1)

caused significant glare effects. With the introduction of electric lighting the dappled nighttime became increasingly harshly lit. While gaslight still retained some of the naturalness of the flame electric light signaled the beginning of the artificial nighttime landscape.

Mass electrification led to a surge in interest for street lighting promoted heavily by utility providers. (Nye, 1990; Jakle, 2001). In less than a hundred years, the repertoire of lighting at night had expanded significantly and the notion of continuous levels of illumination throughout the city became viable. The transition from small, hand-held point sources of light to large-scale infrastructures reached its logical conclusion in the light tower proposals. Bouman (1987) describes the

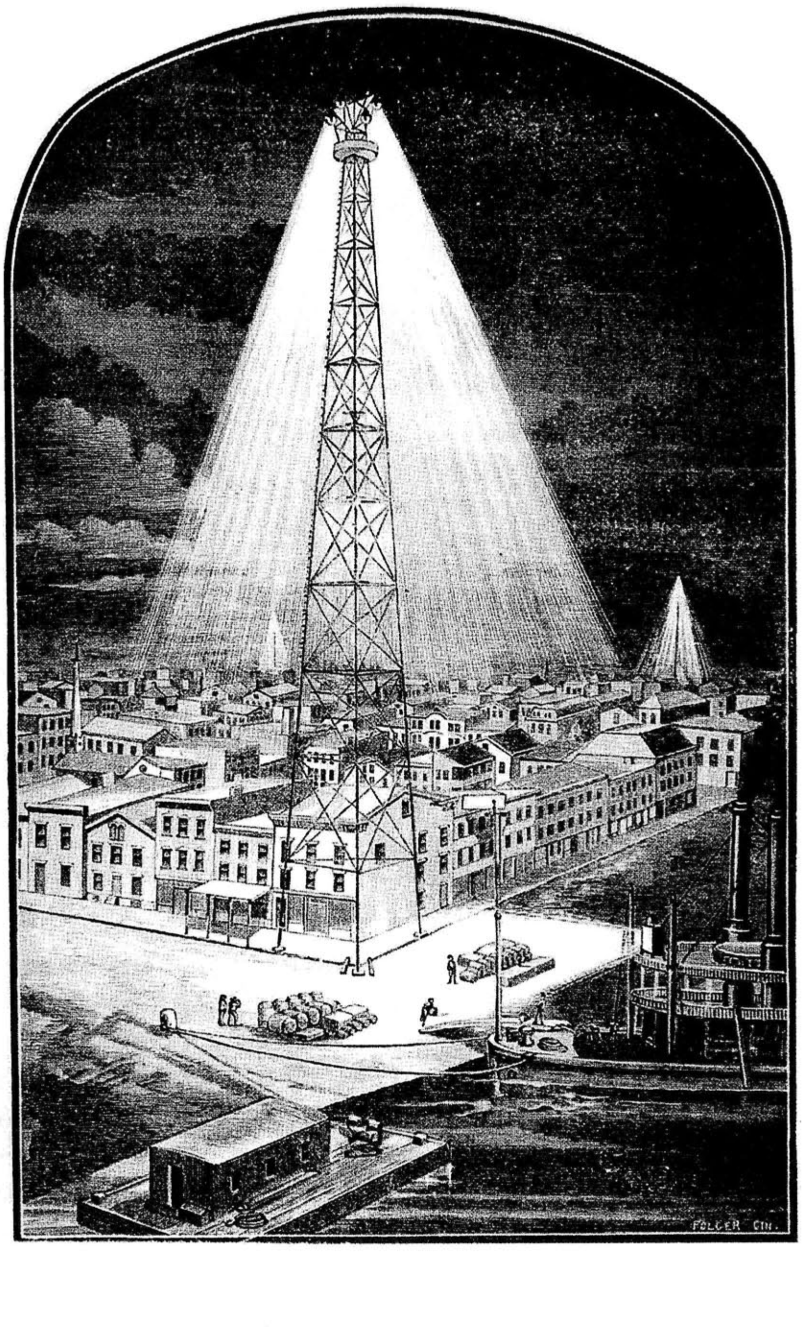


Fig. 2.9. Arc lighting placed at the top of a light tower. Advertisement for the Star Iron Tower Company of Fort Wayne, Indiana, Electrical Review 13, Feb. 10, 1889. (Jakle, 2001, Fig. 2.4.)

"electric moon" in Minneapolis erected by the Minneapolis Brush Electric Company (MBEC) in the heart of the city on Bridge Square in 1883. The 257-foot tall tower consisted of a "...riveted boiler plate and fitted with eight electric arc lamps" which were intended to outshine the existing gas lighting and demonstrate the superiority of electric lighting. Extremely bright, these towers were intended to replace all the small sources which required so much labor to maintain. They were implemented in American cities especially and still exist in Austin, Texas where they are historical monuments. Cities evolved from dark places with only a few flames to guide citizens at night to 24-hour environments under a permanent sun. However, the notion of one large light source for an entire city has not prevailed. Apart from many practical challenges such as shadowing, scale

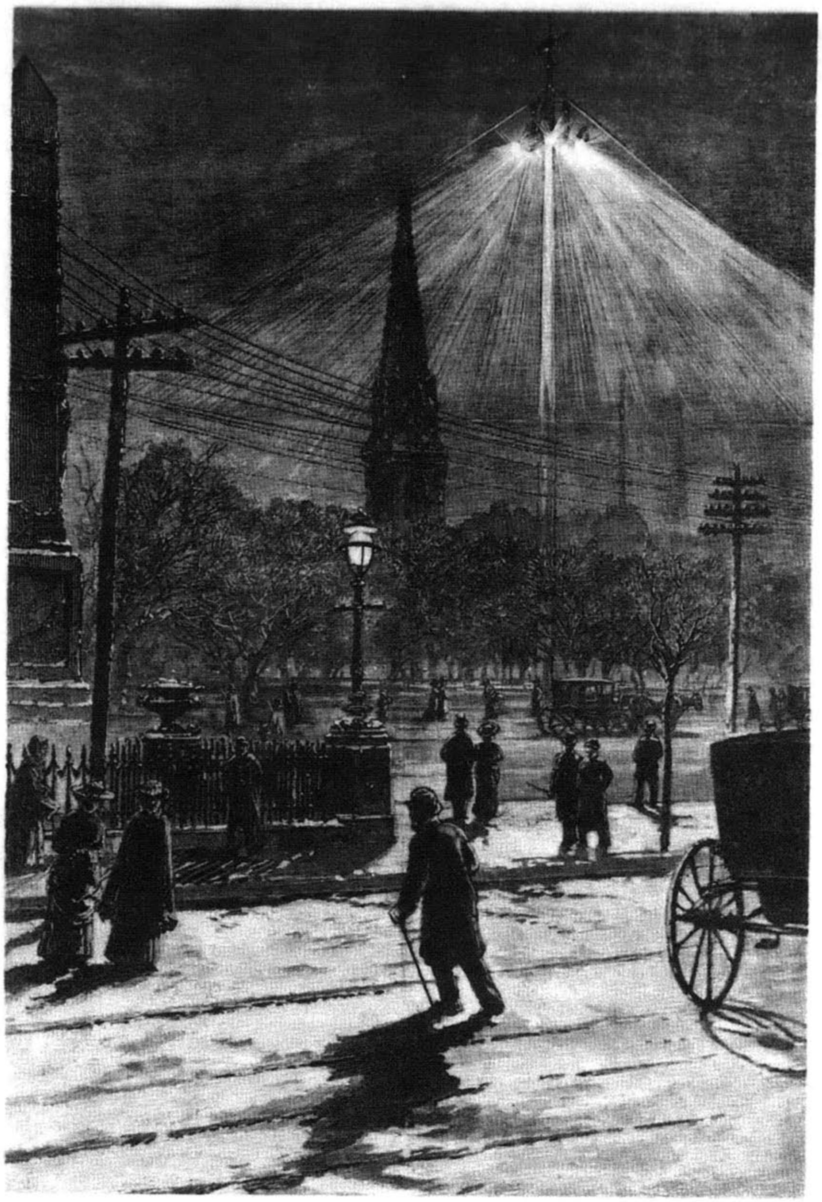


Fig. 2.10. Arc lamp, Madison Square, New York, NY. (Jakle, 2001, Fig. 2.3.)

artificial suns and moons

and cost, these systems were subsumed by a desire to place multitudes of small point sources densely together during festival times.

Celebrating the Night

The preceding discussion focused mostly on functional lighting and infrastructures. However, this history is also closely intertwined with the evolution of celebratory and festival lighting. The themes of function and aesthetics continue to be enmeshed today. As mentioned above the open flame as an individual torch or as a large bonfire was most likely humans' first experience of all light including celebratory light. During the 17th century baroque, large-scale nighttime celebrations were held at grand aristocratic palaces such as Versailles or Vaux-le-Vicomte (Fouquet, 1661, described by Jean de la Fontaine) pushing the boundaries of contemporary illumination techniques. Thousands of torches and candles made for shows of grandeur. The first fireworks complemented these extravaganzas. Representations from the period show the many small point sources of light which created a tapestry of twinkling and flickering. The open flames emphasizing the dynamism of the spectacle even more. As shown by the historian Koslofsky, the shift was part of "...a distinctive development of the late seventeenth century. Prescriptive and descriptive sources show mealtimes, the scheduled closure of city gates, the beginnings of theatrical performances and balls, and closing times of taverns moving ever later." (Koslofsky, 2002, p. 744)

intertwining function and celebration

The festival lighting from the courts increasingly extended out into the public realm of cities. Koslofsky writes about Leipzig, for example: "But the political symbolism of the Baroque court is evident in their [lanterns] use: the power of illumination, which bedazzled at the Dresden court, now served to secure and beautify Leipzig, at the same time muting resistance to absolutist control over the city council. The night and its illumination thus link the representational needs of Baroque monarchs with the practical expansion of urban public space and time." (Koslofsky, 2002, p. 761) This expansion did not necessarily seek to make urban streets more hospitable for ordinary people, but it did present an increase in the use of public space for more than emergency functions (such as midwives, night watchmen, and so on). A drawing of Leipzig lanterns shows a person reading by the light of a street lamp. This image does not imply that brightness levels were sufficient for such a task, rather it demonstrates that people of a certain status were meant to be outside more thanks to the effective street lighting

In the late eighteenth century and early nineteenth century, pleasure parks in England such as Vauxhall or Ranelagh made nighttime celebrations even more accessible to larger portions of the population. Paintings and drawings show long chains of light not unlike our holiday lighting today, small bulbs hanging from wiring. Though perhaps not always the most subtle light sources the emphasis remained on many lights rather than one large light source as the infrastructural thinking had proposed.

Fairs

Electric lighting was important for festive occasions from the beginning. The World's Fairs and the emergence of the Great White Ways in the United States became essential to city identity. Revolutionaries no longer destroyed light to hide in the darkness, but became part of the

Fig. 2.11. Leipzig Street Lighting Scene, 1702, Leipzig, 1891 (Koslofsky, 2002, p. 758).

urban citizenry that enjoyed bright lights in cities at night (Jakle, 2001). Throughout the nineteenth century large-scale festivals later dominated by electric lighting became popular. Starting with the World's Fair and Paris (1881) and up until the 1920s in the United States enormous fairs and exhibitions included impressive lighting displays. Like moths to a flame, people flocked to palaces of electricity, showrooms for different types of light bulbs, and buildings trimmed in lights.

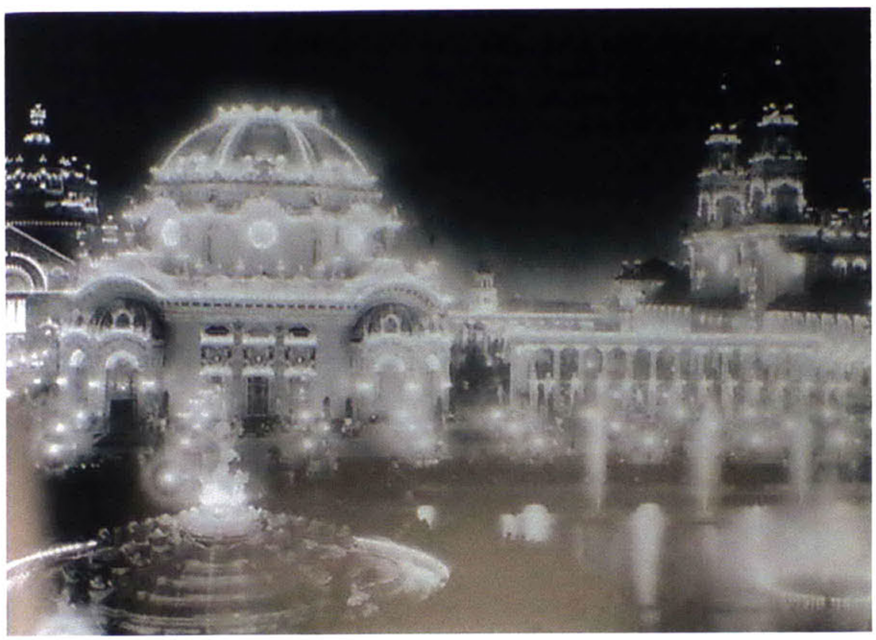


Fig. 2.12. Temple of Music and Machinery, Panamerican Exposition, Buffalo, NY, 1901. (Neumann, 2002, p. 91)

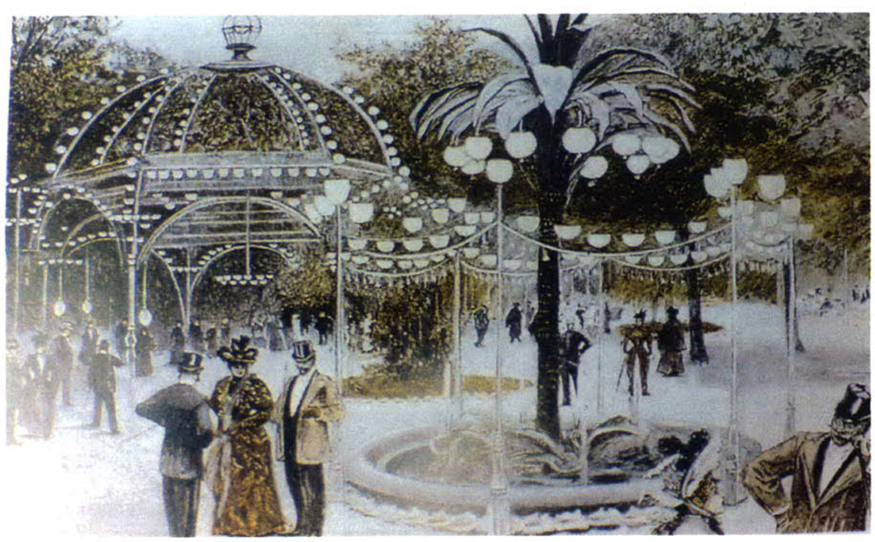


Fig. 2.13. Krollgarten at night, Berlin, 1900. (Neumann, 2002, p. 18)

Retail Lighting

In addition to special events and festivals, retail lighting developed into a central feature described in European city guides. Schivelbusch (1988) sees these commercial, retail lights as sublimations of Baroque lighting festivals and carnivals: "What we think of as night life includes this nocturnal round of business, pleasure and illumination. It derives its own, special atmosphere from the light that falls onto the pavements and streets from shops (especially those selling luxury goods), cafés and restaurants, light that is intended to attract passers-by and potential customers. It is advertising light – commercialized festive illumination – in contrast to street light, the lighting of policed order." (Schivelbusch, 1988, pp. 137-143)

Many of these commercial festive lights were situated along boulevards, a central invention of 19th century European urbanism. The construction of large streets with broad sidewalks ideally configured for strolling also included street lighting and festive illumination (cafés, storefronts, signage). (Armengaud, 2009, p. 71) Through this bright lighting, the boulevard became just as accessible and safe at night as during the day. People flocked to the bright lights at night thanks to the combination of infrastructure and morphology in the boulevard. Enjoying leisure at night became an accepted and safe activity for the urban citizenry.

The Light Bulb as Pixel

Animated billboards and electric signage harnessed the power of the new lighting grid for communicating large-scale advertising messages. Composed of arrays of light bulbs, these displays emerged from the same infrastructure availability as ubiquitous street lighting and represent the seed for the evolution of animated display technologies today, for example, the EPOK programmable display (see references for link to imagery and historic footage).

Lichthunger – Hunger for Light

Urban cultures embraced the potential presented by new types of advertising and retail lighting. Caught up in a "Lichthunger" (translated from German this term means "hunger for light") following the First World War, people flocked to the lights. In "Spazierengehen in Berlin", Franz Hessel writes about a band of quickly running light-advertising. (Spazierengehen in Berlin: "eilig laufendem Band der Lichreklameflächen" (Marte, 2006, p.28) Most street lighting served vehicles and roadways while pedestrian zones were almost entirely lit by illuminated retail stores, advertising and festive lighting.

Again reinforcing Otter's work, it is important to note that these illuminations did not truly transform night into day. They still left much room for experimentation and preserved nighttime as a counter-culture to daytime where more was permitted. Despite the increasing safety and surveillance function of light, this ambiguity became a central feature of urbanity and reinforced disparities among neighborhoods.

Capturing the Effect of Light

Painters were among the first to capture the narrative quality of light developing different techniques over the centuries. One of the most striking techniques in painting emerged during the 16th century: chiaroscuro. This technique involves the strategic insertion of bright elements within a painting or the juxtaposition of light and dark within a scene. These effects add to the drama of a narrative or highlight a particular aspect of the painting. The technique also impacts how viewers interpret the three-dimensionality of the scene. The use of light in these image marks a cultural shift away from a dialectical approach to light and dark. Rather than using light to symbolize good and dark to symbolize evil, these paintings employ light to reinforce the dramaturgical and narrative quality of the painting signaling a turning point in Western civilization. (Armengaud, 2009)

The dramatic and narrative effect of light is demonstrated by chiaroscuro. However, other painters such as William Turner tried to capture light in a more experiential way. In an effort to capture the drama of an outdoor scene, he and later the Impressionists worked with color as well as light-dark effects. Rather than representing a storm with dark colors alone he chooses dynamic swirls of pastels, grays, dark and light which draw the viewer into the center of his scene. (Blühm & Lippincott, 2000, pp. 120-121)

The narrative approach to light and dark effects also carried forward into specific genre paintings. Nocturnes are an example of a genre that

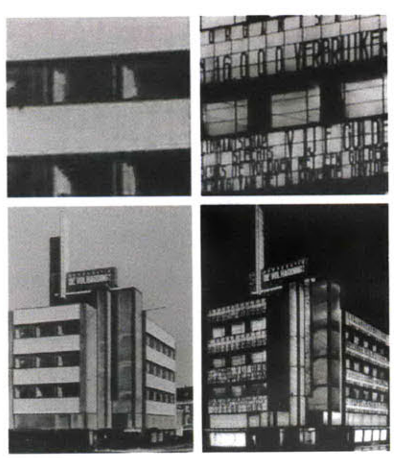


Fig. 2.14. De Volharding Building. (Neumann, 2002, pp. 132-133)

German "light architecture" in the 1920s and 30s. The De Volharding Building, for example, in The Hague is covered in opal glass which appears white opaque during the day and reveals text and symbols when back-lit at night. (Neumann, 2002, pp. 132-133) makes use of chiaroscuro, usually to render a nighttime landscape. Vernet's Night in a Port in Moonlight shows the juxtaposition of the eerie moonlight reflecting on the harbor and the warm glow of the camp fire. The moon emphasizes the depth and distance of the sky/horizon while the fire seems to reach out to the viewer of the canvas. Rembrandt's Nightwatch represents the drama of a dark night in a social setting with hundreds of figures barely lit by an invisible light source.

During the nineteenth century, nighttime scenes were incorporated into furniture or cases that would permit an actual light to be placed behind the image. "Transparencies" were used to illustrate dramatic scenes such as the eruption of Mount Vesuvius. Perhaps these devices could be considered the first back-lit screens. (Blühm & Lippincott, 2000) The 19th century brought forth a host of other inventions that

Fig. 2.15. Franz Niklaus König, The St. James Fires at Lake Brienz, ca. 1815, watercolor, display case for diaphanoramas, Kunstmuseum Bern. (Blühm & Lippincott, 2000, p. 97)

use back-lighting with natural or artificial light for viewing images. These technologies demonstrate the blending of light sources that illuminate space with glowing artifacts that emanate light. The layering further becomes more complex in that the objects are portraying light sources.

The relationship between content and pixels is similar to the reaction between paper and the original (matrix) during a printing process.

Relationships between Substrate and Image

The importance of content for illuminating signage introduces a new mode of communication for lighting systems through the use of images. As alluded to earlier, artists and all image-makers embraced the role of light for creating meaning in their paintings or art works. It is important to tie the shift towards "programmable" displays back to the earlier creation of media where artists paid close attention between the layers of information, the connection between substrate and image.

Fig. 2.16. Erwin Blumenfeld, 1946, reprinted 2008, City Lights, C-type print, 40x30 cm.

The relationship between message and substrate engenders a certain materiality which becomes integral to any art-work and many mechanisms have been explored in the visual arts for exploring this relationship. For example, print-makers have long been concerned with the material quality of the image they create. This material quality arises from the relationship between the image) and the substrate (paper in print-making, screens or networks of pixels in the digital context). Ivins studied this relationship in great detail as the first curator of the Metropolitan Museum of Art in New York's print collection: "(...) William M. Ivins, Jr., examined the microstructures of various print media, explored related conventions for depicting tone, curvature, texture, and so on by means of line and dot patterns, and discussed the ways in which these have rebounded to structure our ways of seeing the world. (...) Ivins suggested (...) that 'objects can be seen as works of art only in so far as they have visible surfaces. .... The magic of the work of art resides in the way its surface has been handled.'" (Mitchell, 1992, p. 76)

Digital programmability confounds traditional mechanisms for matching message and substrate because of the replicability of digital data (Mitchell 1992). Zooming into a digital image does not reveal additional details beyond the point where the grainy pixilated structure emerges. A painting or photograph cannot be reduced to its component parts in the same way. Analog artists have experimented with the qualities of individual points. From pointillism to Andy Warhol artists have worked with deconstructing their images. The inspiration to take away for urban scale displays from this discussion consists in the image of the city as a substrate with the same complex qualities print-makers and painters recognized in their substrates.

Fig. 2.17. Alfred Stieglitz, Icy Night, New York, 1898. Photogravure, 5 x 6 3/8" (12.7 x 16.2 cm). Transferred from the Museum Library. © 2010 Estate of Alfred Stieglitz / Artists Rights Society (ARS), New York. (MoMA, The Collection, www.moma.org/collection/browse_results.php?object_id=51840)

"real picture-making" (Stieglitz)

Photography and Film

Photographers and filmmakers identified their ability to edit nighttime landscapes through the strategic placement of light. The ability to manipulate representations of the city is central to Stieglitz's pioneering nighttime photographs of New York which he began taking in the 1890s: "Such imperfections (like halations) introduced (...) life into nighttime images and recreated what the photographer saw as he exposed the image. This was 'real picture-making,' as opposed to a mere topographical view." (Woods in Neumann, 2002, p. 69) For Stieglitz, the flexibility of the night-time setting unleashed the photographer's true creativity.

Taken to the extreme, Stieglitz's approach leads photographers and filmmakers to distill entire cityscapes to points of light and dark. This reduction changes the spatial cues viewers typically use to interpret representations of three-dimensional space in Western, perspective-based culture. In Film Sense, Eisenstein describes the effect, which he perceptively links to electrification: "All sense of perspective and of realistic depth is washed away by a nocturnal sea of electric advertising. Far and near, small (in the foreground) and large (in the background), soaring aloft and dying away (...) these lights tend to abolish all sense of real space, finally melting into a single plane of colored light points and neon lines moving over a surface of black velvet sky." (Eisenstein 1942, 1975, p. 98) Blumenfeld's skyscraper landscape (1946), illustrates how this technique allows the photographer to subvert representations of space.

ambient lighting as a holistic, spatial experience

Going 3D: Licht-Raum Modulator

The avant-garde movements in Europe moved art history away from narrative features towards more elemental aspects of human perception. Early 20th century Paris saw the revolutionary use of light with dance by Loie Fuller which was captured by many contemporary artists. The importance of "modeling" three-dimensional space started to become a central theme in art. Rather than working within two-dimensional worlds to create three-dimensional effects, these artists worked with all materials to move towards dematerialization. (Marte, 2006, p. 22) Moholy-Nagy based his theories of design on the dynamic tension between different elemental forces. In Material zu Architektur (1929), he writes that creating spaces is the inexplicable Balance between tensions and pervasive spatial energies ("Raumgestaltung ist das unbeschreibbare Gleichgewicht gebundener Spannungen, das fluktuieren einander durchdringender Raumenergien." In Marte, 2006, p. 23) In order to create and design these effects, he used light-reflection, pervasiveness and transparency.

Moholy-Nagy aimed to create environments that mimicked the evolution of surroundings, a second layer of information perhaps that

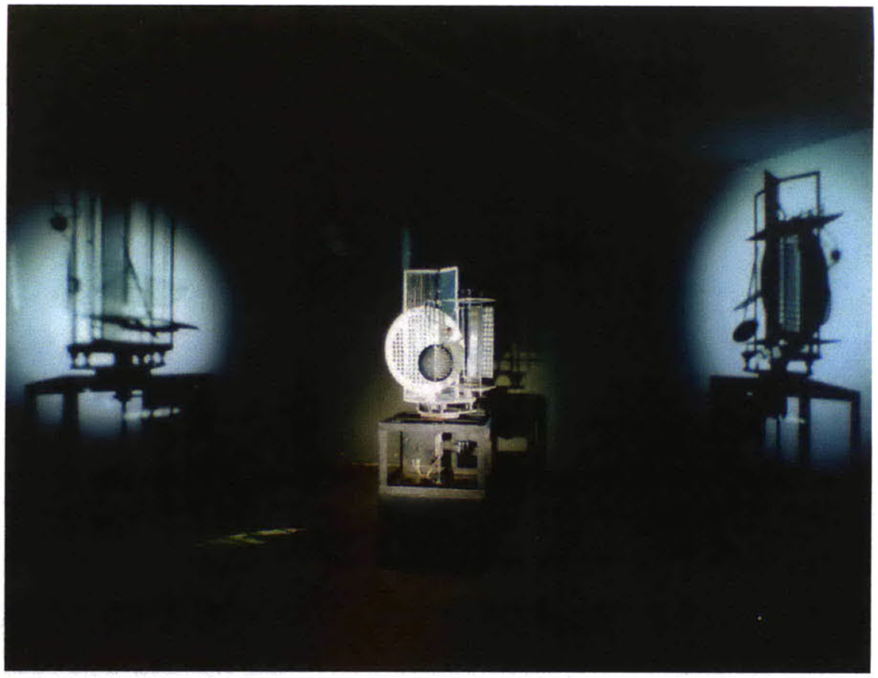


Fig. 2.18. Laszlo Moholy-Nagy. Licht-Raum Modulator. 1922-30, replica 1970. Eindhoven Design Museum, The Netherlands.

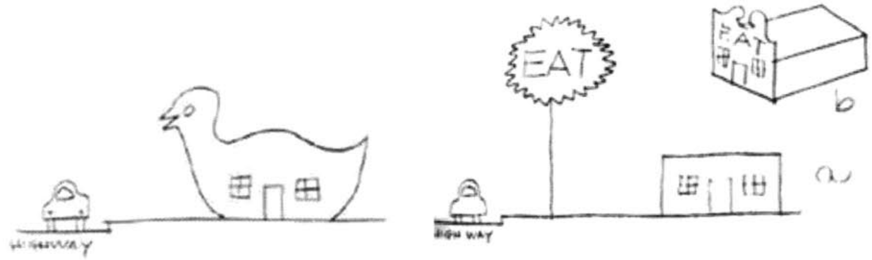
enveloped urban forms. In this way, he anticipated some of the potential for embedded dynamic media facades. Unlike entirely virtual environments, he also rejected a complete dematerialization. He emphasized the back-and-forth between material and immaterial which determined the raw physical experience as much as its dynamic and ephemeral nature. (Marte, 2006, pp. 37-38)

War eventually destroyed the general euphoria around light and light architecture. Artificial and moonlight at night became associated with the dangers of war. Blackouts to protect from bombers doused people's excitement for bright city lights. The dangers of walking on streets during blackouts enhanced people's apprehensions about being outside at night. Suddenly, urban lights became a danger rather than a sign of hope and progress.

Lines of Light – Gaseous Discharge Lamps

Moholy-Nagy's experiments begin to give shape and form to light. New technologies such as neon lights provided a new playground for designers to cast light into shapes. The first experiments with gaseous discharge lamps (mercury vapor) took place during the 1930s. (Jakle, 2001) The increased efficiency and brightness of these technologies quickly overtook the existing electric lights (arc or incandescent) and remaining gaslights in most cities. Still today, most of our public lighting is provided by high-pressure gaseous discharge lamps (high-intensity discharge lamps (HID) such as metal-halide or high-pressure sodium vapor) for roadways and low-pressure gaseous discharge lamps for pedestrian zones (low-pressure sodium vapor). These lamps emit different colors – from the

Fig. 2.19. The duck (above) and the decorated shed (below). Venturi, Brown, & Izenour (1998, 1972)



familiar yellow glow of the sodium lights to bright white. Neon signage takes advantage of the colors produced by Neon gas for information displays.

Gas discharge lamps are much more efficacious (lumens/watt) than any other form of lighting. For example, low-pressure sodium vapor lights produce almost 200 lumens per watt (compared to a standard incandescent of 25 lumens per watt). However, low-pressure sodium (LPS) lights do not provide good color rendering. In other words, the human eye cannot make out colors under this light. In most cases, however, other ambient light from spaces where dynamic lighting effects and new experiences were emerging.

Neon/Venturi/The Strip

Bob Venturi and Denise Scott Brown studied the urban realm and the role of signs and symbols in the 1970s in Las Vegas (1972), interpreting the meaning of infrastructures of imageability as a culturally rooted phenomenon. Their research on The Strip led them to a closer analysis of the relationship between signs and built form. They found that The Strip had separated signs from architecture leaving nothing but a shed behind an enormous sign. Meaning was embedded in the sign and not the architecture. This typology exists in contrast to what they called the "duck" in reference to a walk-in fiberglass duck on Long Island where the sign and the architecture had become synonymous. In a more recent book called "Architecture as Signs and Systems" Venturi and Scott Brown (2004) revisited some of their earlier hypotheses, but reiterate their position towards architecture "as sign rather than space".

Times Square today

Venturi reviews many examples of what he calls "explicit mannerism" including two buildings in Times Square: the Morgan Stanley building on Broadway between 49th and 50th and the Morgan Stanley Dean Witter building on Seventh Ave. and 50th Street both designed by KPF: "Viva the facade as computer screen! Viva facades not reflecting light but emanating light - the building as a digital sparkling source of information, not as an abstract glowing source of light!" (Venturi & Brown 2004, p. 94) Venturi touts the vibrant ornamentation and dynamism these buildings contribute to public space. The architecture itself blends into the background while the sign and the dynamic programming are positioned in full view.

Light-Emitting Diodes (LEDs)

Just like neon enabled a new shaping of glowing artifacts, LEDs are enabling new arrangements and configurations of illumination. In 1962, Nick Holonyak, Jr. developed the first red LED. On winning the MIT Lemelson prize in 2004, the inventor said: "I wanted to work in the visible spectrum where the human eye sees, and everybody else was working in the infrared." Today, LEDs are used in almost all traffic lights, billboards, outdoor video screens, displays and a host of electronic devices. (Holonyak, 2004). The inventor unleashed a trend that has gradually led to the use of LED lighting across the spectrum of lighting and display applications: stage lighting, effect lighting, outdoor displays and signage, indoor home lighting and outdoor street lighting. For a long time LEDs were only efficacious for use in effect lighting indoors or outdoors. However, the base lighting indoors and outdoors is increasingly also being provided by LED lights.

The primary benefits of LEDs compared to other light sources are their low power consumption and easy programmability. Unlike many other technologies, LEDs can be modulated very quickly without damage to the device. As a result, designers can program everything from subtle changes of brightness to fully fledged video animations for LED-based systems. They lend themselves to large-scale installations of many small point sources of lights. The drive towards increasing lumens/watt, however, has led many companies to focus more on brighter LEDs rather than on integrating systems. Kevin Dowling (Former CTO of Philips ColorKinetics) emphasized at a Smart Lighting Workshop (February 2010) the importance of integrating power infrastructure and programmability with LED-based system in order to make the promise of LED lighting come true. Much like Hughes (1983) describes Edison's genius in creating an electrical infrastructure network around the electric lightbulb, LED lighting requires a network of software and new power electronics as well as optics to continue its successful rise.

Challenges for LED lighting exist on many fronts. For outdoor applications, especially for base lighting, there is still a need for more data on LED luminaires' long term performance. In some cases, they may also require a significant infrastructure investment to accommodate different voltage requirements and new communications connections. Indoors as well as outdoors, the type of light emitted by LEDs still surprises some users who prefer the familiar warm glow of incandescent light bulbs (though the broad use of compact fluorescent (CF) energy savings lamps has already displaced most of these lights in the indoor market). For outdoor effect lighting and display systems, LED-based systems require new maintenance schedules to remain up-to-date and engaging for citizens over time.

The following overview focuses entirely on urban, outdoor contexts which span several different applications: base lighting, signage, signal lighting, architectural effect lighting, billboards and large-scale display systems. These applications span display functions and lighting functions even though they are based on the same fundamental element: the LED. The fine-grained controls made possible by LEDs are giving way to a host of more sophisticated and intricate "smart lighting technologies" that blur many different lighting functions.

Issues with the Quality of LED Lights

With the introduction of LED street lighting uniformity of light and glare are once again of central concern. At Lightfair 2009 in New York, LED street lights (Fig. 3.2.) appear almost like oversized shower heads with bright light specs to cover larger areas more uniformly. There are also other challenges which need to be resolved, such as the need for vertical light to illuminate pedestrian's bodies as they cross streets at night at or outside of cross-walks also causes increased glare.

There are also many challenges related to retrofitting existing luminaires. Many communities do not want to replace streetlights that have become a characteristic part of the visual landscape and is further complicated when new bulbs are too large to be accommodated by historic luminaires. In some cases too, for example on the Vienna Ringstrasse, experiments with solar-powered LED lights by the designer Ross Lovegrove led to an uproar in the community about the character of the historic town center. (Fig. 3.4.)

Pervasive Computing Visions for Urban Environments

The Initial Ubiquitous Computing Vision

In 1991, Mark Weiser proposed ubiquitous computing (ubicomp) as his vision for 21st century computing. In his article, Weiser describes how future environments will be suffused with miniaturized computers or computing power in the form of tiny microprocessors. These networked devices provide a responsive, interactive background for our interactions with digital information while we remain grounded in physical space.

Interaction Principles for Ubicomp Environments

Abowd, Mynatt and Rodden (2002) describe particular interaction principles for a ubiquitous computing environment. First, interaction with these environments is not always explicit. Therefore, devices must "incorporate implicit actions into the subset of meaningful system input". Research within computer vision and multimodal recognition technologies (speech, handwriting, etc.) addresses this challenge. Second, the output of digital information is necessarily distributed across multiple modalities and must accommodate all kinds of form factors. Weiser described three scales of interaction at the inch, the foot and the yard to capture varying needs in diverse physical settings. According to Abowd et al. (2002), output channels should enable us to "easily move information between separate displays and coordinate the interactions between multiple displays." Further, they should support "displays that are less demanding of our attention." Third, ubiquitous computing should support a "smooth integration between the physical and virtual worlds." These visions depend on the network of artifacts as Greenfield writes: "The power and meaning we ascribe to it [this experience] 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 there in the world, (...)" (2006, p. 16).

Many challenges are unresolved in this vision such as the need for extensive, connected and compatible infrastructures. Also, a recurring theme is that everything in the environment becomes information. In this dissertation, I sometimes fall into this trap as well, but it should be noted here that this assumption should be challenged and carefully considered before moving forward with such a powerful metaphor for configuring future spaces.

taking an infrastructural view of ubicomp visions for the future

Expanding the Context for Ubicomp

The traditional focus for computing has been the office or work environment. However, ubicomp has contributed significantly to more interest in diverse settings such as the home or urban environments. McCullough goes so far as saying that ubicomp technology has reinstated the role of place in computing: "Digital ground is shorthand for a complex proposition: Interaction design must serve the basic human need for getting into place. Like architecture, and increasingly as a part of architecture, interaction design affects how each of us inhabits the physical world." (McCullough, 2004, p. 172)

The shift away from standard work environments presents a challenge for researchers. And very few systems are actually in effect long enough to overcome novelty effects with the exception of the XeroxPARC Tivoli Capture System and the Georgia Tech Classroom 2000/eClass System (Abdowd et al., 2002) They call for more long term installations which can be monitored as living laboratories.

In response to more complex surroundings, Abowd et al. (2002) stress the need for more diverse evaluation methods in order to capture findings in situations that are not task- and efficiency-oriented. Williams and Dourish call for an approach that expands the horizon of urban computing: "While urban computing has focused primarily on the city's image as a setting and container of action, we argue instead for viewing the city that we experience every day as a product of historically and culturally situated practices and flows." (Williams and Dourish, 2006) In addition, there has been less emphasis on the types of infrastructures necessary to realize the promises made by ubiquitous computing as Grinter et al. (2009) have shown for example in connection with home networking. Collecting data from several studies in the USA and the UK, the researchers showed that individuals spend significant time and resources managing their home networks. This effort is rarely discussed or acknowledged as a central concern for ubiquitous computing and the implied vision for future living.

Ambient Displays

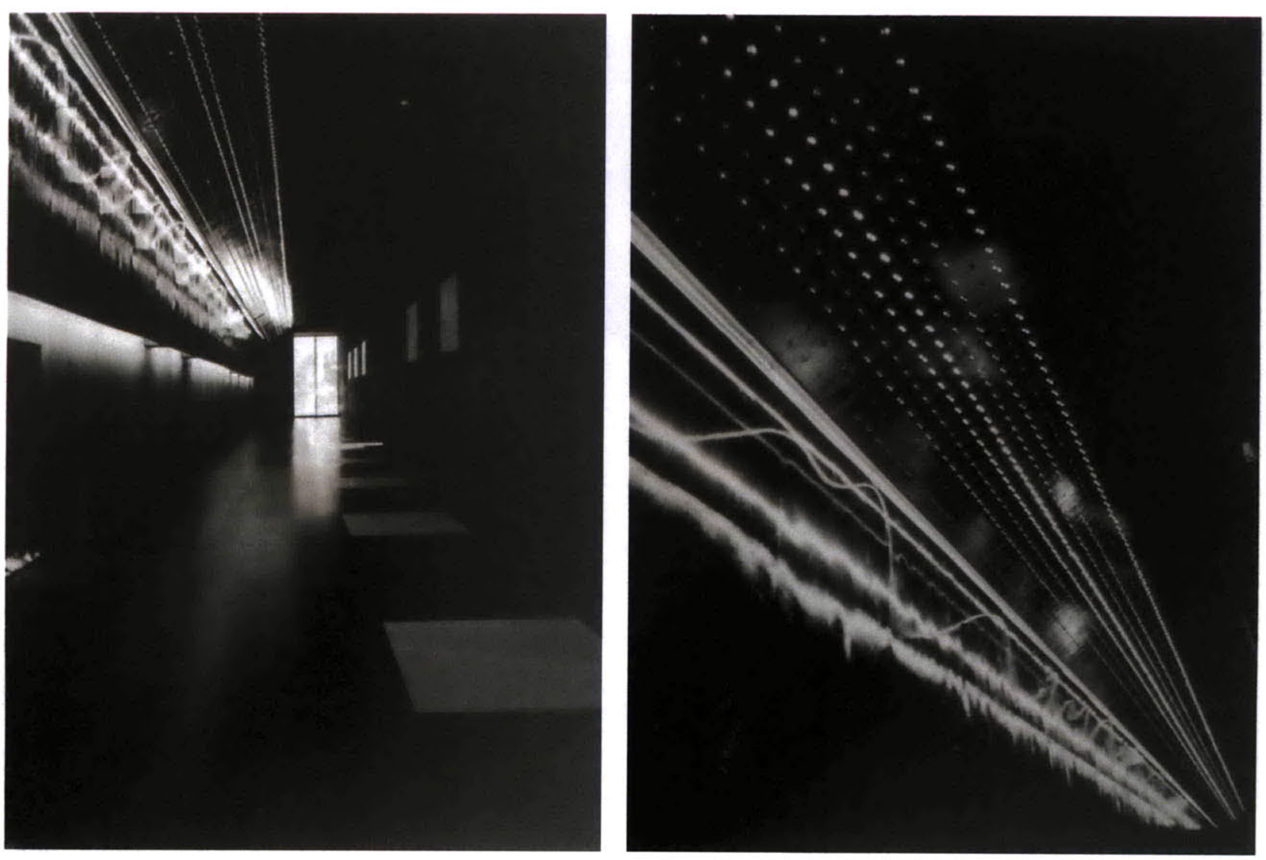
In Washington D.C., the metro is announced by a row of lights embedded in the ground on the edge of the platform like the lights in an airport runway (see red lights embedded in the adjacent image). When the train is about to arrive the lights are animated in a simple wave that unobtrusively announces the approaching train. People do not shudder at the sound of a loud announcement nor are they interrupted in their conversations or reading. And they are not craning their necks to catch a glimpse of the just-in-time information system providing the exact number of seconds until the next train (and the succeeding five trains). Despite its limitations this simple example provides some important lessons for thinking about light, display, and urban environments. First, the strategic location on the edge of the platform signals to people that they should not walk there and draws their attention to the location where activity is about to happen. Second, the context makes the message meaningful because the light and the space are reinforcing each other without competing for people's attention. Third, the calm, ambient message is signaled through a simple animation of low-resolution pixels that are spaced at a significant distance one from the other especially when compared to the distance among pixels on a typical screen. These lights are of course implemented in a limited, functional way that does not support easy reconfiguration. Nevertheless, this example begins to

exact vs. ambient displays of arriving trains in public transit express the power of using light and display in consort and sets the stage for thinking about liberated pixels throughout the city.

Ambient information systems exploit the power of our split attention between center and periphery. (Want et al., 2002; Norman, 1998) In his seminal articles on ubiquitous computing, Weiser described the Dangling String installation by artist Natalie Jeremijenko to illustrate the power of ambient displays. The movement of the string gave people an instant sense of network traffic in the building without requiring significant attention on their part. (Weiser, 1991)

Tangible computing also includes the premise that tangible objects are coupled with calm, peripheral displays that do not interfere with the central object of inquiry. Ishii and Ullmer showed some examples using projection and other media in AmbientROOM (Fitzmaurice, Ishii, Buxton, 1995; Ishii, Ullmer 1997; Underkoffler, Ullmer, Ishii, 1999; Ishii 2008) One tangible strategy for regaining the tension between substrate and image and retaining the programmability and changeability of digital images is to give the pixel a physical form (Heaton 2000). The notion of physical pixels can be traced back to ubiquitous computing, tangible computing and ambient displays. By exploiting humans' peripheral perception

Fig. 2.20. Exhibit design by Gyorgy Kepes, Thomas McNulty, with Mary Otis Stevens, La forma della città di notte. Palazzo dell'Arte, XIV Milan Triennale May-July 1968. (Zardini, 2005, p. 46-47)



physical ambient display systems expand our ability to glean information from the environment. Chapter 4 includes more detailed precedents including explorations involving flexible and frameless displays that start to imply more architectural and visual-spatial effects. Chandler, Finney, Lewis, & Dix (2009) begin to chart some of this territory in their paper on "blended displays" by which they mean displays that work in concert with the environment.

Urban Pattern Languages

reading urban form through light

The preceding history has focused on the sociomaterial qualities of different lighting and display technologies as they have been introduced into various urban settings. The following section moves to the urban scale where I claim that many of the consequences of successive

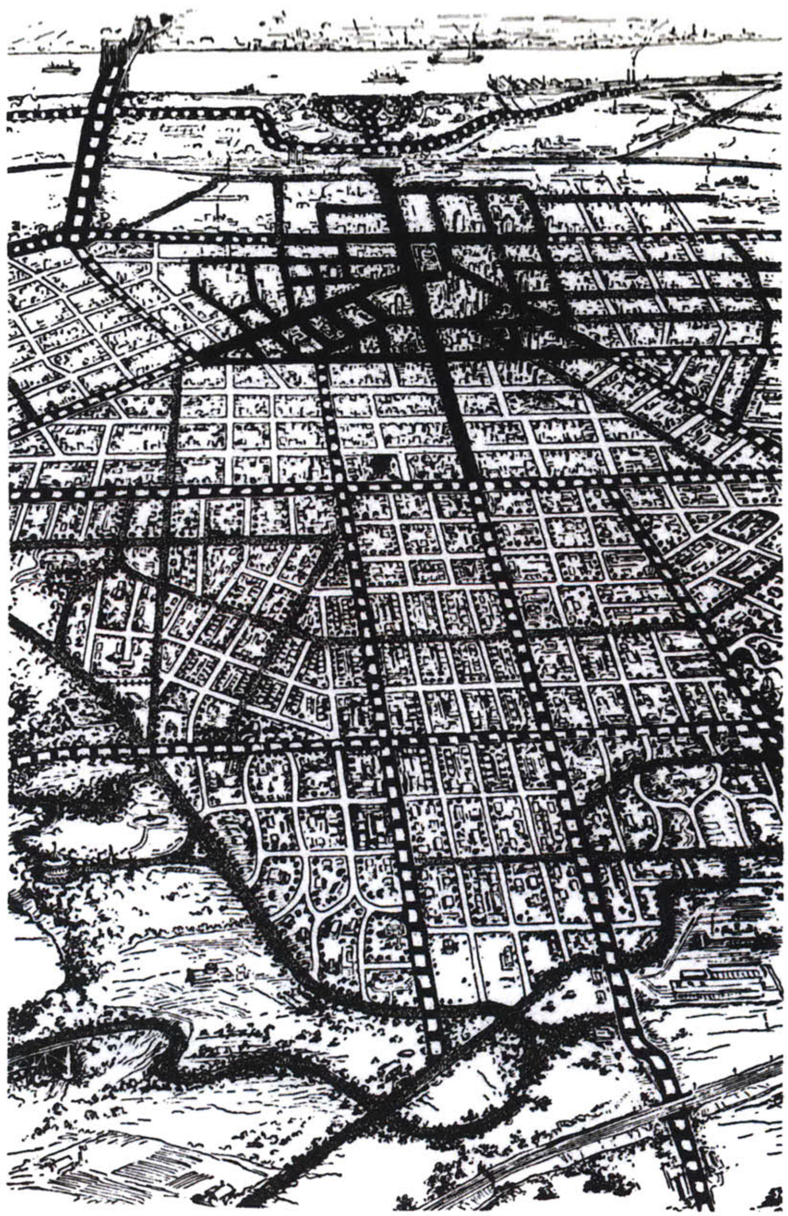


Fig. 2.21. Lights zones of a fictional city with bright zones and moderately lit zones differentiating the busy commercial districts from quieter residential areas, 1930. (Jakle, 2001, Figure 5.7.)

waves of technology can be traced. In particular, urban forms become programmable and changeable as a result of different lighting and display placements. Architects, artists, photographers, filmmakers and painters recognized these possibilities early on and continue to do so. This section traces some of these contemporary and more recent precedents.

Armengaud argues that cities are more characteristic at night than by day. In our time of globalization, the nighttime scenery often brings out the particularities of a place. For example, the Shanghai Bund is unmistakable at nighttime. Signature buildings such as the Chrysler Building in New York are associated with particular lighting effects.

In 1968, Gyorgy Kepes, Thomas McNulty, with Mary Otis Stevens designed a "nocturnal landscape" which was a "multisensorial installation to recapture the quality (stimuli) of the city at night": (La forma della città di notte. Palazzo dell'Arte, XIV Milan Triennale May-July 1968): "In all major cities of the world, the ebbing of the day brings a second world of light. This world is not the world of daylight, the world of a single light source, clear, friendly and legible. But neither is it the world of darkness-shadowed, mysterious, terrifying-loosened by the sunset upon men in the natural state. It is the world of man-made light sources, the glittering dynamic glow of artificial illumination of the twentieth-century metropolis."(Fig. 2.20., Kepes, 1965 in Zardini, 2005)

The excitement about artificial lighting expressed by Kepes has been somewhat tempered today due to environmental concerns and energy conservation.(*) Establishing more fine-grained principles for urban nighttime lighting is a nascent domain, especially in so far as ambient, experiential factors start to play a key role. French (landscape) lighting designer, Roger Narboni describes current practices: a "divide has arisen between those who wish to treat public nocturnal space as a congenial

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*On a side-note, despite the energy savings made possible by LEDs it is important to note that more light is not always desirable. Organizations like the Dark Sky Association have been calling the public's attention to light pollution for years. Nighttime skies above cities can be more than 100 times brighter than undeveloped areas. Apart from the energy losses, natural processes such as bird migration and human sleep cycles are impacted by high levels of stray light. Typically, engineers have focused on developing more energy efficient, directed light sources and reducing the number of overall lights. Reconsidering the connections between display and lighting can provide a new road into planning holistically for nighttime urban environments by exploring the potential for programmability and distributed control systems.

Fig. 2.22. Visual comparison of some contemporary display and media projects. This is just an excerpt of a more comprehensive study which would exceed the scope of this chapter.

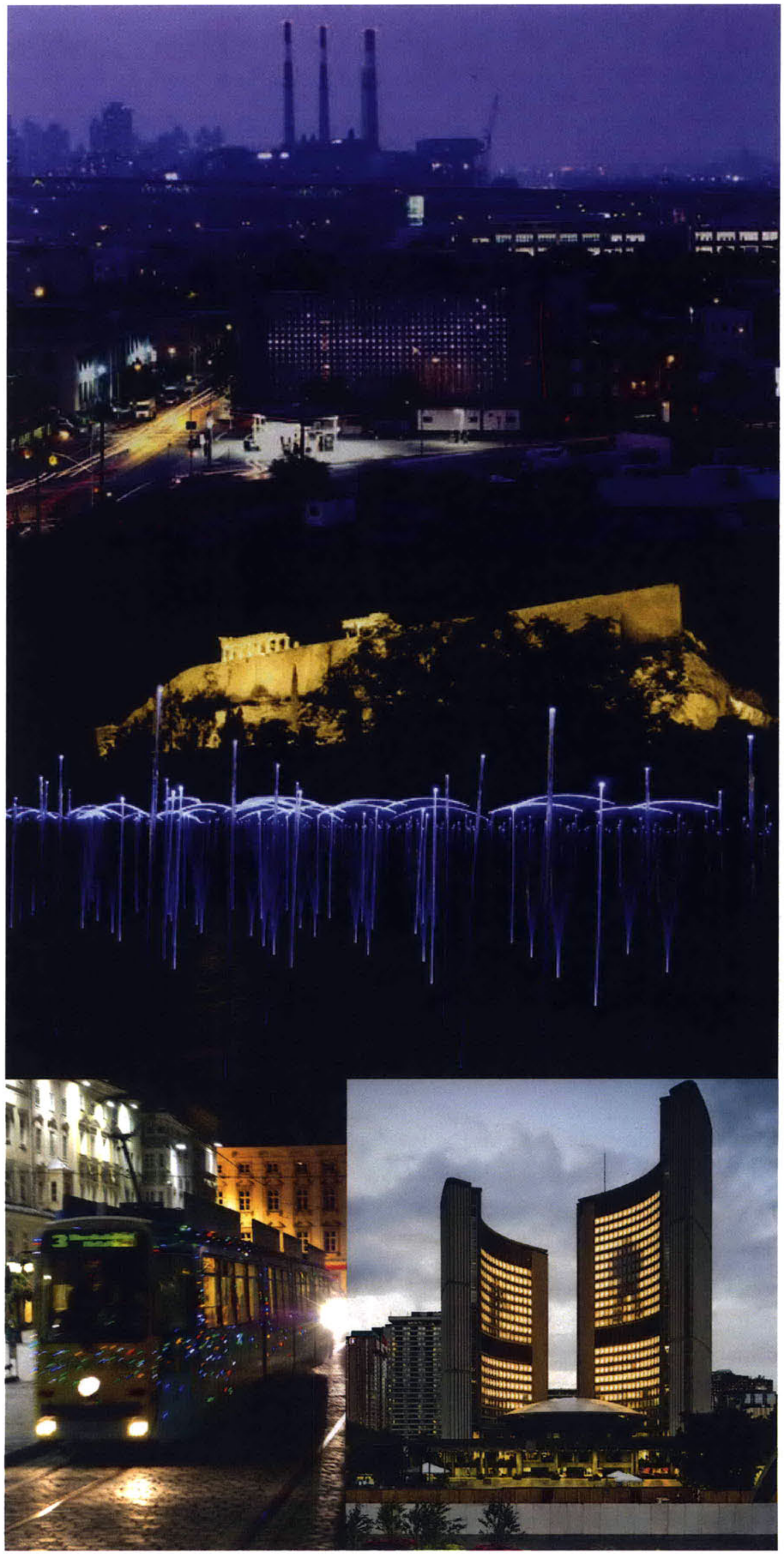
From top to bottom, left to right:

Leo Villareal, Supercluster, 2003. White LEDs, custom software, electrical hardware, suspension material. Installation view. Image courtesy of Gering & Lopez Gallery, New York.

White Noise White Light. Photo courtesy of courtesy of J. Meejin Yoon / MY Studio.

Tram with Throwies. Excerpt of photograph by http://flickr.com/photos/urban_data/243453680/

Blinkenlights installation at Toronto City Hall, Canada, 2008. Excerpt of photograph by http://www.flickr.com/photos/wvs/2909334414/



From top to bottom, left to right:

Yann Kersalé, La ville-fleuve, 1991-1998. © Yann Kersalé - AIK in Aubiron, P. (2004). Futures Past: Twenty Years of Arts Computing. http://www.chart.ac.uk/chart2004/papers/auboiron.html

Allianzarena in blue, Munich, Germany. Photograph by http://www.flickr.com/photos/hcii/61614000/

Laser Tag on a building façade. Photograph by http://www.flickr.com/photos/urban_data/396087351/

Rafael Lozano-Hemmer, "Body Movies" (2002). Linz, Austria. Photo by Antimodular Research.

place for daily living, and those who prefer to encourage the realisation of spectacular effects and the proliferation of monumental illumination" (Narboni, 2004, p. 12). Through the artificial lighting landscape cities become recognizable by their light patterns. Different urban forms –such as the Boulevard mentioned earlier – can be identified based on their pattern of illumination.

German lighting designer Ulrike Brandi (2004) describes how a new trend towards creating lighting master plans in Europe is taking hold. She has developed plans or partial plans for Rotterdam, Bremen, Hamburg, Hanover, Oldenburg, and Dresden. Other cities like Siena have also developed fully-fledged lighting master plans. (Armengaud, 2009, p. 110) While during the daytime the weather plays an enormous role in determining the character of a place, at night artificial light takes over. According to Brandi, the term lighting master plan was first used in the German-speaking world in conjunction with a comprehensive planning project for the Expo 2000 Hanover. The fair provided an impetus for thinking comprehensively about a neighborhood and its nighttime character through light. Brandi believes that dense European cities require a particular lighting response that accentuates the particularity and character of different places. She also observes how cities have attempted to use lighting to revitalize downtown areas under pressure from suburban shopping developments.

Media Facades

In addition to urban forms, media façades themselves have taken on more diverse shapes. In the world of media façades, the side of a building becomes an expressive, dynamic element rather than a one-time architectural statement, for example:

appropriating facades

- Using the building as interface: Blinkenlights transformed the façade of the Haus des Lehrers in Berlin into the world's biggest interactive computer display. People could also create their own animations such as the heart shown here via a program called Blinkenpaint.

building as interface

- Appropriating and interacting with public facades through projection: Laser Tag by Graffiti Research Lab allows people to project graffiti onto a building. Body Movies by Lozano-Hemmer are interactive projections that composite shadows of people currently in the plaza with portraits taken on the streets of the city. Contemporary artists and designers use projection and animation to achieve these very same reconfigurations. (Lyon Light Festival, Kersale, Lozano-Hemmer, Wodiczko, Graffiti Research Labs, Troika and many more) In Nantes, France, Yann

Kersalé transformed the cathedral into a river of flowing water in La ville-fleuve (1991-1998). Rather than highlighting the cathedral's architectural features he chose to convey a new message at night about the city's river-based economy.

placing individual pixels

- Placing individual pixels: Throwies by Graffiti Research Lab are deployable pixels consisting of a coin-cell battery, 10mm diffused LED and magnet.

networking pixels

- Connecting individual pixels: Supercluster by Leo Villareal is an early example of a building-scale digitally programmable façade. The system consists of 640 LEDs distributed across a 45 by 120 foot display that covered the entire façade of PS 1 museum in New York.

architecture as ambient display

- Transforming architecture into ambient display: At the Allianz Arena, Herzog and de Meuron created façade of inflated ETFE-foil air panels that can be transformed with colored light. The ambient display usually signals the colors of the competing teams.

landscapes with pixels

- Creating landscapes with pixels: White Noise White Light, Meejin Yoon was shown at the Athens Olympics 2004. The piece demonstrates the transformative effect of light in a landscape and as a new landscape to be inhabited by visitors.

Social Life in the City and Urban Screens

Urban activist and media researcher Mirjam Struppek has been exploring the "social potential of urban screens" in an effort to enroll them in the project of reinvigorating public spaces. She challenges actors shaping the public sphere to consider the social and cultural role of the multiplying programmable surfaces. She imagines functions such as supporting local community development, supporting social networks in neighborhoods or engaging directly with the public through soliciting feedback via large screens. (Churchill, Nelson, & Denoue, 2003; O'Hara, Glancy, & Robertschaw, 2008)

Safety

The social function of screens connects to the earlier history of lighting and its close connection to safety and policing functions. The Outdoor Lighting Guide differentiates between "lighting to deter" and "lighting to reveal" fulfilling three basic principles (Bean, 2005, pp. 258-265):

- To provide illumination to assist the detection of intruders
- To avoid shadows which might offer concealment
- To deter an intruder by creating an environment of potential exposure.

In public spaces, regular street lighting must accomplish some of these goals. Perception of safety plays a central role in making people feel comfortable: "An important feature of security lighting is to make things appear to be bright. This does not necessarily mean that large quantities of light have to be provided. It is often possible to simply direct light towards the wall of a building so that the intruder will be seen either as a lit figure or as a silhouette against the bright building depending on which side of the lighting fittings he is standing." (Bean, 2005, p. 261)

The history of introducing street-lighting and display technologies demonstrates the impact visual infrastructures have on people's subjective experience of spaces. For example, lighting technologies impact people's perception of safety in surprising ways. Too little lighting can lead people to feel unsafe. Too much lighting can have a similar effect if people feel that the space is over-lit. Jacobs described the ambiguous relationship

Fig. 2.23. Lights are equated with small policeman increasing safety in city streets by scaring away thieves and muggers, Electrical Review and Wester Electrician 56, May 21, 1910, p. 1053. (Jakle, 2001, Figure I.1.)

between lighting and people's perception of safety on city streets: "Good lighting is important, but darkness alone does not account for the gray areas' deep, functional sickness (...) Thus the lights induce these people to contribute their own eyes to the upkeep of the street. (...) Street lights can be like that famous stone that falls in the desert where there are no ears to hear. Does it make a noise? Without effective eyes to see, does a light cast light? Not for practical purposes." (Jacobs, 1961, pp. 41-42)

Tillett Lighting Design completed a project for the New York City Dept. of Transportation in Brooklyn (1995-1998) that illustrates Jacobs' point. Linnaea Tillett convinced the City to install ornamental lighting at civic buildings and places of local pride such as the library and community center rather than the problem corners of the neighborhood. This design proved more effective in increasing safety and the perception of safety in the neighborhood than over-lighting the streets with strong gaseous discharge lamps. (Zardini, 2005, pp. 84-85)

German lighting designer Ulrike Brandi stresses the importance of qualitatively assessing the outcome of a design: "Well thought-out design, however, is based on darkness, the opposite (of turning night into day). It conceives light reciprocally, not glistening, colourful, bright, competing, but as an initialisation into the changing times of day and the seasons." (Brandi & Geissmar-Brandi, 2007, pp. 87-88) The affective and contemplative nature of shadow was also pointed out to me by a colleague from Karachi, Pakistan where she observed that the suffis turn off the street lighting near their temples to assist people in focusing on

Fig. 2.24. These two images from Marie Sester's project ACCESS juxtapose the performative possibilities with surveillance in public settings.

Sester, M. (2002-2003) ACCESS, Ars Electronica, September 2003. Photo by: Marie Sester. http://accessproject.net/archives/pictures/pictures1.html

their prayers. In meditation, of course, it is also customary to close the eyes to facilitate an inward focus. In the case of Karachi, Pakistan these purposeful dark moments contrast with the many inconvenient power outages. In these times, brightly lit advertising signage becomes the focus of street life because those signs are outfitted with their own generators. Street life as usual then goes on under local and global brand displays.

Some interactive lighting installations intentionally exploit the sociomaterial re-configurations of space to illustrate the tension raised in the Karachi example. Interventions have been inspired, for example, by stage lighting design and the established ways of using theatrical lights to support meaning making. Using a spotlight, Sester has created an elegant juxtaposition of the stage and urban setting. In ACCESS (Sester, 2002-2003), she programs a spotlight to follow people, and, in doing so, demonstrates how a personal "limelight" can impact the sense of being in a place, as well as provocatively questioning modern systems of surveillance.

Fig. 2.25. Louis XIV Medallion (1667), Paris introduces independent lighting system - beginning of policing function. (Schivelbusch, 1988, 1995, p. 86)

Fig. 2.26. Visions for mobile street lighting. Lyon workshop. (Philips , City, People, Light, 2007, p. 37)

The sociomaterial history of lighting and display and precedents emphasize several aspects of the relations between people, light and urban environments:

sociomaterial themes

- Narrative
- Ambient, peripheral information
- Change over time
- Blending of functional and aesthetic
- Communicative functions
- Portable versus fixed systems

These themes inspired the design explorations to be discussed in the following three chapters (see Fig. 1.5.). In order to link the current chapter with the discussions following the design explorations, I introduce three meta-themes which emerge from the sociomaterial history. First, our urban environments consist of patchworks rather than blanket-lit settings which I refer to as the tension between building artificial suns and designing pixilated landscapes. Second, the lack of uniformity provides opportunities for personalization, anonymity, possibility, but also danger and insecurity. Finally, the technologies deployed to support all these activities shape the image of the city over time. I refer to these systems as infrastructures of imageability.

seeding alternative narratives

These theoretical themes anticipate the final chapters of the dissertation and are intended to open alternative spaces for lighting future cities. (Swan, Taylor, & Harper, 2004, pp. 20-21) Others such as Philips have also speculated about this future. For example, Philips has developed a series of inspiring design investigations entitled city.people. light. In considering Asian cities, the lantern tradition played a significant role in the re-imagining lighting for cities. The lanterns serve both as a cultural reference and as a precedent for mobile lighting devices. The historical and cultural context of Asia provides a strong justification for envisioning a type of product that does not exist yet. With this grounding, the editors write: "Personalization will meet dematerialization. It is a natural evolution cycle for technology to move from public to personal and to shift from fixed to mobile domains." (Bevolo, Philips, 2007) They go so far as to speculate on how much longer we will have fixed infrastructures for lighting and suggest, in the near future, we will be surrounded by very tiny pixels or share mobile light objects for temporary appropriation.

Of course, Philips has its own motivations for envisioning supplemental forms of street lighting and, consequently, any "natural evolution" from public to personal should not be taken for granted. Again, historical precedents are instructive; the transition from lantern-carrying to fixed-in-place reflector lanterns in 17th century Paris demonstrates how specific decisions by Louis the XIV's administration were a driving force behind the implementation.

We gain some sense of the interplay of shaping forces in an allegorical representation on a Louis XIV medallion from 1667 (Fig. 2.25.) commemorating the introduction of fixed street lighting. A figure holds out a lantern illuminating the night, ostensibly for the public's benefit. A similar gesture means something very different in a Philips scenario sketch. A person reaches for a mobile light object that will enable him to move freely about the city at night. The juxtaposition of visions reveals the associations made with lighting in each period: collective liberty on the one hand and individual independence on the other. Whether in the past or looking towards the future, we discover lighting and its uses emerge from a complex assemblage of "sociomaterial reconfigurations" that is by no means predetermined by any intrinsic or "natural" characteristics of a technology. (Suchman, 2007)

Chapter 3
Augmented Reality Street Light

As described in the previous chapter, urban lighting infrastructures have undergone rapid change in the last two hundred years. Advances in LED lighting technology for illumination in addition to effect lighting have increased municipalities' interest in renewing their lighting infrastructures to reduce energy costs. This chapter explores another take on retrofitting that goes beyond replacing bulbs and ballasts to explore the evocative potential of responsive and dynamic infrastructure. As an incremental step towards more fundamentally different technologies, the Augmented Reality (AR) Street Light serves as a playful introduction

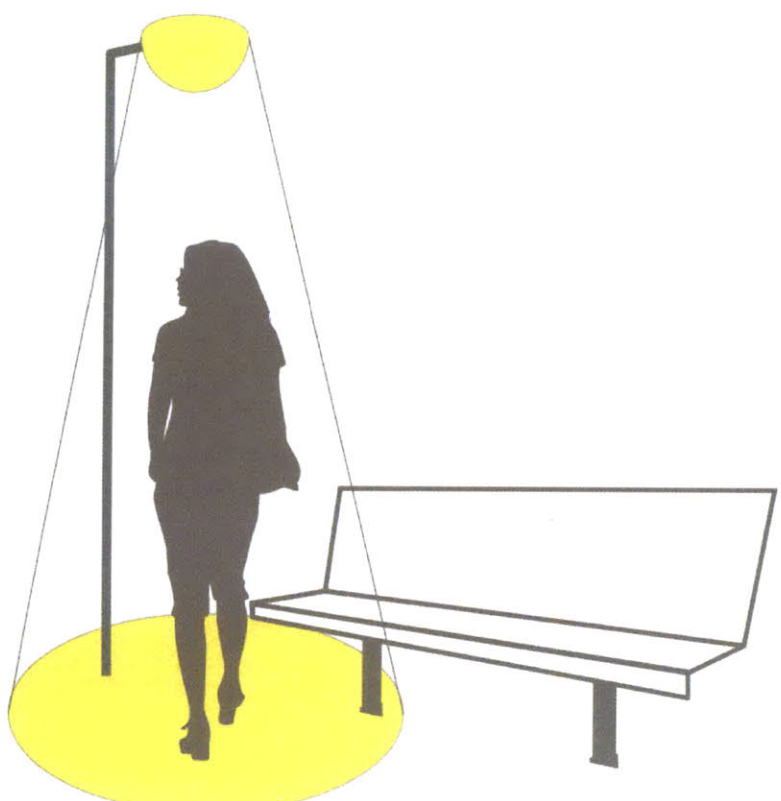


Fig. 3.1. Diagram of the AR Street Light responding to the presence of a person.

Fig. 3.2. Various existing LED luminaire designs.

Top left: Marlin LED Street Light.

Top right, Bottom left; LED luminaires shown at 2009 Lightfair International in New York, NY.

Bottom right: GE's Evolve™ LED Cobrahead Street Lighting System.

to the interventionist component of this dissertation. By experimenting with movement and responsiveness the LED-based street light comes alive and suggests more interactions with public infrastructures. For example, street lights could respond to hand-held devices and change colors as people select them. This functionality would assist people in finding each other at night. The brightness of individual lights could be connected to the paths people select. In other words, the street lights could illuminate in anticipation of a pedestrian movement patterns.

Fig. 3.3. Philips LED luminaire which responds to different ambient light conditions.

Converting to LED Street Lighting

Environmental considerations have motivated many city governments to explore the potential of converting their street lighting to LED-based systems. The US Dept. of Energy and industry initiatives such as the CREE-sponsored LED City project have supported this transition. The real benefits as subsequently argued in this chapter is the opportunity for programmability with LED-based street lighting can offer. As a baseline, the following are some well-publicized examples of cities from around the world that have already converted their infrastructure or are exploring the possibility with public tests as documented by The Climate Group's Lightsavers project as of December 2009:

- Anchorage, Alaska, US: 4,000
- Tianjin, China: 2,200
- Nova Scotia, Canada: 1,100
- Ann Arbor, Michigan: 1,000
- Los Angeles: 800

As more cities around the world convert their street lighting to LED-based systems, programmability becomes a free added bonus. Even though the driving factor for conversions and retrofits is related to long-term cost savings thanks to reduced energy requirements, new applications will be enabled that require more fine-grained approaches to the distribution of illumination. More light where it is needed and when it is needed has been a recurring theme in street lighting. In Germany, Dial4Light allows people to turn street lights on and off using a text messages. On board sensors as well as cameras and projectors could enable a similar functionality just using sensors.

There are many practical and playful application examples that could be explored given the inherent programmability of LED lighting in conjunction with affordable electronics:

- Traffic signaling, traffic safety
- Bicycle lighting
- Emergency management

- Sensing and monitoring of the environment, e.g. parking availability, activity levels, environmental conditions such as temperature and wind
- Festivals, large-scale events
- Integration with personal devices, allowing people to temporarily "appropriate" street lights (in pedestrian zones)
- Using illumination as projection, every light as a mini-projector

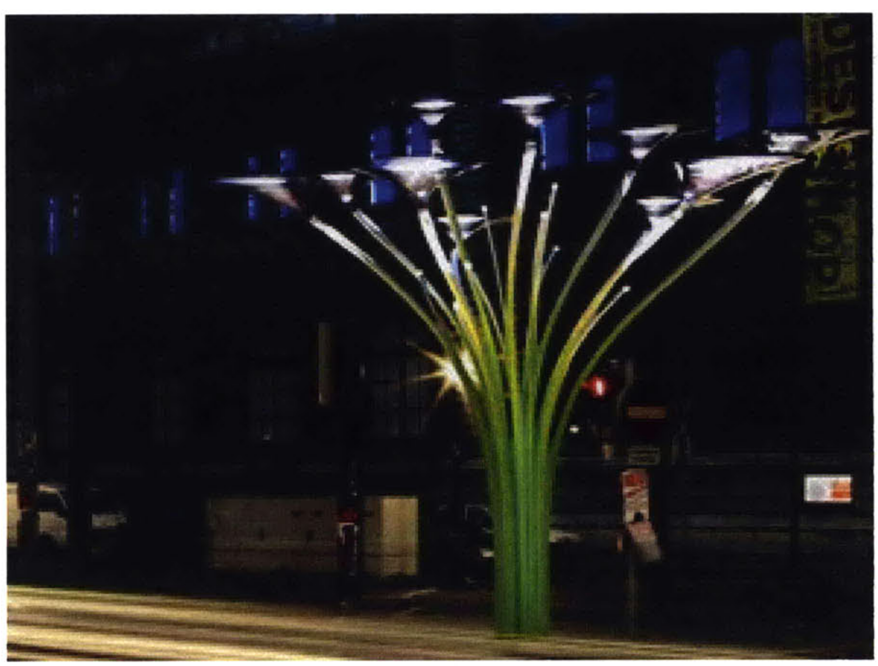
Related Work

LED Luminaire Design

Some recent inspiring forms have been sparked by the desire to develop more sustainable luminaires:

- Solar Flower Petal Lamps: Philips proposed these responsive city lights that charge during the day and illuminate the city at night.
- Solar Tree: Lighting Design created the organically inspired Solar Tree street light to collect energy from the sun and illuminate the street at night.
- ECOlumn: EON, the utility provider, has designed the ECOlumn which combines an LED luminaire with on-board energy production (built-in wind turbine for microgeneration). They have also taken the production of the street light into consideration in calculating the carbon footprint.

Fig. 3.4. Ross Lovegrove solar lights. www.rosslovegrove.com



There is an emergent category of intelligent luminaires. For example, the IP Intelight by LG for the Digital Media City in Seoul, Korea presents an innovative product that spans multi-media consumer electronics and lighting to create a novel public infrastructure. In general, the trend towards LED-street lighting presents an opportunity to explore new types of combinations of infrastructure such as those proposed in the Intelight as well as added programmability and adaptability of lighting.

Prototype Design

A prototypical street light base was designed in computer-aided design (CAD) software Rhino as a platform for experimenting with some of the interactive proposals described above. The design was inspired loosely by traditional forms of pendant pedestrian-scale street lights. The scale was also selected to be comparable to a full-scale pedestrian. The design consists of ribs placed at equal distance along the curve of the pole. The cross section of the pole widens to provide a strong ground that can be reinforced by placing a weight in base. Cables can be run through the center holes in the cross sections. We selected cardboard as a cheap and flexible construction material. The cross sections were cut by hand and then glued to the outer sheets with hot glue. A finishing lamp shade was temporarily constructed from paper in the same color as the cardboard. (For construction details refer to Fig.A.9. in the appendix.)

The lamp head of the luminaire consists of a custom-designed pan-tilt head with two servo motors with a platform for mounting the lights. Thanks to a donation from Philips ColorKinetics, we were able to mount a high-brightness RGB ColorBlast6 LED board to the head which supports full color and high brightness effects. A simple Sharp distance sensor was mounted adjacent to the lighting element to detect the presence of people.

An Arduino Duemilanove board controlled the two servomotors as well as the lights. We experimented with various mappings between orientation of the head and a color space. We attempted to take advantage of the spectrum supported by the powerful Philips ColorKinetics ColorBlast board as well as enable playful and delightful interactions. The primary scenario resulted in a program that moves the head away from where a person is standing to a new location in order to incentivize their movement towards the pool of light. Each time a person enters the pool of light the head moves again revealing another patch in the color space. Without any interaction the head moves back to its base position projecting white light directly underneath the pendant head.

Fig. 3.5. Colorblast 6 donated by Philips ColorKinetics.

Fig. 3.6. Street light prototype in cardboard on display in the Smart Cities lab space.

Fig. 3.7. (opposite page) Color pools created by the light.

In the Lab

The street light has been presented at three Media Lab sponsor weeks during the public open house sessions (spring 2009, fall 2009, spring 2010). The light has also been part of our lab environment for approximately 12 months. It is turned on occasionally as an added ambient feature in the working space. For example, a group of undergraduate students working late night hours asked whether they could turn on the street light as a colorful companion for their work session. Though restricted to a lab environment, they still appropriated a public infrastructure for their activities.

Discussion

Though very preliminary, the AR Street Light begins to hint at the potential programmability brings to the table for public infrastructure. The shift towards LED lighting may eventually lead to the replacement of equidistant posts altogether. However, during the transition phase it is worth considering the more playful and interactive potentials of such infrastructures. These should serve no necessarily as serious product features to be included in all future street lights, but as tools for breaking open conventional notions of what urban infrastructure should be.

Color

The street light reveals a color space as it moves around. Each location in a semi-circular area around and in front of its base is associated with a different color space. The goal was to encourage people to explore the color space by "dancing" with the light and revealing more of its patchwork. From observing people, it is not clear whether the idea of the color space was readily accessible to them. Most people assumed that the color changes are random.

The high brightness LEDs provide a wonderful color-washing effect on the ground. The exploration with color could be extended with LED-based projector modules or screens placed in the beam of the high-brightness LEDs to act as a programmable theater gobo. This effect was also tested as an ambient information display to symbolize the charging cycles of an electric vehicle (from red to green).

Motion

Students and visitors alike are intrigued by the evocative motion. The explorations are preliminary, but they begin to hint at the possibility for a more responsive infrastructure. As many researchers developing robotics have already established, motion is by definition associated with life and thus implies some kind of intelligence. The degree to which the light follows an observer will have a great influence on the role of motion. As Marie Sester's project ACCESS (2002-2003) demonstrates surveillance and the "lime light" can be two sides of the same coin. (The project is described in more detail in chapter 2, Fig. 2.24.)

Sensing

The distance sensor performed reasonably in identifying the presence of a person in the beam of light. For some of the higher orientations of the pan-tilt head, the beam overshot people standing in the light. Or rather people assumed that they were standing in the path of the light when the actual pool of light was further away from the base of the street light. A more open, less cluttered environment would have made it easier for people to grasp the connection between the orientation of the head and the pool of light on the ground.

The sensing device on the street light could also have been a camera in order to track groups of people or specific individuals. This approach moves more in the direction of surveillance and away from the playful applications explored here. As more street lights become LED-based it may also be possible to use the LEDs themselves as sensors to detect the presence of something as a shadow. Many lamp posts are already used as mounting locations for CCTV surveillance systems. Technologists and designers should take seriously the implications of transforming an infrastructure of illumination into one of surveillance. The consequences of these shifts will require more consideration from the multidisciplinary stakeholders contributing to the field of lighting, public infrastructure and safety.

Reaching for Evocative Urban Infrastructure

Many urban planners or city officials consider the notion of programmable street lighting only in connection with energy savings. They are excited about being able to dim lighting when there are no people on the street. However, they shy away from considering the experience of being on the street and including more playful elements into the interaction with public infrastructure because of safety concerns. Street lighting should be always on. However, this expectation is only approximately two hundred years old. Safety should continue to be central, but the preceding considerations are intended to break open an underexplored design space.

The notion of playful interventions in existing infrastructure using light was explored through a series of intervention design by students in a course, which I co-taught with Anne Beamish, entitled World of Night: Interaction Design for Nighttime (MAS.961, Fall Semester 2009). The interdisciplinary group of architects, planners and technologists developed a series of full-scale interventions in the city, near the MIT campus in Kendall and Central Square. The aim was to engage with the "other 12-hours" of urban life. Using the same approach grounded in the cultural history and psychological and social questions related to nighttime, the students developed a series of interventions that demonstrate another possible set of design explorations. Though more short-term, these projects illustrate further the importance of designing for specific sociomaterial conditions.

Five projects were developed in the course that range from completely analogue to wireless and autonomous. Each participant designed for a specific context after a series of field-work and site observation exercises. One of the projects entitled Shadow Playground by Wayne Higgins demonstrates another playful approach to ordinary, everyday infrastructure.

Playful Infrastructure: Shadow Playground

Shadow Playground by Wayne Higgins is an analog sculptural element that can be mounted onto the base of any street light. It uses the beam of light from the street light to cast a shadow (in this case of a hopscotch field) onto the ground. People can use chalk to fill in numbers or augment the shadow leaving a trace of the activity for daytime visitors. During the day, the shifting position of the sun also casts shadows, but only at nighttime the true content of the sculpture is revealed.

Fig. 3.8. Shadow Playground mounted to a street light in on December 2, 2009 in Kendall Square, Cambridge, MA. Wayne Higgens.

Though the project did not take advantage of digital interactivity as much as it could have, the project illustrates how people's point-of-view vis-à-vis infrastructures of imagebility is essential. Shadow Playgrounds only works if people engage with the system and leave traces of overnight activity. In moving towards alternative configurations of people, place and light, shadow playgrounds is a promising example of how a sociomaterial contextualization of display and lighting can motivate out-of-the-box designs for urban public spaces.

Chapter 4
Urban Pixels

Rethinking Urban Screens

The term "screen" evokes neat rows and columns of pixels bounded by a fixed frame and addressable via a human-computer interaction device. Their state is scripted and programmed from a distance. Not only small-scale screens in our desktop computer behave this way, but also large-scale displays in most urban environments are designed according to the same logic only much larger. Urban Pixels break out of the dominant logic of screens to enable a rethinking of urban screens as proposed in the introduction.

Design Criteria

Urban Pixels are networks of physical pixels that can be placed flexibly in any configuration on any surface in the city. They support low-resolution, context-sensitive ambient displays. Users may interact with the units by placing them spontaneously, by triggering sensors or by sending messages from their mobile devices. Together, these capabilities present design criteria for a new generation of urban display and lighting technologies that support the following features:

- Autonomous power: Each unit should have a power-source on board that can either be recharged locally (through an integrated solar cell or other renewable energy source) or in batches between deployments.

In this chapter, "we" refers to the team involved in this design exploration. Please refer to the Acknowledgements and the following publication for further detail: Seitinger, S., Perry, D. S., & Mitchell, W. J. 2009. Urban pixels: Painting the city with light. In Proceedings of the 27th international Conference on Human Factors in Computing Systems (Boston, MA, USA, April 04 - 09, 2009). CHI '09. ACM, New York, NY, 839-848. DOI= http://doi.acm.org/10.1145/1518701.1518829.

- Flexible placement: The mounting system should enable users to place lights on any surface in the city and should be adaptable to different contexts.
- Unbounded: The wireless range should support potentially long distances between individual units making it possible to "fade out" the display through the physical distribution of pixels.
- Variable resolution: The network should allow for placing pixels at uneven distances from each other rather than in neat rows and columns.

These criteria move us away from thinking of urban screens as large-scale images in the city and towards thinking the city as a network of individually programmable and addressable lights that can be recruited for different purposes.

Programming Urban Pixels

The proposed design criteria require a new way of programming for urban screens that incorporates the environment and ongoing interaction with people into the design of the experience. First, different arrangements of Urban Pixels will generate a new substrate or canvas upon which an artist or designer can paint. This substrate should take into consideration how the display wraps around the existing architecture. There are no wires between pixels so the creators have complete freedom to place units strategically in space.

Second, different patterns and images can be programmed for the pixels. Unlike most existing displays high-resolution images and text may not be the most effective displays to show. Rather, creators should explore the dynamic interaction between simple patterns and animations in conjunction with their selected substrate pattern thereby again highlighting the specificity of the arrangement in a certain urban place. Villareal describes the power of simple patterns: "Supercluster, a "system," combines related elements in a complex whole. While some aspects of the project, such as the grid, imply order, the animation within the framework displays a more chaotic dynamic, which conveys a sense of being alive as the pattern evolves. This project unites Villareal's interests in particle systems and cellular automata: individual elements, governed by their own set of rules, accelerate, decelerate, collide, multiply, explode, live and die in a larger system." (Villareal, www.villareal.net/ps1.html)

Finally, viewers have the ability to "reprogram" a display through sensor feedback loops and their own position in the environment. Of course, people always move along side screens, however, the images are rarely designed to change as a result of a person's point of view. With completely flexible systems, viewers' movements could become an integral part of the experience.

Programming an experience with Urban Pixels goes far beyond selecting a series of images or video because of the three elements describe above. The designer must establish a substrate pattern in relation to the context in which the units are meant to appear. Then she must create a series of programmed patterns, animations or rules that seed an initial series of images. And then the dynamic effects generated by the presence of people in an urban place interact with the two basic parameters established by the designer to create a full experience that is truly at the urban scale and transforms the city into a series of responsive (cinematic) effects.

Simulations and Scenarios

Three components come together to create the overall effect of Urban Pixels: the arrangement of the substrate (that is how the pixels have been applied to a surface), the type of program running on the pixels, the type of interaction or the number of people expected to be interacting with the pixels. Because the units do not require any wiring, in theory, any substrate organization is possible. Unlike existing approaches or technologies, this flexibility allows the "display" to cover any existing or temporary structure. New architectural statements are often accompanied by new types of displays, but old buildings are often crudely retrofitted or become overtaken by the technology as shown in Times Square. Using a more subtle system that enables flexible substrate arrangements, designers can place pixels as individual "dots", in semi-regular "lines", as modified grids, in amorphous clusters, and finally and most importantly they can easily take advantage of the three-dimensionality of architectural space. This area presents the most unexplored possibilities for future display concepts.

The second component relates to the type of programming. As hinted above, programs can consist of pre-programmed images, texts or video or they can arise from rule-based systems as well as combinations of the two. In addition, the program will interact with the selected substrate of pixels.

Finally, people's point-of-view is essential for reading the meaning of such situated and contextual displays that are intentionally placed to highlight different aspects of the environment. Both interactivity supported by sensors and the simple fact that people move around add a factor of unpredictability to the images. There have been experiments with

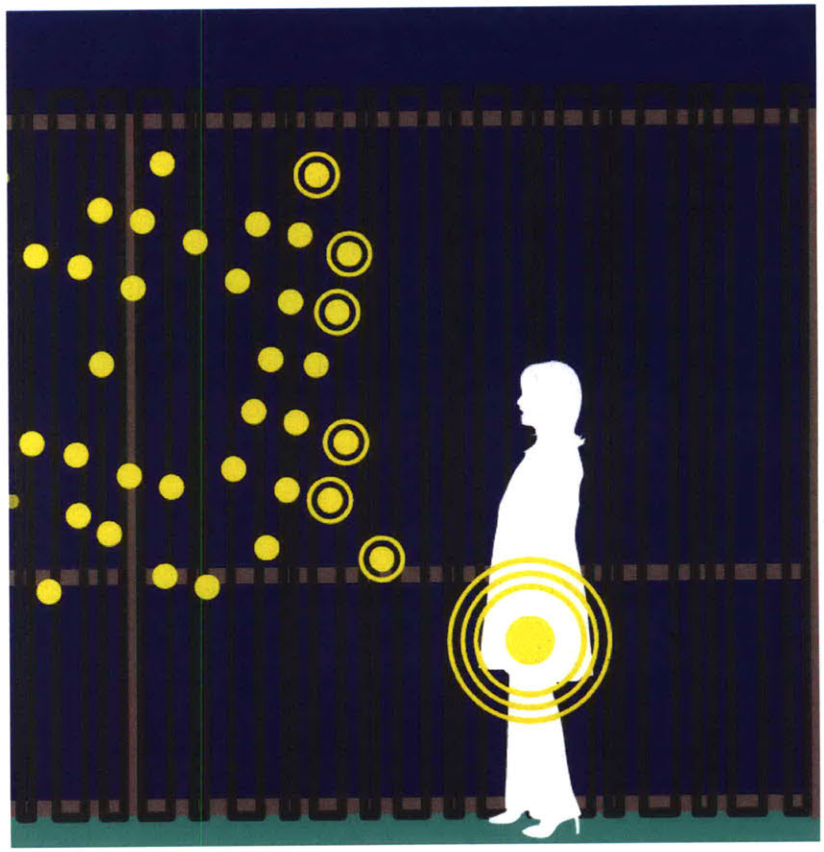


Fig. 4.1. Urban Pixels scenario showing a person placing or removing pixels in any ad-hoc configuration on a fence.

images that go in and out of alignment –going back to the anamorphosis– however systems such as Urban Pixels could enable an animated, dynamic and responsive version of such representations.

Scenarios describe how the principles listed above almost as a pattern book would be translated into context. These scenarios are not exhaustive, but they serve to illustrate how the capabilities of Urban Pixels would be translated into urban situations. Unlike the design simulations or visualizations described above, the following interaction scenarios emphasize compelling use cases in the city:

- Announcing the arrival of public transit: calm urban displays, low resolution, subtle displays
- Marking a (temporary) route in the city: paths to and from schools, temporary outdoor events in parks
- Festival uses: coordinating display effects across a street, neighborhood or skyline
- Part of an urban game: integrate responsive elements
- DIY pixels: allow individuals to place pixels

Related Work : Sensors and Displays

Typical sensor networks do not incorporate a feedback element on board because the devices are intended to be used at a great distance. In this scenario, the aim is to provide the flexibility of a sensor network architecture and the feedback through light of a display system. As described in chapter 2, there are precedents for wireless devices working together to form a display. There are also large and small wired physical pixels. Urban Pixels is another instantiation of a network of devices that provides a flexible substrate for placing pixels in an urban setting.

Sensor Networks

Individual devices communicate with each other via different wireless systems ranging from infra-red (IR), radio-frequency (RF), to optical. The nodes resemble each other and coordinate their display content and behaviors just as nodes in a sensor network. According to Akyildiz (2002) the basic requirements for a sensor network are:

- support very large numbers of unattended nodes
- adaptive to environment
- adjust to unpredictable task dynamics

This notion of sensor networks is approximately ten years old. (Estrin et al., 1999) The first reference to sensor networks was thirty years ago in "Distributed Sensor networks" Carnegie Mellon University Workshop proceedings. Dec. 1978 (Lifton, 2007). The envisioned applications for sensor networks are often in hostile environments such as war zones or post-emergency situations, but there are projects in the smart home/ smart environment space as well. The application spaces identified by Savvides et al. (2004) include: passive habitat monitoring, asset tracking, smart environments and emergency zone monitoring. Even though these systems are focused on sensing and not display, the underlying technical problems of coordinating a distributed, real-time responsive system are the same. When designing nodes for sensor network many parameters come into play (Akyildiz, 2002). The table in Fig. 4.2. compares Akyildiz's general parameters with specific considerations for networked, sensing and lighting units.

Precedents

Unbounded displays are part of the vision for a ubiquitous computing environment as described in Chapter 2. (Weiser, 1991; Ishii, 1997; Underkoffler et al., 1999) They form the ambient surfaces that inhabit the periphery of people's awareness only to be highlighted when a relevant task emerges. Research on surface computing (Patten, 2001) and projection (Tomitsch, 2008) for indoor environments presents a step towards unbounded interactive walls and tables. And there are practical user-oriented design guidelines for unframed projection-based displays.

General Parameters for Sensor Networks (from Akyildiz et al., 2002)		Sensing and Lighting Units (third column added by Seitinger, 2009)
fault tolerance	continue unhindered operation despite node failure	node failure should not interfere with display behavior
scalability	10s, 100s, 1000s	system must function with few nodes and many thousands
production costs	the more units the more production costs should be kept low	depending on the application costs could become a critical factor
hardware constraints	sensing unit, processing unit, transceiver unit, power unit, and location finding system, power generator, mobility unit	lighting element must be appropriate in addition to other hardware
sensor network topology	pre-deployment, deployment, post-deployment, adding units, redeployment	densities and number of units both vary significantly; units should be easily re-deployable; can assume one-by-one placement, however, system should still support localization
environment	relationship with object to be sensed; inside or close to the thing being measured	units are in the space they are intended to impact
transmission medium	RF, IR, optical	RF for outdoor applications, lower frequencies better
power consumption	limited power source; splitting power consumption among sensing, communication, data processing	power source should be renewable; reduce need for communication among units during display sequences!

Fig. 4.2. Table describing the general parameters for designing sensor networks. Adapted from Akyildiz (2002) specifically for small-scale lighting and sensing units such as Urban Pixels.

(Pinhanez & Podlaseck, 2005) Raskar has also developed a hand-held projection unit that overlays digital information onto any surface (RFIG). (Raskar et al. 2004)

The vision for reconfigurable lights proposed above is built on physical units that represent pixels of light. The notion of physical pixels can be traced back to ubiquitous computing (Weiser, 1991), tangible computing (Ishii & Ullmer, 1997) and ambient displays (Dey et al., 2002). There is a lineage of physical pixels that support distributed display functions, for example:

- Nami Project, Heaton & Poor (Heaton, 2000; Heaton & Poor, 1999)
- DataTiles by Rekimoto, Ullmer & Oba (2001)
- Digital Cubes, Schiessl (2002)
- Pushpin Computing, Lifton, Broxton, & Paradiso (2007)
- Embodied Emergence, Bouchard & Maes (2006)
- Siftables, Merrill & Maes (2007-ongoing)
- Paintable Computing, Butera (2007)
- Urban Pixels, Seitinger & Mitchell (2007-2009)

Some of these examples such as DataTiles and Siftables include high-resolution displays that convey meaning individually and as a network. Other examples such as Pushpins and Namis represent individual pixels that convey meaning as a network through low-resolution, ambient visual displays.

There are also wired examples of physical pixels that enable flexible displays as well. Most notable among these precedents are the Fireflies developed at Lancaster University. Though wired, the system supports ad-hoc assemblies of individual LED modules and communication modules. Commercial products such as Flex lights by Philips Colorkinetics provide comparable functionality, but they do not enable the same kind of ad-hoc behavior. A Dutch group developed Wixels which also wired physical pixels that can be individually addressed and used to form amorphous clouds of lights.

The table in Fig. 4.3. adapted from Heaton (2000) summarizes the parameters which can be used to compare pixels. These parameters can also be used by designers of networked, responsive lighting systems to create new systems.

	On-screen Pixels	Physical Pixels	Urban Pixels
Location	On screen	Table-top	Distributed in 3D space
Senses	Visual	Visual, graspable	Visual, graspable
Address	Fixed	Ad-hoc	Ad-hoc
Framework	Cartesian	Relative, unbounded	Relative, unbounded
Processing	Central	Distributed	Distributed
Power	Electrical grid	Battery	Renewable
Resolution	High resolution	Variable resolution	Variable resolution
Distance	mm	cm-m	cm-many m's
Examples	PC display, electronic billboards	Nami (low-res), Siftables (high-res)	Urban pixels (low-res)

Fig. 4.3. Table describing the differences among physical and screen-bound pixels. Adapted from table by Heaton (2000).

Early Prototypes

Before deciding on the Urban Pixels form factor, we experimented with several different hardware configurations and shapes. The earliest prototype consisted of an 8-bit AVR microcontroller, a LINX transmitter and receiver, white LEDs and a NiMH rechargeable battery module. After initial bread board tests, we designed and tested a simple circuit board in house.

The shape of the early prototypes provided space for solar cells to enable easy recharging during the day. Using a petal configuration or a panel configuration, we attempted to integrate charging. However, the limitations on placement of the units (for example, not being able to place devices on the north façade of a building) as well as the relative inefficiency of individually charging units and added cost per unit caused us to eliminate the on-board renewable charging constraint for the final design.

Urban Pixel Units

Using a second prototype with a sphere shape, we developed a prototype network of fifty Urban Pixels to demonstrate the importance of exploring new approaches to urban displays and lighting. Each unit includes a CC1010 microcontroller and RF transceiver (433 MHz), LED module (ten bright, white LEDs), 2.5mm power plug for charging, rechargeable 3.7V, 66000 mAh Li-Ion battery pack, IR sensor and renewable energy source such as photo-voltaic cells. The communications hardware and firmware is modeled on the RFRAIN nodes (Laibowitz & Paradiso, 2004). We have expanded each node to include an LED module, IR sensor and larger battery pack for longer deployment and brighter display capabilities. Two

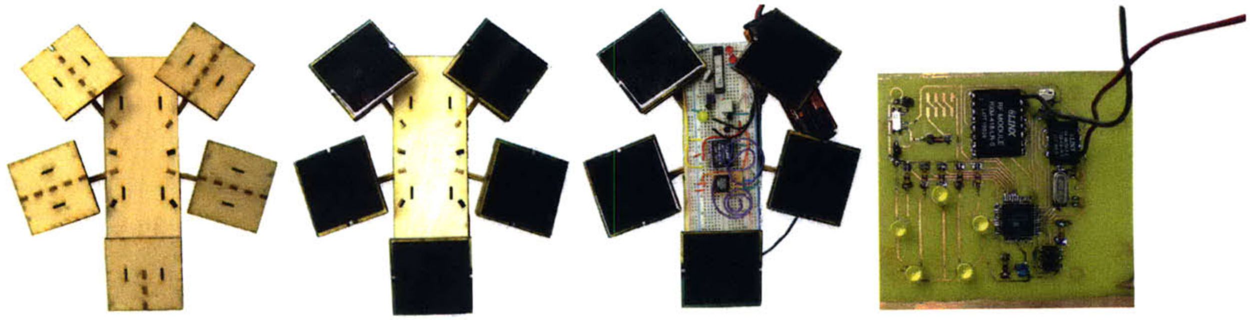
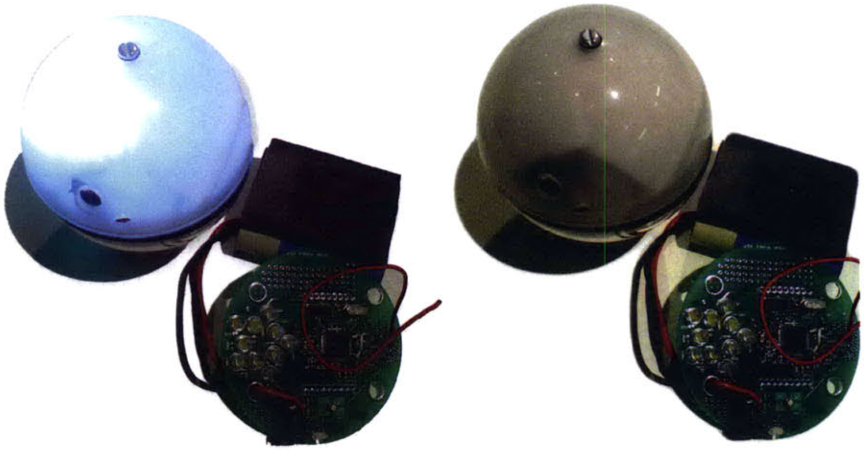
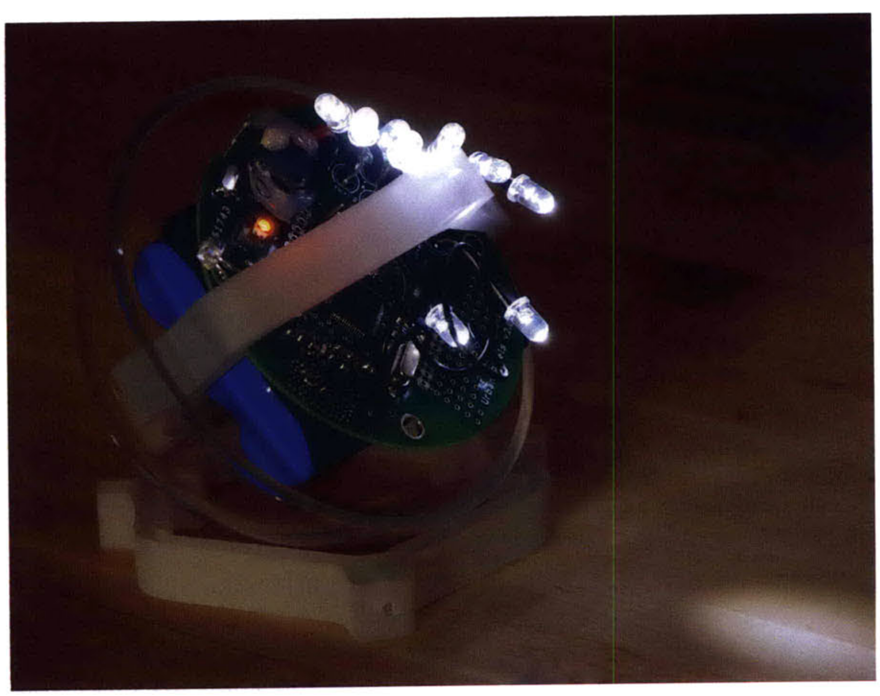


Fig. 4.4. Design iterations of hardware for Urban Pixels. Various form factors including solar cells and final sphere-shaped prototype below.





four inch diameter acrylic half-spheres protect the components from the elements. They are held in place by a circular rib structure water-jet cut in polycarbonate. One half-sphere has been sandblasted and lined with a layer of 1/8" stuffing material to diffuse the light emanating from the individual LEDs. The units can be opened easily by hand with a thumb screw. Each unit can be connected via a 6/32" threaded screw to various connectors depending on the surface type including brackets, suction cups, and others. No additional wiring is needed for communication so that the units can be mounted individually to any surface.

Communication Protocol

The current single-hop network with centralized control facilitates pattern generation for flexible arrangements of units. Unlike most distributed sensor networks, each node in Urban Pixels is unaware of the other nodes. When initially programmed, nodes in the network receive a unique address in order to uniquely identify it, but do not receive information about the number of other nodes or structure of the network. A centralized node broadcasts all necessary information about the network to all of the other nodes. A laptop controls the entire network via a standard RS-232 serial connection with the centralized node. Thus, the structure of the lighting network can be changed with a laptop without necessitating the reprogramming of all of the distributed nodes. Since the number of patterns the network is capable of displaying is substantially less than the number of nodes in the network, it is more efficient to encode patterns. The encoding of messages depends on the pattern type. Units receive a pattern type (see "Interactions" below) and parse unique address, each node is not individually addressable in the network.

IR Sensors

It is critical that the lights for a distributed lighting network do not affect the network's light sensing capabilities. A node in a lighting network that operates only at night should not shut off because other nodes in the network are lit. The IR sensor detects radiation in the 850 nm range which is on the fringe of the visible light spectrum. As a result, the sensor can detect any light source containing a substantial amount of red light (e.g. the sun, incandescent light bulbs).

Since the bright, white LEDs output light in the upper range of the visible light spectrum, approximately 500 nm, they do not affect the on board IR sensors. The IR sensor was connected to one of the several 10-bit ADC channels on the CC1010 without any amplifying circuitry. Initial tests indicated that the IR sensors on each node could detect an incandescent flashlight at a range of 20 ft. The Urban Pixels needed to have the ability to dynamically adjust to different environments without being reprogrammed which necessitated self-calibrating nodes. At initialization each node obtains several samples from the IR sensor. These samples are stored and averaged in order to obtain a threshold, which can be different for each node. In addition to this, each node periodically re-calibrates and updates its threshold in order to dynamically adjust to the environment.

Interactions

In the current system, people can interact with Urban Pixels in three ways. First, they can control the entire display from a base station connected to a laptop computer. The interface allows the user to reconfigure the number of rows and columns, change the display frequency, reset the units and change patterns. The available patterns were direct interaction mode, random flashing, vertical lines, horizontal lines, and rain.

Second, they can send a text message (SMS) single-digit code to a GSM modem that changes the pattern. The SMS system was handled by an adaptation of a commercial product developed by Richard Wilson of Distance Lab, Forres, Scotland. The same patterns were available as displayed in the interface above. Finally, people can control individual units with a flashlight via the IR sensor when they are set to direct interaction mode.

Urban Pixels in the Lab

Unlike previous experiments with physical pixels, Urban Pixels were specifically designed to function at an architectural scale (not usually the scale of human-computer interaction (HCI) research which tends to focus on the hand-scale) hence their large size. At nighttime, their large size and the two layers of diffusive material (upholstery layer and sand-blasted acrylic shell) enable an even distribution of light that overcomes the typical glare problems associated with LED systems.

The overall system cost was relatively low with half the cost attributable to the Li-Ion battery packs. Only one microprocessor was necessary and supported both communications and display functions.

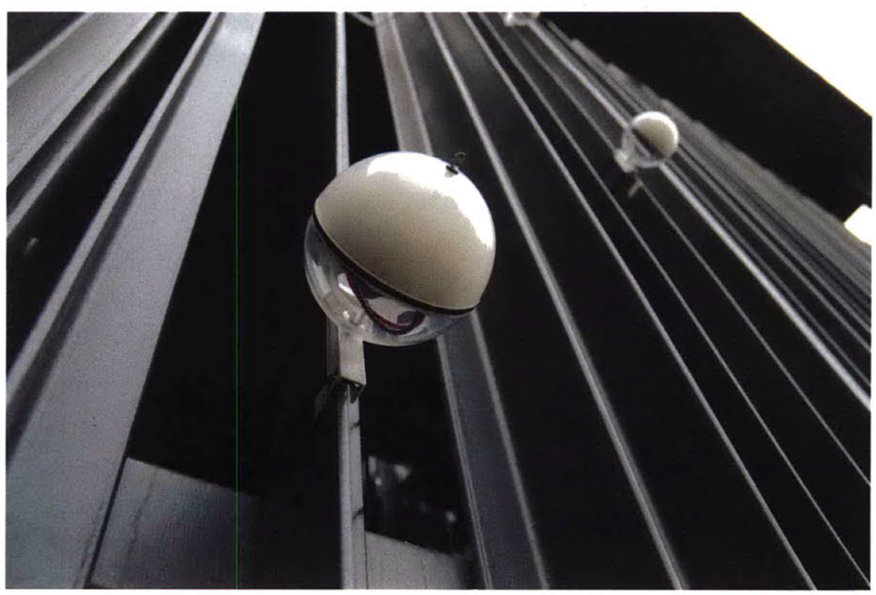
The pixels enable an unbounded display because they can attach to various connectors that are adapted to different materials. The final design was tested on different materials such as MDF walls with peg holes where the lights can be screwed in at different locations and on various smooth surfaces such as glass where the lights were attached using suction cups. These experiments allowed us to do an initial proof-of-concept check.

The initial system only consisted of white LEDs, but full color could easily be added for future implementations. The requirement for color depends significantly on the specific application. In an abstract configuration (such as those tested with the Wixels system), color expands the repertoire of potential effects. However for Urban Pixels, we intended to emphasize the role of animation and the idea of "highlights" rather than color effects.

Facilitating users' interaction with the software and programmable aspect of Urban Pixels would be important for future implementations. There are two directions that could be developed. First, a program that enables a frame-by-frame system that allows individuals to set key-frames, for example, as with typical video editing software. Second, allowing people to seed different emergent behavior which interacts with on-board sensors or pre-programmed behaviors to achieve different outcomes.

Fig. 4.5. Rendering of how unbounded pixels might look on a building facade.

Fig. 4.6. Detail of the units mounted on the facade of Eden Court Theater, Inverness, Scotland.



More sensors such as temperature, wind, or additional light sensors could add to the repertoire of potential interactions and programming effects. The current system does not currently use its on-board IR sensor for localization, but it could be adapted to do so. Past systems such as Pushpin computing supported ad-hoc localization using an external flash of light. Others use cameras or other external imaging devices. For larger implementations it would be useful to add ad-hoc localization, but for current proof-of-concept localization did not limit the experimentation in the field.

As discussed above, a renewable energy source should be integrated with each unit or with a batch of units. This integration would make it easier to deploy the system. More form factors could be explored. The spheres were chosen because they provide a hovering effect of not being attached to the façade that other designs did not. Future systems could be adapted to specific applications. Also, large-scale implementations would enable us to test the potential, aggregate monumentality of such a self-organizing network of pixels. A large scale would require implementing a multi-hop network, perhaps with localized master units.

Urban Pixels in the Wild

Deployment 1: Urban Pixels in Inverness, Scotland

A network of 50 Urban Pixels was displayed on a façade of Eden Court Theater the premiere cultural venue in Inverness, Scotland from June 1-June 7, 2008. The original 1976 theater by Law & Dunbar-Nasmith was recently reopened after a two-year renovation period which entailed the construction of a new wing designed by Page/Park architects. The façade of the new wing is finished towards the park with a custom, irregular fence that provided an ideal mounting surface for Urban Pixels. The theater is located along the banks of the Ness River and can be seen from both banks.

The system was active evenings from approximately 10pm until midnight when the theater closed. The late hours were necessary due to the long days in the north during mid-summer. Fliers were distributed throughout the building explaining the SMS codes for the available patterns. There was a public opening on June 3, 2008 that was attended by approximately 50 people. During the opening, the research team assisted guests with the SMS system or flashlights. Throughout the week, the public was encouraged to change display patterns via SMS or to interact with individual units via flashlights. We observed and informally interviewed guests and passers-by interacting with the façade.

The installation was able to be temporary because it could be easily attached to the facade and did not require support infrastructure. In addition, the network of pixels enhanced the building leaving no traces behind after its deployment. The interactions between changing natural conditions and the lighting units enriched the preprogrammed display patterns significantly. Together, the natural and programmed patterns demonstrated the merits of a painterly approach to deploying points of light in an urban scene that could be explored further. Visitors to the theater enjoyed interacting with the system and the visual effect it had

Fig. 4.7. New wing of Eden Court Theater, Inverness Scotland, with Urban Pixels mounted on the facade.

Fig. 4.8. Visitors pointing to Urban Pixels displayed on Eden Court Theater, Inverness Scotland.

on the theater. Looking back on the design criteria enumerated above (flexible placement, autonomous power, unbounded, variable resolution, responsive) Urban Pixels fared well during its week-long deployment.

Liberated Infrastructure

First, Urban Pixels was easy to deploy requiring less than one hour and two people to mount on the building façade. The metal brackets and zip-ties also allowed for easy reconfigurability of the display arrangement.

Second, some units were distributed throughout the theater grounds where people could touch them and move them around. This flexibility links Urban Pixels to traditions of lantern festivals all around the world with the additional characteristic of programmability.

Third, the low resolution nature of the display proved surprising for many people: "Why was there no text? Why couldn't they write a message for their friends?" After recovering from their initial surprise, onlookers enjoyed the calm nature of the installation.

Fourth, Urban Pixels enlivened the façade of Eden Court throughout its week-long deployment without detracting from the building. The ability to layer ambient information onto an existing structure proved very powerful. People still recognized their theater shining through the light. The round form factor and mounting strategy further enhanced the hovering appearance of the system in front of the architecture.

Painting with Light

The late sunsets and long dusk in Scotland in June provided particularly interesting conditions for experimenting with the mixing of digital and natural lighting. The units were bright enough to be visible during early evening and then really became visible late at night when the building faded into an invisible night-time background. These transitions were particularly interesting because they showed how the system was constantly in conversation with the physical environment.

Painters such as William Turner and the Impressionists tried to capture these effects on the canvas through the strategic placement of light and dark zones. Digital programmability confounds traditional mechanisms for matching message and substrate because of the replicability of digital data (Mitchell, 1992). Zooming into a digital image does not reveal additional details beyond the point where the grainy pixilated structure emerges. A painting cannot be reduced to its component parts in the same way.

Urban Pixels recaptures these painterly techniques three-dimensional display networks of digitally programmable points of light.

As mentioned above, the notion of physical pixels can be traced back to ubiquitous computing (Buxton, 1996), tangible computing (Ishii, Ullmer 1997; Underkoffler, Ullmer, & Ishii, 1999; Fitzmaurice, Ishii, & Buxton, 1995; Ishii 2008) and ambient displays (Tomitsch, Kappel, Lehner, & Grechenig, 2007). By exploiting humans' peripheral perception, physical ambient display systems expand our ability to glean information from the environment. Urban Pixels couples the power of physical pixels with the painterly strategies for capturing a mood or transforming a landscape-scene through light.

Responsive – Interacting with Urban Pixels

Direct interaction using flashlights to turn individual pixels on proved to be very enjoyable for people. The clear connection between cause and effect seemed to facilitate a more personal and social set of interactions around the lighting system and façade (Struppek, 2006). Experiences with other installations such as the Tactile Luminous Floor (Delbrück et al., 2007) have shown the potential for enhancing people's experience of space through an ambient lighting system.

The SMS system gave full control to users, which was very popular. However, they could never be entirely certain when their SMS had reached the system. Transitions from pattern to pattern happened quickly and there were many repeat requests that led to longer stretches of the same pattern rather than more rapid transitions among patterns.

Fig. 4.9. Solar urban pixels (see chapter 6 for a rendering of a floating pixel unit which uses wind and waves to power the device).

Many people also simply enjoyed the display from afar in its default mode cycling through all of the possible display patterns and frequencies. The fast-paced transitions of patterns seemed to elicit more enjoyment similar to the effect of firework displays. These early interaction examples only hint at the many possible responses that Urban Pixels could elicit among people. There are many more social interactions that could result from placing Urban Pixels in different urban contexts. Additional systematic user studies should be made to expand the validity of Urban Pixels as an approach to innovative, low-resolution urban interactive displays.

Future Technical Requirements

The technical implementation functioned reliably throughout the week-long test period. Future systems will provide increased redundancy, localization, multi-hop communication, and the ability to individually address all nodes. The implementation confirmed the ease of use and the benefits of applying wireless sensor network techniques to a display system. (Dey et al., 2001; Savvides, Girod, Srivastava, & Estrin, 2006)

The expressivity of the system would be significantly enhanced by full-color lighting modules. The possibility of interacting with natural light conditions would be greatly enhanced. Also full-color would enable a broader range of signaling despite the low resolution.

Fig. 4.10. Rendering of floating Urban Pixels in the River Ness, Inverness, Scotland.

Wireless communication and battery packs supported free and autonomous placement for the duration of the installation. For long-term deployments or inaccessible locations, an on-board renewable energy source would support even more flexible placement of pixels. Previous design iterations (discussed above) have incorporated PV cells into the pixel units.

Other solutions such as wind generators and wave or river currents could be explored. Power challenges are typical of any wireless network and may require different combinations of power and lighting modules to accommodate diverse application scenarios. There have been scientific (Savvides, Girod, Srivastava, & Estrin, 2006) and artistic (Bruges, 2007) experiments with power harvesting. And these questions will continue to play a key role in advancing ubiquitous computing infrastructures (Yick, Mukherjee, & Ghosal, 2008).

Deployment 2: Urban Pixels on the Media Lab Facade

Urban Pixels were placed on the façade of the 1985 I.M.Pei Media Laboratory (MIT Building E15). The regular grid pattern of the building provided an excellent background for exploring the potential of existing architecture interacting with a digital layer of information. The façade includes a regular grid-pattern that allows simple animations to create optical illusions for onlookers.

Ambient Wayfinding

Animating the lighting elements in a simple sequential wave pattern directs people towards a specific direction. This type of animation is used to signal the arrival of the subway trains in the Washington D.C. metro. Inspired by this real-world example, we experimented with this arrangement on the plaza in front of the building and it provided a clear directional signal. As there was no ongoing event or activity, we could not tell whether people would easily understand the directional aspect of the animation. Still, the pattern itself achieved a very effective visual result.

Transparent Display

The building façade is cladded with regular square aluminum panels. This rigid substrate interacts interestingly with the simple animations of horizontal and vertical lines on the pixels. When the lights are in motion the underlying substrate also appears to be animated and moving. The buildings regular square pattern appears to be moving. This type of display logic interacts with the given characteristics of the environment and enhances them rather than covering the existing architecture as large-scale displays often too. For existing architecture, this approach provides a much more subtle and flexible mode of intervention.

Outlining Images and Words: The MIT Logo

Like the early days of displays, large physical pixels make it easy to outline shapes or words. We experimented with the MIT logo on the façade of the building which showed the benefits and limitations of such a system. Effectively rendering the image required all the pixels to be placed on the façade. Because the logo is very regular it was somewhat difficult to discern the information. However, with the help of an animation that only lights some of the units, speeds up and then suddenly illuminates all the units the logo appears very vividly for a brief moment only to disintegrate back into individual dots of light. This test showed how the interaction between a changing substrate and the animation provides opportunities for experimentation revealing and concealing animation through the combination of the two elements.

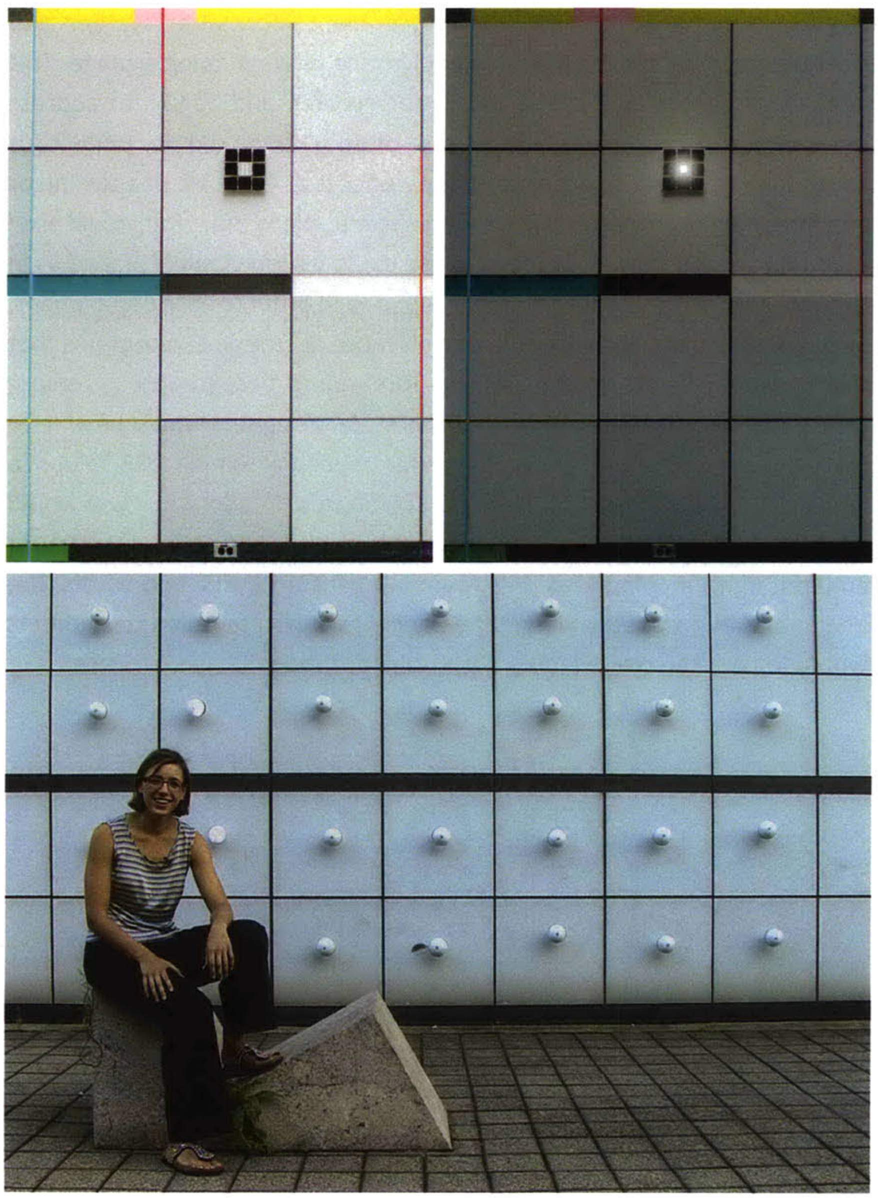


Fig. 4.11. Various urban pixels prototypes shown on the I.M. Pei Media Laboratory building (1985).

Reaching for a City-Scale Vision

Urban Pixels provided a platform for experimenting with a display-lighting installation fulfilling the criteria of autonomous power, flexible placement, unbounded display range, variable resolution. Based on the initial deployments, we believe that systems like Urban Pixels can enable new interactions among citizens, displays or light and urban environments. They can support user-deployment as well as private- or public-sector deployments. People will be able to reprogram these systems directly, via sensor interactions or by simply experiencing them in a dynamic urban setting. These capabilities will also enable more social potentials for display infrastructures such as those which Struppek (2006) sketches.

More long-term and larger-scale deployments are necessary to further strengthen the case for infrastructures like Urban Pixels that blur the boundary between urban displays, ambient information systems and existing infrastructures such as street lighting or wayfinding signage. This work expands the scope of typical HCI research and begins to address infrastructural challenges which are often overlooked in ubiquitous computing research. In order to achieve effects at the scale of a skyline or an entire neighborhood or even a whole street, many more individual pixel elements are necessary. Some of these could be individually placed as in Urban Pixels; others could be connected to each other to ease deployment. Such a dense distribution would permit more aesthetic explorations that take advantage of shifting scales, foreground-background reversals, transparency or layering effects. At this scale, designers would be able to explore new programming paradigms far beyond assigning RGB values to individual fixed pixels as on large LED billboards. In addition, they would be considering depth, position, adjacent architectural context, level of ambient light, moving elements, dynamic sensor inputs, and so on. The image of Zaragoza, Spain (Fig. 0.1.) begins to illustrate how these effects would impact the overall image of a neighborhood.

Chapter 5
Light Bodies

Introduction

Everyone has used their mobile phone screen to find something in a bag, insert a key into a lock at night, illuminate a rough garden path or wave it in the air at a concert. When we appropriate our handheld screens for the purposes of illumination we are harking back to a much earlier historical moment when hand-held lighting was the rule. In "Light Bodies," we invited people to actively engage with their lightscape in different performance settings. Our aim was to enable people to shape lighting as well as explore their physical and social environment under different lighting conditions. Some of the questions we investigated in this work include: How can people explore their environment with mobile Light Bodies? Can a portable responsive light enable a more active relationship between people and lighting? How can this approach allow us to revisit the communicative aspects of lighting and their potential role in public spaces?

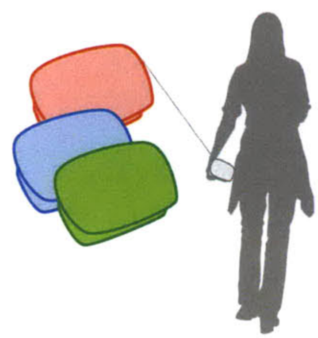


Fig. 5.1. Diagram of Light Bodies as they were prototyped and implemented.

Design Criteria: "Excuse me, Miss, your bag is on fire!"

The title for this section stems from a passerby who commented on the glowing bag of lights that one of the authors was carrying to an installation site (Fig. 5.5.). It demonstrates how eye-catching an illuminated object can be. The playful comment also reiterates, the serious concerns involved in deploying experimental lights in public space. Giving people a conspicuous, brightly-lit prototype can bring unwanted attention and

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In this chapter, "we" refers to the team involved in this design exploration. Please refer to the Acknowledgements and the following publication for further detail: Seitinger, S., Taub, D. M., & Taylor, A. S. 2010. Light Bodies: Exploring interactions with responsive lights. In Proceedings of the Fourth international Conference on Tangible, Embedded, and Embodied interaction (Cambridge, Massachusetts, USA, January 24 - 27, 2010). TEI '10. ACM, New York, NY, 113-120. DOI= http://doi.acm.org/10.1145/1709886.1709908.

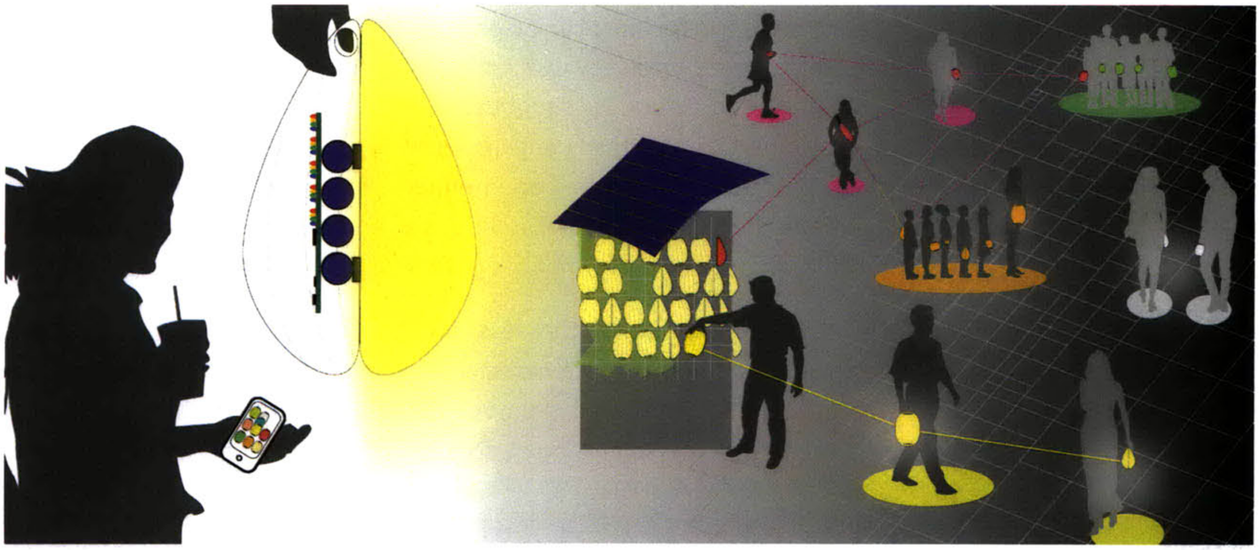

Fig. 5.2. and Fig. 5.3. (opposite page) These scenario drawings show hand-held, mobile light artifacts proposed as a semi-private, semi-public light infrastructure. Individuals may carry the devices with them and own them. The devices respond to proximity with each other as well as en mass collectively (as shown in the light sculpture in a park).

Fig. 5.4. (this page) Recharging stations with renewable energy sources could be placed throughout the city to support this self-organizing light infrastructure.

contribute to a feeling of unease at night. Such a scenario would invariably lead to a focus on safety which already dominates debates around urban lighting. In this work, we sought to move beyond discourses of safety and enable people to actively engage with spaces and each other using light. We thus selected secure, open-ended settings that would allow us to explore the more communicative, social, and playful aspects of hand-held lights. A series of performances provided this type of setting.

Our emphasis on the less functional qualities of mobile lights introduced another parameter: the range between performance and everyday life. In the city, unpredictable lighting conditions present a challenge for deploying point sources of low-intensity light. While the

Fig. 5.5. "Excuse me, Miss, your bag is on fire!" A passerby made this comment as we were carrying the bag of Light Bodies shown in this photograph to a performance in Vienna, Austria.

cumulative effect of multiple natural and artificial lights is interesting, the impact of a particular light source becomes difficult to pinpoint. At the other extreme, stage lighting provides control over every aspect of an environment. We worked to strike a balance between the high degree of control afforded by stage settings and the unpredictable nature of everyday environments. In doing so, we aimed to blend exceptional with mundane and bring aspects of performance into everyday life.

Lastly, our interests were not only in how lighting influences contextual cues by modulating the appearance of the environment, but also how it shapes the relationship between observer and observed or audience and performer. Contemporary theatre often subverts the 19th century tradition of hiding the audience in the dark. This practice relates to the important role lanterns once played in signalling a person's presence in public spaces at night. In exploring different settings, we intended to further examine the dynamic relationship between observer and observed.

Related Work

To investigate the open-ended objectives described above, we built a modular prototype. In order to conduct our research in the chosen settings, we used sound and vibration as the primary environmental inputs. As a consequence, our work builds on a number of inspiring installations that use sound together with light as input and output respectively. For example, Meejin Yoon's White Noise White Light, Usman Haque's Burble or a series of works by Achim Wollscheid like polyson and intersite. These projects could also be considered a subcategory of a broader area recently entitled as "sonic interaction design" which includes many projects about urban soundscapes in general, e.g., the mobile system Ambient Addition or the architectural-scale Gamelan Playtime. (Castelo & Mongiat, 2006; Haque, 2007; Wollscheid; Yoon; refer also to the projects in Fig. 2.22.)

Hardware

We used the Arduino-compatible Funnel board as our primary input-output module. The benefits of this platform include an integrated lithium-polymer battery charging circuit, an expansion socket for XBee® wireless modules, and a sufficient number of accessible digital output and analog input pins. (www.arduino.cc, www.funnel.cc) We designed a custom expansion module for the Funnel to provide to provide audio input and visible outputs for the performances which we needed for the performances.

Each expansion module was fitted with 20 LEDs in four clusters of five colors each: red, green, blue, (RGB) amber (A) and white (W). It was important to include more than just the standard RGB configuration to support a larger color palette. We used 120° wide-angle, super-bright LEDs manufactured by CREE.

A Kobitone electret condenser microphone served as the primary analog input. The audio signal was amplified and filtered with a high-pass (above 3kHz) and low-pass (below 100Hz) Sallen-Key filter configuration using a TLV2374ID quad operational amplifier. Each output of the op-amp was connected to an analog-to-digital converter (ADC) pin on the Funnel board. In addition, each unit included a MSI piezo vibration tab which was amplified and also connected to one of the Funnel's ADCs.

Candle Mode (Enhanced Responsiveness)

Intensity Flicker	*Normal Mode* > 3KHz	*Normal Mode* < 100Hz	*Normal Mode* Vibration	Random Fades
Amber	Amber	Blue	Blue	Blue
Red	Red	Red	Green	Green
			White	White

Fig. 5.6. Table showing the color space. Table by Daniel Taub.

Fig. 5.7. Light Bodies unit up close.

The Funnel and LED breakout board were powered separately to maintain modularity and isolate the power usage of the lighting element. The Funnel board was powered with its own 3.3V 900mAh li-polymer cell, while the LEDs were powered with a detachable, rechargeable 1850 lithium-ion 3.7V 2600mAh cell.

Casings

For these preliminary explorations, we bought translucent acrylic cases (soap dishes) with bevelled edges that afforded a smooth and pleasing tactile experience. Two additional diffusion layers were necessary to evenly distribute the light. First, we positioned a sheet of Mylar above each board on 2mm nylon screws. Then, we placed a thin layer of upholstery stuffing in the lid.

Software

The first version of the Light Bodies software used the amplitude measured by the unfiltered audio signal to determine the collective brightness of the red, amber and white LEDs. This simple relationship and restricted color palette resulted in an "audio-candle" effect designed to match the choreography and costumes in the first performance described below.

In the next revision, we added support for more interactive scenarios. The updated program continuously responds to all sensor inputs and uses a larger palette. The high and low frequency signals trigger different colors as shown in Fig.5.6. The thresholds for triggering these colors were dynamically updated by averaging the ADC values separately for each of the two filtered audio signals over 64 cycles. The overall amplitude determined both brightness and drop-off speed— when the audio level was louder, the lights faded more quickly. Tapping and low vibrations elicited a markedly different blue-green color to distinguish this response from the automatic and more-frequent audio responses.

We also added an ambient candle mode based on a modification of the previous version's software to bridge long periods of inactivity in the musical score. Green, blue and white LEDs faded up or down at random while amber and red LEDs responded directly to the unfiltered amplitude levels. The colors used in the candle provided a visible link between the two modes, as in all cases, the audio signal response uses red as its base color. The sum-total effect was to create a slightly individualized—but still consistent—response pattern in each unit.

Light Bodies in the Wild

As a preliminary step towards exploring the problem space outlined above, we opportunistically integrated Light Bodies into three public settings. Through personal connections and by chance we were able to formally and informally experiment with the prototypes in three very distinct explorations. As a result, our observations remain speculative, but they will guide us towards future implementations and designs.

Klang.Körper and Licht.Körper[1]

The Wiener Musikfreunde Orchester celebrated its 150th Anniversary with a special community-building project inspired by Sir Simon Rattle's "Rhythm Is It!" project performed in a new concert space at the Vienna Technical University. Two dance companies consisting of amateur dancers were recruited in a school and through a community centre to dance in the Romeo and Juliet Overture by Tchaikovsky as well as in the first and last movements of Symphony No. 1 by Brahms. Through a personal connection with the orchestra, we were able to develop the first version of Light Bodies as a stage prop for the performance.

We used the audio-candle mode (the first software version described above) to provide a subtle, ambient effect that would not distract from the music, enhance the choreography and blend well with the dancers' costumes. The choreographers incorporated Light Bodies into the entire performance which lasted approximately one hour. At the beginning of the show, the dancers carried the lights on stage and placed them around the perimeter of the dance floor. The stage was not elevated, positioning the dancers and the audience at approximately the same level.

Throughout the piece there were several notable moments when Light Bodies were an important component of the choreography. Three instances illustrate how they contributed to the performance. First, in the Brahms symphony, each teenage dancer (24 in total) brought a personal artifact like a hair brush or a cell phone on stage that he or she placed next to one of the Light Bodies on the perimeter of the dance floor. At the climax of the first movement, each dancer picked up a light instead of a personal object and used it in a vigorous shadow boxing sequence before sinking to the ground with the light color washing his or her white costume. The lights symbolically replaced the worldly artifacts on a search for identity, which is one of the themes in this piece. Second, at the end

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1 Klang.Körper means body of sound in German and inspired the equivalent Licht.Körper which we then translated into English as Light Bodies. The choreographer chose this term to describe the effect of being engulfed by a cloud of music, dance and also light that amounts to more than a sequence of musical notes.

Fig. 5.8. Performance at the Technical University of Vienna. Photograph TU Wien.

of the first movement, the dancers left the stage and the lights remained sprinkled across the stage as a ghostly reminder of their presence. Third, midway through the last movement, the dancers returned in shorter solo sequences. As they leapt across the stage, they left a trail of deep red and amber light.

Before the closing sequence, the dancers handed the Light Bodies to audience members. This moment proved the most interesting because audience members who had been sitting in the dark suddenly became an extension of the stage. Like in our subsequent observations, we saw that people quickly started to play with the small devices. The unlit audience area also made the attractive colors of Light Bodies more visible.

Play Me, I'm Yours

For the second of our explorations, we made use of a project entitled "Play Me, I'm Yours" by the artist Luke Jerram. Run for three weeks, Jerram's project installed thirty "street pianos" in public spaces such as streets, parks, train stations and markets around London. The pianos were purposefully arranged so that bystanders and passersby would be encouraged to play them. As the project's website explains: "Questioning the ownership and rules of public space "Play Me, I'm Yours" is a provocation, inviting the public to engage with, activate and take ownership of their urban environment." (Jerram, 2009)

Choosing one of the pianos installed in a public square, we were curious how the Light Bodies might further augment the public's interaction with the surrounding space. As the devices responded to sound, we hoped they might introduce an additional medium of engagement, enabling interplay between sound, light and space. The "Play Me, I'm Yours" project also conveniently offered a contrast to the more choreographed dance/ orchestral performance in Vienna. It afforded an exploration of the relationship between performance and audience, creatively juxtaposing and confounding the roles of performer and participant. Further-more, it situated the interactions in an urban setting, something that resonated with our interest in the antecedents of state-controlled, city lighting.

For our exploration, we placed eight of the lights, each programmed to respond to different elements of sound, around the piano and allowed members of the public to continue playing. This unfortunately only lasted for one hour, between 7:30 and 8:30pm, as we were constrained by the closing of the square. Also, we never quite reached nighttime darkness because of the extended hours of summer daylight in London. Nevertheless, we observed what we felt to be two noteworthy results. One we found people interacting with the Light Bodies directly, tapping,

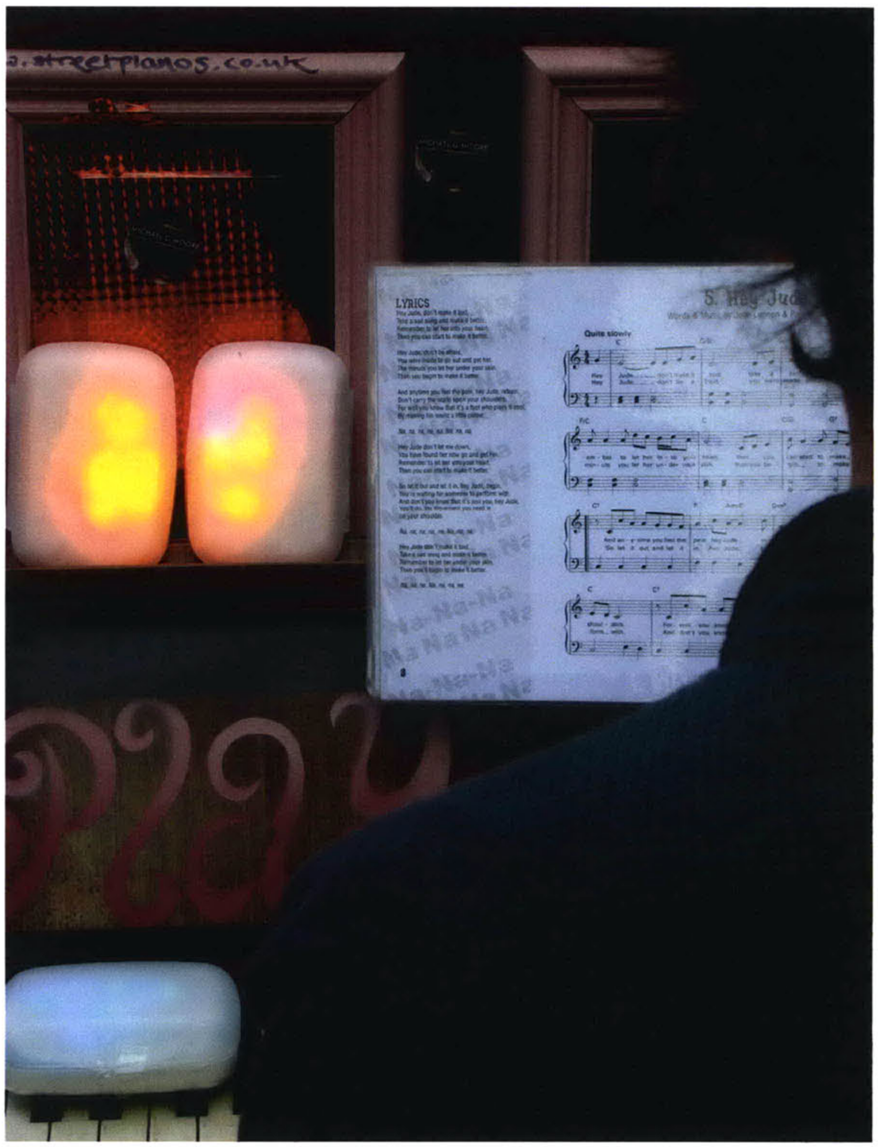


Fig. 5.9. Play me, I'm yours! Photograph by Abigail Sellen.

shaking and re-orienting them to trigger the lights. Their holdable size and form, and importantly the ambiguity of their relationship to different sounds appeared to prompt this. Moreover, the dynamic quality and obvious responsiveness of the lights served to prolong people's engagements—there was an observable curiosity about the lights' behaviors and to what they might be responding.

The second and perhaps more unexpected result was that the Light Bodies provoked different ways of experimenting with the music and the piano. For instance, people standing around and listening to someone playing experimented with placing the Light Bodies on different parts of the piano. They were placed on the keys, beside the sheet music, and by the open lid of the instrument—near the strings and hammers. In effect, the lights were being used to explore the piano's structure and the relationship it had to the music being played. At the risk of reading too much into people's casual and off-hand experimentations, it seemed the lights afforded a means to explore the intersection of form and sound, re-experiencing space-in-the-small, so to speak.

Something we didn't see was the use of the lights to investigate the wider environment. We will discuss this in further detail in the discussion section. A possible explanation for this was the localised impact of the Light Bodies. The effects of the lights were really only detectable when standing around the piano, whereas we had hoped they might be noticed by the many people passing through and sitting around the square. On a practical level, we felt the draw of the lights was diminished by the ambient light levels and that they probably would have worked better in darker conditions.

Electrovision

In the third of our explorations we incorporated Light Bodies into an audiovisual event, Electrovision, also in London. (Seeger) Electrovision, held every two months, offers a small collective of VJs (video jockeys) a place to showcase their work in a bar purposefully arranged to view video and film. Projectors display content on three of the bar's large walls and visitors to the bar sit at tables and in couches surrounded by the projections. The bar is dimly lit and music is played alongside the visuals. We distributed twenty of the lights across the tables for the entire evening (approximately six hours). Again, the lights were programmed to respond to a combination of sound and vibration in a variety of ways. We used the revised software with enhanced audio and vibration responses that produced more distinctive outputs across light and color.

Our interest here was to further explore the relationships between performance, public space, and light and sound. We saw Electrovision as somewhere between the Klang.Körper/Licht.Körper performance and "Play Me, I'm Yours" Installation; the visual performances were clearly in the control of the VJs, but the audience had the freedom to talk, interact and freely move around the informal performance space. Thus, in the case of the Light Bodies, we hoped that people would freely interact with them and treat them as adjuncts to the visual performances. In short, we were interested to see if the lights might impact how the bar-goers experienced the space and engaged with the performance.

In a number of respects, the exploration revealed commonalities with the previous exercises. Again, people interacted with the objects to explore them further and also appeared to use them to investigate particular elements of space and form. Several features of the interactions warrant remark. In addition to tapping and shaking the lights, people appeared to be interested in the subtleties of interaction in that they made efforts to purposefully control the different effects with sounds and voice. For instance, we observed people blowing on the devices and, in one case, repeatedly singing to them. Some tried to control the lights' colors suggesting that they understood the lighting schemes were mapped to specific sound ranges. These interventions also, in several instances, evolved to incorporate multiple Light Bodies. We saw people gathering groups of Light Bodies from around the bar onto their own tables and subsequently stacking and organizing them. They explained how they wanted the lights to interact with one another, and how one might be set off to then trigger others, causing a relay effect.

What we found particularly interesting were people's playful experiments with physical forms and the performance space. On a number of occasions, we observed people using the lights to augment their own

Fig. 5.10. Interacting with Light Bodies. Photograph by Daniel Taub. More images available at www.flickr.com/photos/tentacles/sets/72157608649677169.

bodies and movements. Several put lights under their shirts, using the bass of the music to mimic their heart beats. Others used the lights as props, simulating birds, ear phones, soap bars, etc. Those collecting the lights sometimes organised them into patterns on the tables, drawing attention to certain areas of the bar. For example, one pattern depicted a large arrow pointing towards one of the wall projections. The lights were then simultaneously triggered, at maximum brightness, by vigorously knocking on the table. Some seemed equally happy to let the devices perform in an ambient way. Some people even turned the light upside down to color wash the table. We saw one group of people bring their light body with them as they moved from a smaller table to a bigger one. They appeared content to simply let it respond to the ambient sounds near their seating area.

Of course, we are well aware of the particular kinds of audiences that attend events like Electrovision and their likely enthusiasm for devices such as Light Bodies. However, we were encouraged to see people engaging with the lights in the ways they did. Overall, our impression was that this experience set out trajectories for further thought and investigation. Specifically, as we will go on to discuss, they highlighted a number of design possibilities worth exploring.

Discussion

Drawing inspiration from historical developments in urban lighting, we have presented preliminary work investigating the relationships between (urban) spaces, light and responsive, hand-held lights. We designed and built a prototype system enabling people to directly and indirectly influence their personal lightscape. Though the designs were very preliminary, we opportunistically introduced Light Bodies into a series of performance-like settings which are summarized in the following diagram (Fig. 5.11.). The diversity of the settings provided us with some starting points for imagining future theoretical, technical and design trajectories. In conclusion, we reflect on the central themes we have drawn from this work and how we hope to further pursue it.

Unexpected Affordances

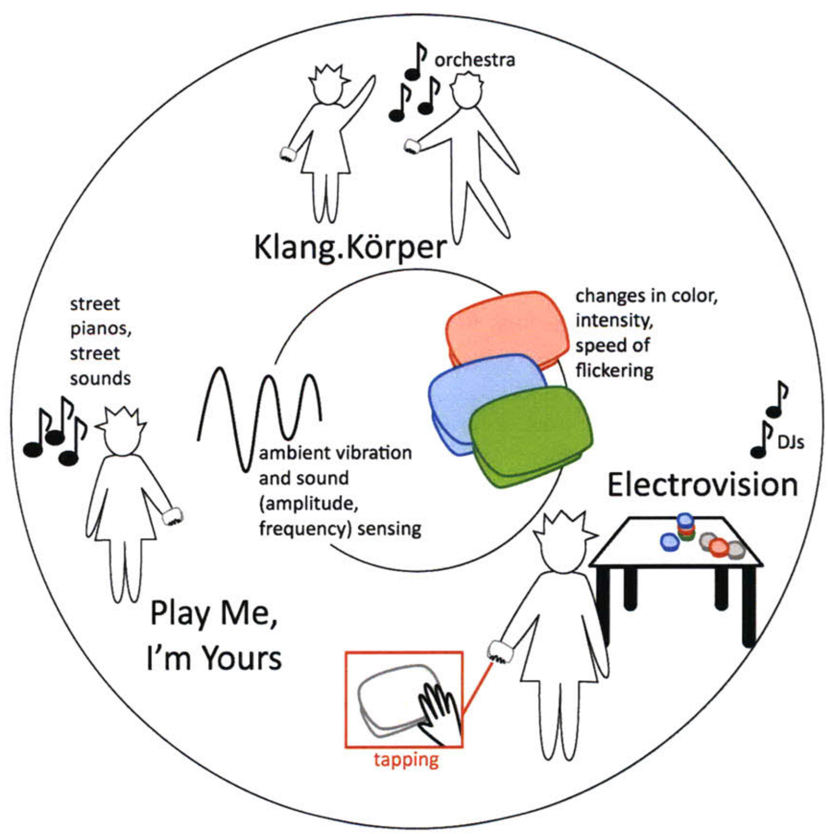
In all three explorations, we used off-the-shelf casings for the lights. We selected them because of the translucent shell and rounded edges that felt good to touch. Moreover, their easy availability allowed us to prototype the devices early in the design process, and, in doing so, invite feedback and speculation. As we have suggested, we were encouraged by the many playful interactions with the lights and, to some extent, felt the simple form of the cases provided an open-ended platform that encouraged exploration. Many of the interactions, however, were directed at either the lights themselves or the objects and furniture they were placed on. Although there were a few promising exceptions (especially at Electrovision), we saw little evidence of the lights being used to re-experience the surroundings. In this sense, at least, they appeared to be far more ambient in their behavior than we had intended.

Reflections on Open-ended Explorations

The three chosen venues provided a valuable platform for studying Light Bodies. By observing their use in performance settings, we found ourselves looking beyond the technical features of the Light Bodies, drawn far more to how they integrated with and occasionally disrupted people's behaviors. Pursuing the new designs, we've been struck by the impact this has had on all levels of implementation, from the form of the lights to their programming.

For example, our observations of people repeatedly tapping and shaking the lights or knocking on objects around them to extend the responses, led to us programming the dynamically changing thresholds (e.g. increasing brightness of a light pattern to staccato sounds, or increasing the trigger thresholds as overall audio levels increased). This, in turn, has helped us with re-designing the lights' casings and how they might work with directionality of audio. In future design scenarios, for example, we imagine the lights to decrease in brightness as one orients

Fig. 5.11. Interaction diagram showing the three deployments of Light Bodies.



the device towards the sound. The counter-intuitive relationship might encourage, we hope, a rethinking of regions of relative quiet.

Whatever the case, we've found the interjection of the Light Bodies into the live, open-ended and choreographed events has provoked us to think imaginatively about the interleaving of the computational workings, form, and usage of the lights; the observations have very much promoted reflections on the intersections between these layers.

Performative Space through Light

Our explorations all revolved around purposeful performances, even if the degree of preplanning and orchestration varied. The range of performances allowed us to witness very different audience-performer arrangements. For example, in Klang.Körper the explicit separation between audience and stage made the act of handing the Light Bodies to audience members symbolically significant. In the other explorations, people engaged with Light Bodies and became performers as a result. Inevitably, the lights became part of the performance and people treated them as stage props or ambient artifacts rather than as mundane, everyday objects (e.g. lanterns).

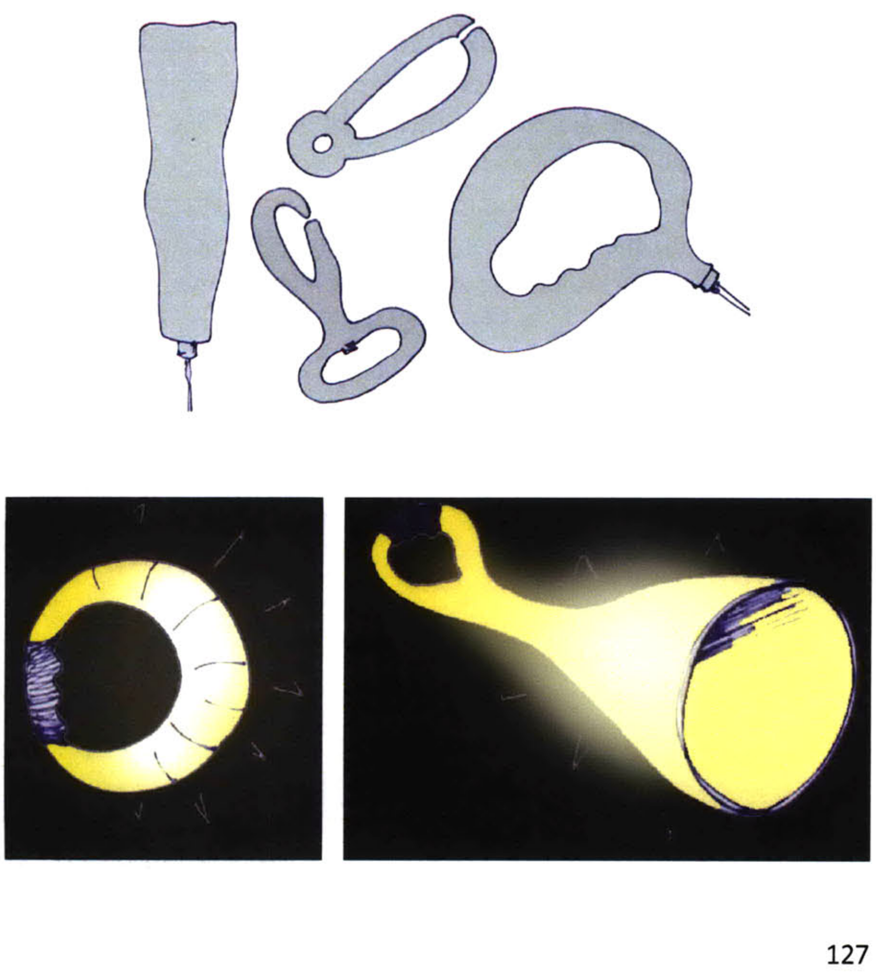


Fig. 5.12. Three alternative form factors for Light Bodies that might evoke different interaction patterns and relations between the environment and the devices.

Reaching for an Everyday, Urban Experience

Our current design work has been influenced by these observations. To expand the repertoire of the mobile lights and specifically to encourage people to use them to engage differently with space, we are working on more evocative cases. For example, we are experimenting with handles and hooks on the casings that might allow the responsive lights to be worn on coats, bags or bicycles and thus be visible while moving through public spaces (Fig. 5.12.).

Also, we are considering how different forms might suggest the orientation of the microphone in relation to the direction of the light, and how simple buttons or rings could adjust colors, beam angle and response patterns. We are also exploring designs for groupings of Light Bodies that would impact each other, prompting interaction across distances and between people.

Consequently, in our next explorations, the hope is to focus on urban environments that are not explicitly bound to performances. Rather than situating the lights in events where they are clearly intended to be experienced in unusual and unexpected ways, we want to examine their use in everyday, mundane settings in which the purpose of their advanced functions may be far more ambiguous. Many urban theorists have explored the performativity of urban spaces in reflecting upon the meaning of the public realm (Tonkiss, 2006). In future projects, our aim is to build on the examples we saw of people casually exploring the dynamic relationship between space, light and social interactions. As with the illuminated arrow and simulated heartbeats, we hope to see the designs we are working on provoke impromptu actions that alter the relations people have with their spaces and one another. In the long term, we intend to explore the interesting ways in which interactive, mobile lights can become a more mundane feature of our urban environments.

Chapter 6
Lessons Learned

This chapter has two primary goals. First, the aim is to reconnect the design explorations with the analytical perspective of sociomaterialism introduced in chapter 1. I review how the interventionist design method selected reveal the seeds for alternative futures of social-urban-technological assemblages. Second, the chapter summarizes the technological and design findings made through the physical implementations (additional materials are also available in the appendix). The chapter begins by describing the sociomaterial configurations explored in chapters 3-5. The recapitulation of the design explorations is followed by specific lessons learned for technology development and lessons learned for design. The chapter concludes with a review of the contributions of the thesis.

Envisioning New Sociomaterial Configurations

The three design explorations described in the previous chapters do not seek to provide an exhaustive view on the field of urban lighting and displays. Rather, they seek to be evocative examples and demonstrations of what is possible in light of the sociomaterial history and precedents described in chapter 2. The aim is to illustrate the contingent and entangled nature of these technologies in an urban context to enrich the repertoire of possibilities practitioners might imagine in the future. Significant technological shifts taking place in the LED-lighting industry make these futures incredibly relevant and have the potential to impact trajectories especially as certain shifts open a window of opportunity for new configurations.

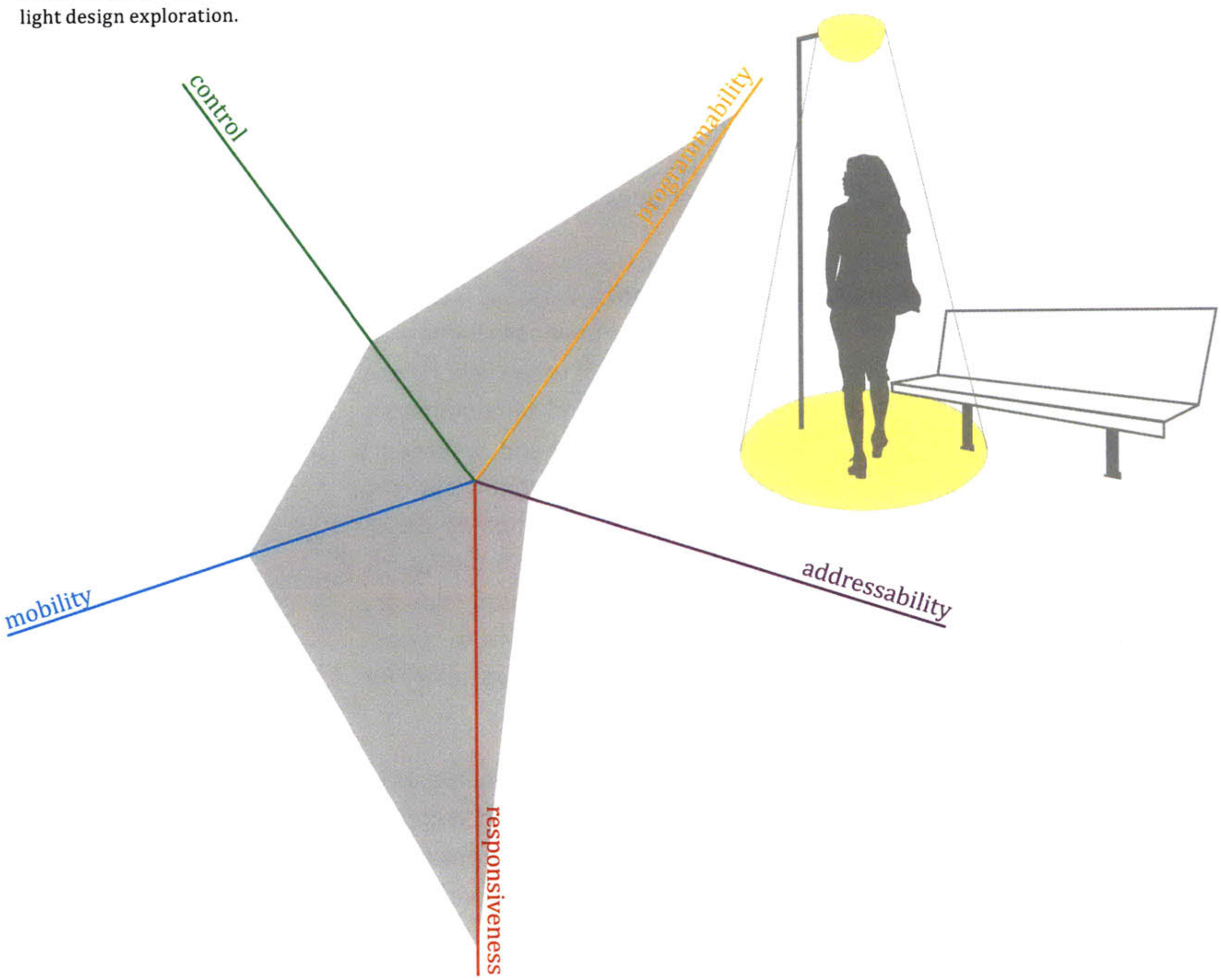
tipping points in complex, contingent systems

Dennis and Urry (2009) identify two ways of considering moments of possible change within a complex, interdependent social and technical system. In their study of the automobile, they identify two interpretations of possible tipping points. On the one hand, there are "moments of heightened openness" (Ibid., p. 59) within complex systems. On the other hand, they introduce the concept of "self-organized criticality" (Ibid., p. 60) which is a more chaotic and unpredictable potential for sudden, far-reaching change. It exceeds the scope of this thesis to determine which type of moment the field of urban, dynamic lighting is undergoing. Nevertheless there are important changes which motivate the need for alternative suggestions for moving into the future. That is the concern of the final chapters of this thesis.

models of creating new "figurations" of the past and the future

In a modest way, the perspective on urban histories and precedents reorients future trajectories in a way that echoes Haraway's (1991) use of the "cyborg" to overturn dominant discourses of technology, femininity, and identity. By "re-figuring" (Ibid., p. 3) actors such as women, she argues for an alternative order that embraces society as "multiply heterogenous, inhomogeneous, accountable, and connected human agents" (Haraway, 1991, p. 3). Similarly, I seek to break out of simple molds such as more light is equal to safety or assumptions around the distribution and placement

Fig. 6.1. Mapping the dimensions of liberated pixels onto the AR street light design exploration.



of illumination as a source of information about/onto the environment. Haraway's work transformed an entire discourse and reoriented it towards more multi-faceted theorizing around differences among actors. In a modest way, I intervene in existing contexts (rather than discourses) by inserting new artifacts that address different aspects of lighting and display. In the following recapitulation of each exploration, I highlight the specific sociomaterial aspects of that example. Chapter 7 then takes a step further to make broader claims about alternative futures.

AR Street Light

The AR Street Light adds color and motion to a commonplace infrastructure that is typically characterized by its fixed, unchanging state. In fact, street lighting typically goes unnoticed until there is an outage. Though lighting engineers dim street lights for energy savings, for example, there is much room for experimenting with more playful and delightful behaviors in these technologies. As shown earlier, the history of a regularly-spaced lighting network in the city dates back two hundred years at the most. And yet most people assume a blanket of illumination at night. Fig. 6.1. illustrates how AR Street Light maps onto the dimensions of liberated pixels introduced at the beginning of this dissertation. The system offers especially high degrees of programmability and responsiveness. The motion of the lamp to displace the pool of light implies some sense of mobility, but the device itself is fixed in place. Users have control over the responses of the light through their own movements, however, there is not direct control. As mentioned in chapter 3, it would also be interesting to give people the ability to change the color and orientation of the light directly. Finally, the light is not addressable from a distance in its current configuration, but this feature could be easily added to create effects across multiple street lights.

infrastructure with personality, programming behaviors for systems

In experimenting with the new capacities of programmable LED-based systems, designers can take greater advantage of the fine-grained adaptation made possible by responsive and programmable technologies. This notion raises broader questions of "intelligent infrastructure" which go beyond the scope of this discussion. Projects such as Ada, the luminous, tactile floor, illustrate how a simple series of rules leads to assumptions of intelligence on the part of users. (Delbrück et al., 2007) Related issues should be addressed in future research on intelligent urban infrastructures.

Urban Pixels

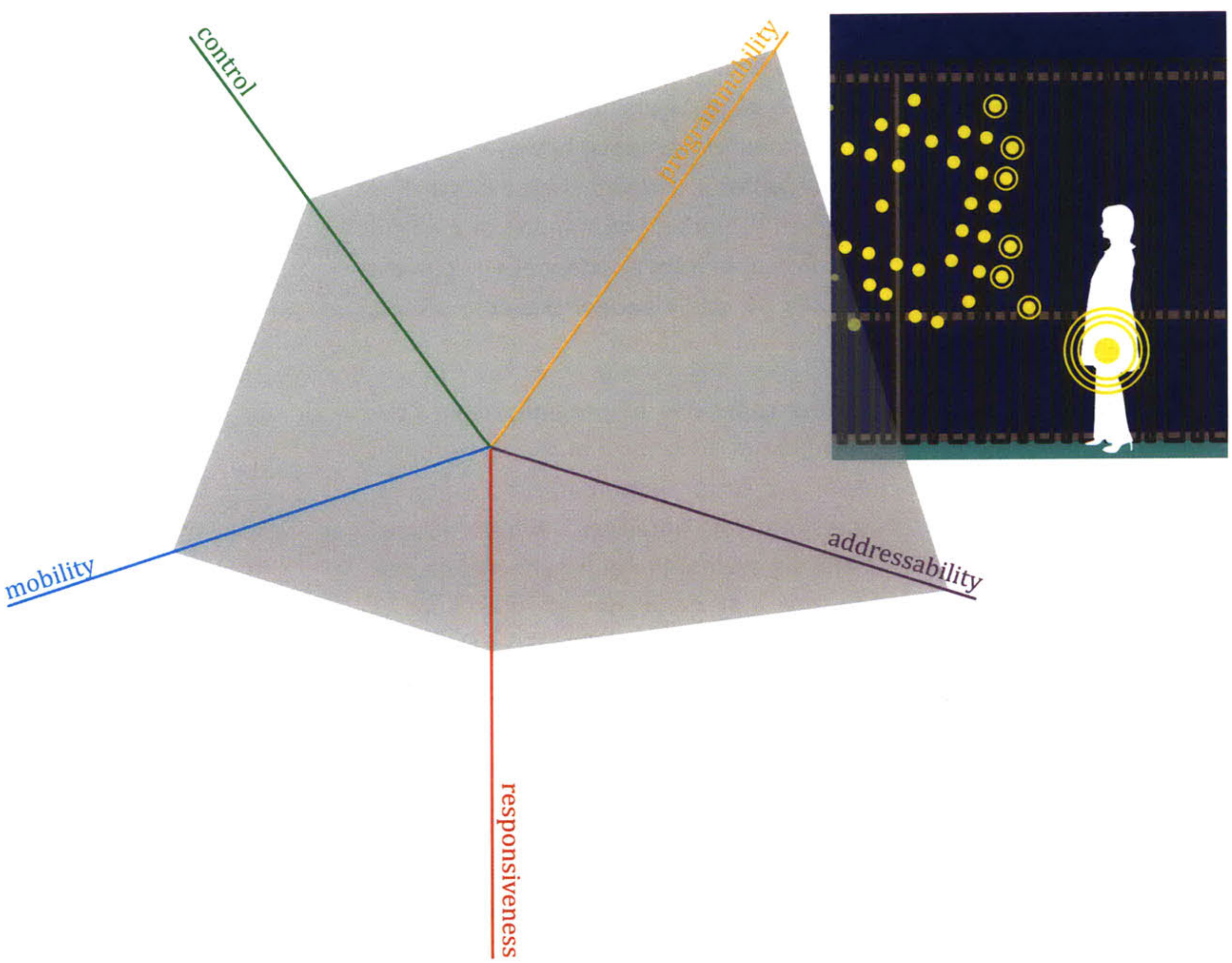
Urban Pixels focused on the disaggregation of pixels into independent elements that can be deployed across the physical landscape. In the early days of electric signage, each incandescent light bulb served as one pixel in the message. Similarly, each Urban Pixel presents one element of a programmable, flexible substrate. By combining the power of wireless networks with physical lighting elements, Urban Pixels recaptures the ability to recruit every point emanating light in the landscape into the display capabilities of a space. Meaning arises from the interplay between the physical context and people's interpretation of cues. Fig. 6.2. illustrates the high degree of programmability evidenced by Urban Pixels.

meaning-making through context and interaction

Among the other dimensions, mobility closely relates to programmability in Urban Pixels because rearranging the organization of pixels changes how content can be displayed on the network. The system exists between a public infrastructure (if we imagine a very large network) and an individually placed series of devices. Therefore, it receives half of the full marks under the mobility dimension in the diagram.

Addressability measures very highly in Urban Pixels because every unit is part of a wireless network. As already described in chapter 4, there are multiple ways to think about addressability that go beyond technical meanings to include the importance of the environment (built architectural

Fig. 6.2. Mapping the dimensions of liberated pixels onto the urban pixels design exploration.



forms), interjections through natural conditions (such as fog, rain), the position/point-of-view of observers (as a sensor trigger and simply as a way of framing what is visible at any given moment), and finally of course the basic technical addressability via a wireless network at a distance. It is this sociomaterial re-interpretation of addressability that makes Urban Pixels more than a reconstruction of large-scale billboards with flexible pixels. It allows for and encourages a more fluid notion of addressability as arising through a combination of social and technical factors. Rather than relying simply on the technical logics of addressability, this system highlights the importance of social actors and contextual information to provide new meaning contingent upon a given architectural setting. Neither large-scale billboards nor sophisticated programmable architectural facades necessarily have this ability. They are individual icons within the cityscape rather than connected and contingent networks of elements that can be recruited for different experiences.

identity and communication through mobility

User control and responsiveness are similar to mobility in that they are supported by Urban Pixels, but could be expanded upon more. In terms of responsiveness, the system used inputs from text messages and light sensors to change programs. With additional sensors, many more responsive and interactive behaviors could be explored. User control was also limited by the existing sensor inputs. More sophisticated open control platforms online or in situ would have allowed citizens to modify the display content more easily.

The notion of many small point-sources of light contradicts the dominant lumens/watt discourse driving contemporary LED-technologies. Urban pixels seeks to provide an alternative future of millions of point-sources in the city rather than a few powerful lights. In a way, we are witnessing a new march towards the light towers of the 19th century re-instantiated in a new technology. This project offers a way of talking about the potential benefits of other figurations for new networks of illuminated points.

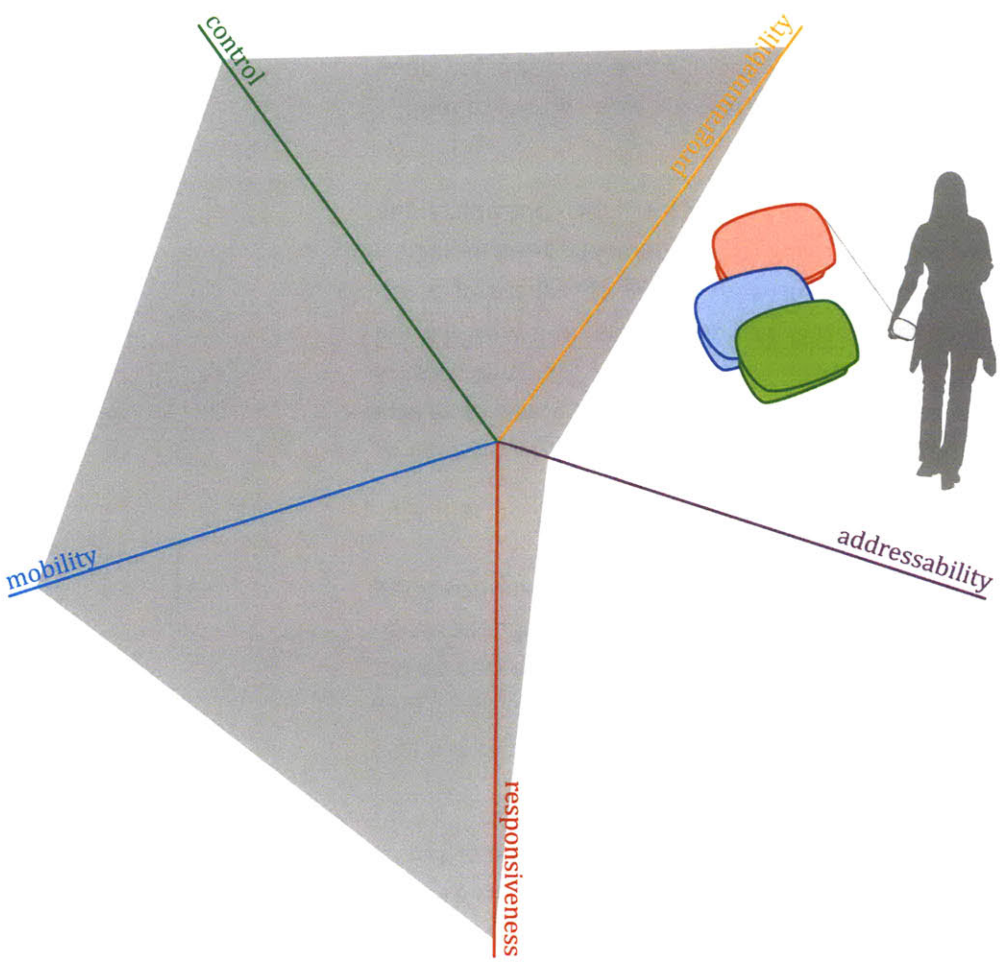
Light Bodies

Light Bodies could be described as Urban Pixels removed from the facade and placed into the hands of individuals moving through the urban environment. In this scenario, each pixel becomes a personalized object for navigating the landscape. For this reason, Fig. 6.3. illustrates very high degrees of mobility and control. Like Urban Pixels, Light Bodies are also easily programmable in terms of color and thresholds.

The performances used the audio-environment as a source of sensor data for modulating the colors and brightness of the devices. As a result, the degree of responsiveness is higher than in Urban Pixels which relied on fewer sensor inputs. They are not networked with each other, but it would be possible to couple the networking from Urban Pixels with the responsive nature of Light Bodies. Therefore, addressability is very low in this system. After liberating pixels from their position within an array as part of a media facade in Urban Pixels, Light Bodies enables mobility through the constant repositioning of devices that are connected to people in an attempt to reimagine the communicative qualities of early day lanterns. Light Bodies are communicative in that they aim to give feedback to the carrier about the environment and in turn make the individual's presence more legible to others sharing a space.

In many Western cities, we take regular street lighting for granted. We assume that the most appropriate form of urban illumination consists of lights mounted on regularly spaced posts. As discussed in chapter 2, this configuration dates back to the late 17th century when the first broad attempts were made in Western Europe to illuminate city streets. (Schivelbusch, 1988) Until then, people carried lanterns of all sorts to light their way and make their presence known. Schivelbusch (1988) compellingly describes how lanterns served both as illumination

Fig. 6.3. Mapping the dimensions of liberated pixels onto the light bodies design exploration.



and more importantly as communication. Carrying a lantern signaled to others that one was legitimately moving about the city at night. This view on a historical moment before brightly lit urban environments reminds us of the ephemeral and temporally-bound nature of nighttime and mobile illumination devices. This exploration attempts to take seriously the proposition of mobile lighting in the city today to recapture some of the dynamic and performative aspects of an earlier era. The aim is not to recreate a dark city, but to explore how illumination allows people to shape their experience of social, public spaces.

Mobility as a feature and characteristic of a material artifact such as a light enables people to play with their presentation of self in public space and modulate their communications with each other and the environment. Their ability to perceive spaces becomes dependent upon the brightness, orientation, beam configuration and sensing capabilities of the devices. They are an interface or lens for re-orienting to the social and the physical in an urban context. Today, people rarely have a glimpse of the degree of agency a mobile light places in their hands because there is so much base lighting available. It should be noted that the assumption here is of a light that throws in a 360-degree radius rather than leaving the holder in the dark (as a flashlight might). Though it exceeds the scope of this thesis, it should be noted here that more directed lighting would have very different effects on the communicative aspects of mobile lighting as it has been re-figured above.

Adding It Up

Blurring these three explorations provides a taste of all that may be possible in illuminating future cities. Rather than focusing on one technical artifact like street lighting, I weave together the histories of display and lighting, festivals and functions because in our experience of the city these technologies are not separate and independent from one another. Our interpretation and use of these technologies has changed over time and emphasized different qualities of evolving lighting and display technologies in accordance with specific socio-historical contexts. I focus on specific moments that present turning points in the outdoor, public use of light rather than providing a complete history of a particular system or technology. Revisiting specific moments including contemporary changes reveals a rich ongoing dialog between the qualities of specific technical systems and the associated sociomaterial arrangements from which they arise. We can trace a movement from personal, small-scale systems to large-scale infrastructures. We can recognize the ongoing oscillation between functional, safety-oriented systems and aesthetic, celebratory ones. Excavating these qualities provides a foundation for remixing them in new ways and taking advantage of the opportunities presented by advances in contemporary technologies (LED lighting and miniaturization of processors).

Explicitly reconnecting different qualities of light in outdoor public spaces through new systems also reflects how we have continuously added more infrastructures and systems to the public realm rather than replaced technologies wholesale. This additive mode is analogous to the way colored light mixes. When different sources of colored light overlap they mix in an additive fashion. In other words, we see the sum of all the wavelengths the light sources emitted which triggers more responses from the photoreceptors on our retina than each individual source. For example, red, green and blue overlapping light sources will allow us to see white. This notion of additive mixing provides a useful metaphor for considering urban spaces which are always lit from multiple sources that humans assemble into meaningful information about their physical and social context.

mixing light,
red + green + blue = white

Convergent information and illumination systems based on LED technology and miniaturized communications open up a rich design space that requires more exploration. Blurring is a theme that emerges from this exploration that harkens back to Stieglitz's affinity for halations in nighttime photography. He considered nighttime photography the true art because the lighting conditions were essential for the resulting image. Instead of producing a rendering of reality, the nighttime image requires the photographer to analyze a scene and use the camera to

Fig. 6.4. Rendering of floating pixels in the Arno River, Florence, Italy.

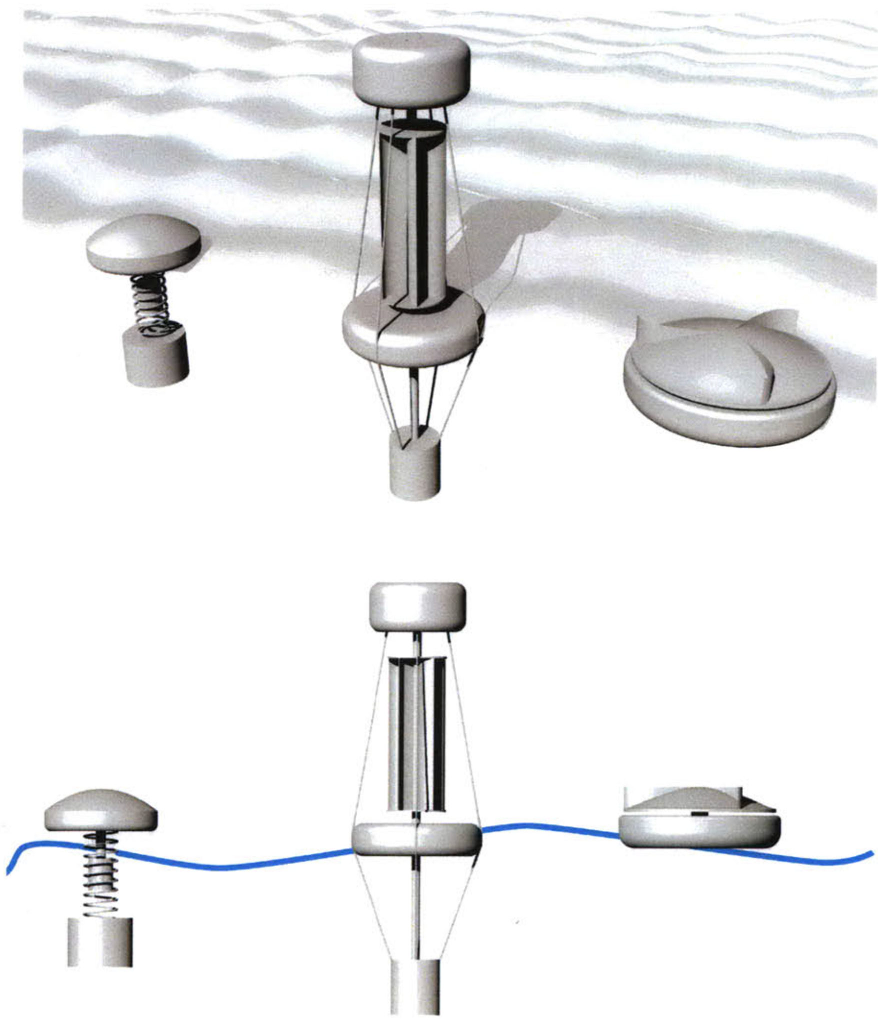


Fig. 6.5. Three proposed floating light artifacts powered by wave movements.

From left to right:

Option 1: LEDs in plastic casing and electronics, bobbing spring mechanism generates power, foam and concrete floating anchor to house batteries.

Option 2: LEDs in plastic casing approximately 1-5" above water level for better viewing, rotor blades capture wind, again foam and concrete floating anchor to house batteries.

Option 3: LEDs in plastic casing with rotor blades to capture wind, spins on its axis, again foam and concrete floating anchor to house batteries. (Renderings by Peter Schmitt)

provide her version of the image. Another photographer may choose an entirely different way to capture the light. In other words, this view takes the programmability and lack of fixedness of nighttime into account. By adding mobility and addressability made possible by wireless networking, low-power devices, and small form factors, future illumination and display systems can transfer new concepts into the lived experience of city dwellers to enhance their enjoyment, safety and quality of experience.

As an aside, it should be noted here that the particular logics for any "emergent" behavior among the series of lights have been neglected throughout the discussion. In general, all the systems proposed here are built upon increased degrees of local agency within the network or the artifact than most existing systems. Urban pixels were controlled from a master unit in the implemented project, but if there had been many more pixels a multi-hop network with localized masters would be been necessary. They were not however treated as single-cells within networks only dependent on relations with their neighbor units as in game-of-

Fig. 6.6. Visualization of pixels placed along a building facade for a temporary guidance system guiding people to a museum.

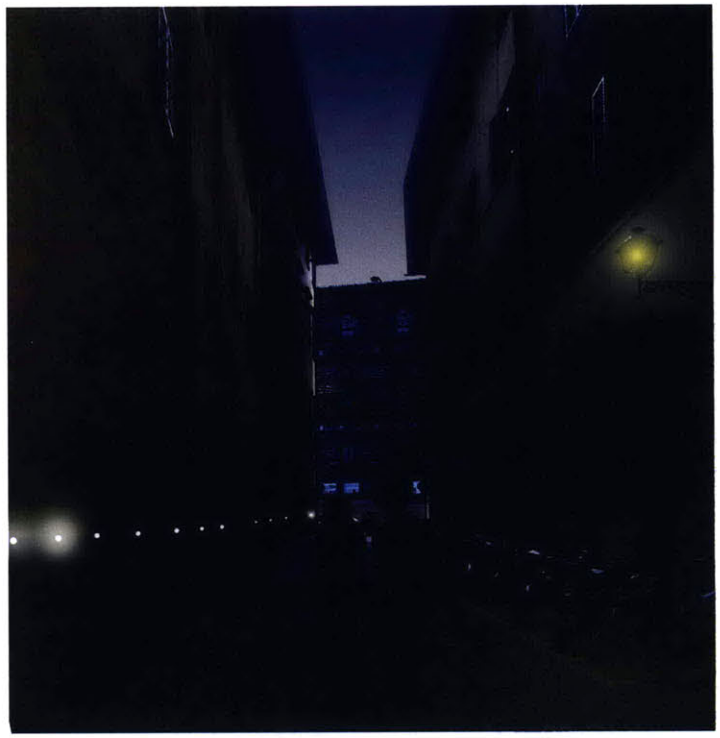


Fig. 6.7. Visualization of pixels placed on a building facade for a temporary light show. People are carrying hand-held versions of the same devices. Some of the existing infrastructure has been adapted to communicate with the ad-hoc devices.

life contexts. Though an interesting approach, this type of behavior privileges the system as a self-contained entity more than the system in its urban and social context. Urban pixels or light bodies could be used to implement various rule-based programs, but their value would arise from their integration within a particular social-urban setting.

Guidelines for Future Technologies

Though some of the following conclusions may have been reached in other related technical research projects, they are rarely presented as co-dependent or explicitly related. The convergence taking place around LEDs for lighting and display coupled with the miniaturization of electronics enable a new way of thinking about infrastructures of imageability, the collective term for new blurred lighting and display technologies termed in chapter 2. The lessons learned for technology are divided into three domains: illumination and display, responsive environments, sensor networks.

Illumination and Displays

- develop displays as three-dimensional artifacts
- work at the scale of the city rather than scaling up high-resolution, desktop metaphors for screens, urban screens are not large animated billboards or television screens
- understand street lights as lighting plus information

Technologists should design urban screens in three dimensions. The flexibility of substrates, the addressability of pixels over large distances, the reliability of addressing, etc. are all essential components of the creation of flexible urban-scale displays.

Along similar lines, the technical development of screens must move away from scaling up desktop-scale or even room-scale screens to the urban context. Rather they must take into account the potential of low-resolution, more distributed networks of pixels that together form information-conveying substrates. Urban screens are not large TVs or computer screens. They are a different animal related to the contextual links between ambient information in the city and the potential of emerging technologies.

While displays are overpowered by their message-oriented function, street lights are rarely considered for their information-displaying qualities. In considering the possible additional content to be conveyed with street lights we can imagine every pole with a light as a mini-projector that displays content onto the ground. Either by inserting analog or digital

Fig. 6.8. Diagram illustrating the continuity of content and display information across scales and technologies. The goal is not to reduce everything to "information", but rather to highlight the continuity which exists across scales and illuminating elements in the city. Designers should be empowered to create schemes which exploit these synergies.

filters between the light source and the ground we can imagine adding more information to an already ubiquitous infrastructure of illumination.

Responsive Environments and Ubicomp

- take advantage of the ubiquitous nature of lighting and illumination
- program for "auto-activity"
- support user-generated content, the appropriation of lighting and display systems

"auto-activity" (Sauter, 2010)

Ubiquitous computing depends on the networking of sensing infrastructures throughout our environments. These "invisible" infrastructures are supposed to support a more responsive environment of seamless computing experiences. Though we are seeing an increasing number of sensors in urban spaces, there is a long way to go towards any type of ubiquitous or coherent network. This challenges is often overlooked or underplayed in existing work on ubiquitous computing and HCI. As pointed out by Grinter, too often assumptions are made about the robustness and pervasiveness of a given infrastructure. Lighting and display systems could serve as the ideal substrate for experimenting further with the promise of more extensive responsive urban environments because their presence in cities is already strong and growing.

Sauter (2010) of the Berlin-based design firm Art+Com recently proposed that responsive environments have transitioned from being interactive, to being responsive to being –what he terms– auto-active. In other words, the environment has a series of ongoing behaviors that are punctuated by responses to people and environmental factors. Rather than thinking of illumination and display as simple outputs technology developers should think of them as ambient systems that are always on and at times respond to different factors.

Along the same lines, lighting and display infrastructures should support user-generated content more and allow for their appropriation (within the realm of safety standards as far as base lighting goes). As Struppek has called for elsewhere, we can imagine an internet of public screens (and I would add lighting) that are accessible and open. These networks can be local in order to take advantage of context or over a distance to connect architectural spaces across cities. This openness adds to the dynamism of systems as they respond to the comings and goings of people in the city.

Sensor Networks

- include feedback within the nodes of the sensor network
- increased awareness for the materiality of sensor networks
- consider the increased or reduced power requirements holistically

Sensor network rarely include a feedback mechanism on the nodes which stems from their primary use-case in hostile or inaccessible places. As we start to deploy more sensor networks in populated environments, feedback within a node becomes increasingly important. Urban pixels demonstrates the power a simple feedback mechanism has within a system of networked, wireless devices. More similar approaches are needed in the domain of lighting and display.

As sensor networks move into inhabited environments, their materiality will increasingly become important. The nature of the feedback, the type of lighting, its quality, and responsiveness are all tied to a specific node in this view. Rather than understanding sensor networks simply as the data gathering system we must think of them as data presentation devices as well whose material qualities matter.

Power requirements will continue to play an essential role for lighting and display technologies. As we increase the number of power-hungry systems in the environment, we must account for the increase in consumption. Low-resolution shows how technologists might couple information systems with lower power requirements. Using off-the-grid systems with battery-intermittent energy source combinations are another avenue for inquiry. Finally, wired, grid-tied systems should be considered for certain applications. In any case, though, we must reconcile the current contradiction between the push towards LED street lighting for energy savings and the explosions of LED-based screens throughout the environment. Thinking of these infrastructures as networked sensing devices that can work in concert will allow technologists to think more holistically about power requirements.

Guidelines for Design

The lessons learned for technology focused on the technical components that are important for achieving the kind of convergence between urban lighting design work and computing research alluded to in the introduction. The following lessons learned for design are intended to serve as a common language for these diverse practitioners in creating new types of dynamic, ambient lighting systems for cities. The lessons are thus also design guidelines for future projects.

Exploit the Programmability of LED-based Systems

Designers of display and lighting systems for urban environments should take advantage of the full range of benefits related to LED-based systems. Color, modulation, addressability enable a host of underexplored potential for rethinking fixed and temporary systems. The shift in public lighting towards more LED-based systems also enables a simpler coupling between lighting and display systems around these functionalities.

programmability ++
(Inspired by Mitchell, Me++, 2003)

Despite all the benefits of programmability, the field also requires an increasingly sensitive design approach that merges decades of lighting design knowledge with digital programmability. Many LED-based systems are programmed in harsh ways with rapid-fire changes of color and brightness. Like moby fireflies attempted to overcome the limitations of LED modulations by imitating a biological system, future designs should pay special attention to controlling even the most subtle shifts in brightness and color. The outcome does not have to be biologically inspired, but it must be designed with a very specific effect in mind. The merging of ambient, mood-setting systems like illumination and content-oriented systems like displays require such a sophisticated approach in order to be successful contributions to the public realm.

Design Transparent Displays

Lighting designers have a strong sensibility for architectural spaces. They use their skills to enhance them through modeling of spatial relationships or creating strong atmospheres. Displays rarely take advantage of the surrounding, existing conditions. Instead, they cover existing buildings (unless the building itself is conceived of as a display surface). In designing or redesigning existing urban spaces, designers should take the potential of synergies between display technologies and the existing (analog) context into account strongly. Like the simple animations overlaid onto the Media Lab made the parallel lines of the building façade come alive through optical illusions future systems should be thought of as transparent systems that work in concert with their context.

display plus existing context, dynamic plus static together form a whole

As a result the surroundings matters even more than context-aware computing or ubicomp have claimed. Whether information or ambient mood-setting features are presented on a display, the information should be tightly coupled to the existing conditions. A simple wave pattern to indicate a direction, for example, depends entirely on its placement in context in order to assume meaning. Under this criterion, ambient information systems transform into a type of layered, semi-transparent display system.

Create More Illusions

Urban display and lighting technologies should create more illusions through their interaction with three-dimensional space. Designers must consider these screens as extensions or at least elements of the physical environment and program content that takes advantage of this information. They can subvert the existing spatial relationships or reinforce them. This approach provides the possibility for illusion and magic to enhance citizens' experience of their cities at night. It is reminiscent of Carolyn Marvin's (1988) analysis of the advent of electrification and the battle between "magicians" who exploited the technology to create wonder and "engineers" who attempted to rationalize the phenomenon in order to exert control.

Link Personal Devices and Collective Infrastructures

personal and collective systems

People's mobile devices can serve as extensions of the ubiquitous public display and lighting infrastructures. Either as inputs, sensors, controllers etc. these personal devices can be augmented through the appropriation of collective systems. Conversely, collective infrastructures can bleed out of their fixed locations onto mobile, hand-held systems that individuals' control.

Create Place through Display and Illumination

placemaking

Lighting designers have already worked strongly on using illumination to shape place. Europe (and France) has been leading the trend towards placemaking through lighting. Displays writ broadly are slowly finding their way into this space via interactive, mostly short-term art installations. Increasingly, these strategies are converging in urban illumination design for the holistic rethinking of urban public environments. It is essential that designers continue to move in this direction in order to enhance the quality of the urban public realm beyond the functional requirements of traffic and pedestrian safety.

Contributions of the Thesis

This section summarizes the main contributions of the dissertation which can be divide into three general areas: historical and contemporary precedents for rethinking approaches to lighting and display in the city; three original and implemented design explorations; a vision for liberated pixels.

The thorough historical and contemporary review of evocative uses of light and display in cities using a sociomaterial lens plays an important role in contextualizing the design explorations. Within HCI and ubicomp research this task often exceeds the scope of the projects due to space and time constraints. It was important to me to provide the socio-cultural grounding before suggesting steps towards alternative futures.

The three original design explorations touched on topics from evocative and playful infrastructure to ideas around flexible and three-dimensional displays composed of wireless physical pixels. Each project and especially Urban Pixels evolved through many design iterations. Though fifty pixels is still limited, Urban Pixels begins to move in the direction envisioned for future systems of many individual connected point sources of light. All three explorations provided lessons learned for various technical domains including illumination, display, ubiquitous computing infrastructures, and sensor networks. Pushing for full scale implementation also informed future design choices more than visualizations or design proposals could have.

The final contribution, the vision for liberated pixels, is elaborated more in chapter 7. The proposal suggests alternative configurations of light and ambient display in cities. Future research and design projects can benefit from this vision as a source of inspiration and reminder that any instantiation is only one possible embodiment of an idea.

These contributions are a first step towards taking advantage of the window of opportunity within urban lighting design described throughout this dissertation. The significance of the work consists in the attempt to take seriously the flexibility, and three-dimensionality of displays. The projects emphasize the transparency made possible by using many, individually addressable points of light. There is a serious attempt to revisit the importance of communication and light through hand-held, personal, mobile devices. Finally, the significance of evocative infrastructures that reflect back information about the environment to users within a public context is explored together with new roles of lighting in the city.

Chapter 7
Conclusions

The concluding chapter of this dissertation fulfills the promise in the title to propose alternative narratives for lighting future cities. Rather than suggesting specific technical and design guidelines as in chapter 6, the goal here is to provide more general conclusions that can support powerful new figurations of urban space, technology and interaction with light. (Haraway, 1991) The chapter is divided into two sections. The first describes the alternative narratives or configurations as they arise from the design explorations and preceding historical, sociomaterial discussion. The second section reiterates and expands upon the liberated pixels vision as it is posited in the introduction.

Alternative Narratives for Lighting Future Cities

This dissertation aims to suggest new ways of imagining and designing illumination and display in cities of the future. The salience of this topic rests on a contemporary technical convergence between lighting and display functions at the most elemental level: the LED. Unlike past light sources, LEDs require more fine-grained programming to perform their best. The concomitant miniaturization of control electronics enables this programmability "for free" as the cost of additional computing power plummets. (Haitz's Law is the equivalent of Moore's Law for the rapid increase in computing power as measured by industry's ability to double the number of transistors in an integrated circuit every 18 to 24 months. Haitz's Law states that the For LEDs, the equivalent is a tenfold drop in the cost per lumen and a twentyfold increase in the amount of light generated for a given wavelength per LED every ten years.)

Though contemporary technical developments are the initial impetus for this exploration, the alternative narratives arise from a historical and socio-cultural framing of display and lighting in the history of urban form. The following narratives are facilitated by the LED revolution, but they are not dependent on it. As we have learned from science and technology scholars, technical systems are not independent of their use-cases. Designers, technologists and people have the power to shape the narratives of the technical systems with which they live. (Nye, 2006)

Blurring: A Metaphor

In chapter 6, I introduced the notion of mixing colored lights to describe the overlapping between display and lighting as a result of the technical convergence within these systems. Beyond this similarity, the notion of blurring serves more as a metaphor to describe a growing affinity among these systems based on how we might envision their use in cities of the future. Blurring also implies that the boundaries among these systems are less clear. In the early days as shown in chapter 2, illumination and communication coincided. The same device – the lantern – served both purposes. These two functions separated from each other in subsequent centuries creating a new boundary. Under the blurring metaphor, this boundary is again becoming fuzzy as it is conceivable that hand-held, communicative lighting devices will be deployed in cities. There will be a reconnection among disparate elements.

compare this discussion to additive mixing in chapter 6

Ubiquitous computing, tangible computing and ambient computing all share the notion of seamlessness. Even when the seams are explicitly discussed it is usually to overcome them. Scholars in the field have increasingly aimed to show the importance of these seams. They require work to overcome. For example, Grinter and colleagues (2009) provided a vivid description of the work required to maintain a home network. Unlike the happy, easy images shown in TV advertisements of the networked home, people struggle to maintain their networks and spend significant amounts of time. This time is not spent in vain, but it should be acknowledged and understood.

Blurring is another take on seamlessness that attempts to take the boundary into account. Rather than assuming that things are the same, blurring makes them fuzzy and oddly related in a new way. The goal is to change the expectations we have vis-à-vis our lighting and display technologies just like HCI researchers have increasingly identified the benefits of engaging with technologies at the boundary. The sociomaterial history provided in chapter 2 frames the blurring between display and lighting identified as fundamental for liberated pixels. Three narratives emerge from this framing of the design explorations. As other designers and scholars move forward these narratives are both powerful inspirations and also reminders of the importance of narrative for the positioning of technology's role in society.

From the Artificial Sun to the Pixilated Landscape

This narrative addresses the two trends within the history of display and lighting towards brighter and more devices. Each new lighting technology was accompanied by an enormous increase in brightness. At the same time, the number of individual light sources has proliferated. LED-based systems lend themselves to both brighter and increasingly pixilated environments.

One cut through the history of illumination shows the steady increase in brightness with the advent of every new lighting technology. At each juncture – even the early reflector lanterns – contemporaries hailed the new devices as the brightest they had ever witnessed. The march towards illuminating the night culminated in the myriad proposals for artificial suns. As shown in chapter 2, large towers mounted with extremely bright arc lights were imagined as replacements for regular street lights. According to this logic, the individual number of point sources of light would be reduced in favor of fewer, brighter solutions.

Another perspective identifies the proliferation of individual light sources. From the earliest days, festivals, celebrations and later advertising were based upon more points distributed in space. The approach generates a programmable landscape rather than illumination like on a stage set. Instead of envisioning illumination as a reconstruction of daytime, these designers and professionals focused on creating special, nighttime experiences based upon the proliferation of smaller, individually less bright light sources. These animated billboards, signs, and displays became at least as important for understanding (and reading the image of) cities as the parallel installations of street lights.

The historical narrative of brightness has been overtaken by the parallel narrative of more point-sources. Even as we continue to build street lights for base lighting throughout our urban environments, we are witnessing the proliferation of (public and private) ambient displays, screens and illumination as well as different types of public street lighting. LEDs will not replace all lighting wholesale as current debates in industry magazines demonstrate (see Light+Day, Magazine of the Illuminating Engineering Society). As a result, we find ourselves in a pixilated landscape. Extremely bright artificial suns did not replace all other systems and thus designers, engineers and planners have the opportunity to create proposals for multi-faceted and ever expanding design spaces rather than focusing only on the technology of the moment. The screen-based metaphor of the pixel serves to highlight this potential.

A Malleable Environment

The notion of a pixilated landscape implies the ability for more fine-grained control which provides more opportunities for design. I call this condition a malleable environment. Nighttime has always been associated with potential threats and possibilities for exploration. Even though spaces are becoming brighter, nighttime still shapes social encounters because of the variegated nature of illumination. Unless we deploy mirrors in outer space to imitate the sun by night, we will continue to live in a cyclical environment of light and dark which means a dependency on artificial light sources to navigate public space at night. Thus individuals' ability to shape their environment (personalize lighting versus collective infrastructure) extends the age-old tension between danger and possibility in the urban night.

The earliest forms of illumination were hand-held, mobile devices such as torches, candles and lanterns. These devices combined the communicative function of identifying someone's presence with the practical function of lighting the ground. Though this simple description does not yet address what is meant by "communication" it highlights the difference between personal devices and fixed infrastructures. A pixilated landscape does not have to consist simply of fixed elements, but can and perhaps should include a network of personal elements as well. In this narrative, the environment is shaped by the presence of individuals who navigate the complex social situations which arise at nighttime.

Binary situations such as light = safe and dark = dangerous are called into question by this notion of an emergent nighttime landscape. In Goffman's terms these early interactions were "focused" even though they took place among strangers at a distance (1963, p. 24). He defines "focused interaction" as something that takes place "when persons gather close together and openly cooperate to sustain a single focus of attention" (ibid.) While "unfocused interaction" is "the kind of communication that occurs when one gleans information about another person present by glancing at him" or the "management of sheer and mere copresence" (ibid.). These early urban lighting systems implied a willingness to engage in a focused interaction at least for a fleeting moment.

The choreography of nocturnal city spaces not only impacts the appearance of physical forms, but also the types of social situations (Goffman, 1963) which are the primary focus of this paper. First, the transformation of spaces through light at night changes a fundamental parameter and necessary precondition for interaction: a shared physical space. In Goffman, a social situation depends on "full spatial environments anywhere within which an entering person becomes a member of the gathering" (Goffman, 1963, p. 18). If the definition of this environment fluctuates, the social situation, gathering and any interactions taking place therein are impacted. Goffman's notion of "conventional situational closures" consists in physical architectural elements such as walls. He discusses how a window can create an ambiguous environment for exchanges to take place (Goffman, 1963, Chapter 9). Communication technologies – and light as we have seen is part of this category – engender even more ambiguous conditions.

A caricature of an interaction at night in a Beijing Opera performance illustrates that the sharing of physical space is a prerequisite for social interaction. The Beijing Opera performances are traditionally staged without alterable stage lighting. A scene's context is thus conveyed to observers through the use of props and acting techniques. In one particular scene, two fighters are trying to engage each other in a brawl at nighttime. In order to convey to the audience that this scene is taking place at night the two actors dance around each other and only occasionally fight when they happen to bump into each other. This technique conveys to the audience that the scene is taking place at night. In other words, the audience interprets an absence of direct interaction as a nighttime scene. In Goffman's terms (1963), a "focused interaction" between two people would not be possible under these conditions because light creates the "room" or framework for interaction.

Second, artificial lighting makes it more difficult to perceive others which can inhibit interaction. For Goffman, perceiving one's counterpart is a necessary precondition for interaction: "When one speaks of experiencing someone else with one's naked sense, one usually implies the reception of embodied messages. This linkage of naked senses on one side and embodied transmission on the other provides one of the crucial communication conditions of face-to-face interaction." (Goffman, 1963, p. 15)

Some messages then may not be perceived as embodied under poor lighting conditions. Third, limited perception of the environment and other people can lead to misunderstandings about the content of a message. A study done by General Electric in the mid 1920s shows how a statue can be transformed through different floodlighting schemes. A person's face can appear quite differently and in contradiction to what she is saying given a certain illumination scheme. In other words, a message may be embodied, but there may be a contradiction between that presence and the content of the message.

All these factors contribute to an overall point: what you perceive and how you perceive it are no longer assumed to be equivalent and indeed they are no longer equivalent at night. During the day we expect to see all there is to see with our visual apparatus. This congruence is considered the "normal" state. At night, however, we know that our eyes are limited to those parts of the environment which are illuminated. In Goffman's language the environment "impinges" on us at night because we cannot take it for granted (Goffman, 1974, p. 33).

Adkins et al. (2006) refer to Goffman (1974) to study cognitive impairment paper, "Indeed, adults in urban communities may move about through months of their days without once finding themselves out of control of their bodies or unprepared for the impingement of the environment – the whole of the natural world having been subjugated by public and private means of control." (Adkins et al., 2006, p. 33)

Light is a technology in the hands of humans that facilitates social interaction. While lighting technologies are primarily discussed in a historical context, mobile communications devices have unleashed a debate over the nature of social interactions mediated by technologies in cities today. Logically expanding on Goffman's theories led Meyrowitz (1985) to conclude that electronic media inhibit social situations because they cause a discontinuity in the space of the social situation. This finding has been debunked by many studies of the use of mobile communications devices (Ito, Taylor, Rheingold, and more). For example, Ito has studied the use of mobile phones in Japan and uncovered a rich set of social interactions. She introduces the concept of "technosocial relation" which "relies on a formulation of place and setting that accounts for flows of electronic media but is still grounded in material architectures and structuring social orders." (Ito, 2005, p. 272) Ito's notion of the technosocial relation needs to be adapted to lighting technologies. On the one hand these systems also impact the experience of place. On the other hand, lighting is part of the environmental cues impacting a social situation – which is something mobile devices, for example, cannot do. As a result the types of social interaction which might arise are still grounded in many of Goffman's explanations for social interaction such as the need for a shared physical space which the following section discusses in more detail.

Shared Places for Interaction

Studying mobile communication devices raises several relevant issues that reveal factors about interactions facilitated by light. First, while using a cell phone, for example, people are connected with their "virtual social group" rather than the people around them (Ito in Rheingold, p. 28). Second, other categories of social interaction become possible in public spaces including "intimate and private contact with physically absent others" (Ito, 2005, p. 271-272). Third, people's sense of place or space shifts when the focus of their social interactions does not coincide with their physical location.

This last consequence is significant for urban environments in particular. Bull describes how music players generate a "privatised conceptual space" (Bull, 2004, p. 111) around listeners. He refers to "technologies of accompanied solitude" that people crave in order to "[shrink] space into something manageable and habitable" (Bull, 2004, p. 106). In response to the contradictory impressions of the city they create a protective bubble around themselves. This protective bubble can impact sense of place. There have always been technologies – such as the newspaper – which have "shielded" (Goffman, 1963, Chapter 3) us in public space, but they have never enveloped our senses or transported us to other social situations.

Furthermore, certain "interaction shields" (Goffman, 1963, Chapter 3) privatize the surroundings. Bull claims that the "distinction between private mood or orientation and their surroundings (Walkman users) is invariably abolished" (Bull, 2004, p. 113) when people listen to music players in public places. In other words social interaction especially with strangers must necessarily change as a result. And not only does this inhibit interaction, but it also erodes any feeling of connection to public place.

Bull's reading is too simple because it does not account for moving back and forth between participation in public life and a privatized experience of urban spaces. Turkle (2006) introduces the notion of "liminal" space rather than privatized space to describe how people move back and forth between their private and public experiences. They switch back and forth fluidly between private and public.

If the conditions for social interaction are dependent on something as uncontrollable as street lighting today neither Turkle nor Bull's theory accurately captures what is at stake for people at night, however. People are experiencing an exceptional state where the environment can infringe upon them at any point regardless of their desire to behave in a certain way. This difference to daytime situations is significant because the uncertainty of night time interactions can shift a situation from enjoyable to frightening in an instant.

This interpretation explains why the topics of fear and danger have dominated discussions of cities at night. Cities would lock up their gates at night to protect themselves from invaders (Schivelbusch 1988). Intra muros was not always safe either, though, as the description of early lantern bearers in London shows who colluded with bandits to rob citizens at night (Schivelbusch 1988). Today most discussion of urban lighting are still about safety. Even levels of light make people feel safe because they imitate daytime. Overly bright or very dark places cause people to feel uneasy.

All our social interactions are mediated by artificial light sources at nighttime. (Again I'm not considering other senses for the purposes of this exploration even though they are important. However, they are beyond the scope of this thesis.) Our implementation of lighting technology has changed over time with increasingly powerful lights. Instead of carrying lights on our bodies we have simply extended daytime into the night. This technological feat allows us to extend our daytime social practices into the night as well. In some situations, however, the environment "infringes" upon us to use Goffman's language when there is a discontinuity in lighting. When we no longer apprehend our surroundings we can enter into a state that Goffman would consider exceptional or not normal. This condition feels unsettling and perhaps even unmanageable. We no longer have our private lights as recourse in these situations – as in the Middle Ages when people could respond to the question "who goes there" by illuminating a lantern to show themselves. As a result privatizing technologies such as music players become even more alluring – they protect us from these destabilizing situations because they overlay a connective tissue onto the shifting social "field" of night.

If lighting then is a technology for interaction rather than a simple functional feature of urban infrastructure urban lighting design should be adapted. Rather than a safety device lighting should be thought of as a communication device that marks our presence in urban places. It can support many types of interactions that change rapidly. These social situations specifically address issues of social isolation which tend to be promoted by aesthetizing technologies (Bull 2004) such as music players that disconnect us from place. McCullough makes a strong argument for the role of technologies in shaping our relationship to place. Lighting may be one strong tool that allows us to "get back into place" and provide an alternative narrative for the importance of illumination and displays as social technologies.

Infrastructures of Imageability

As described in chapter 2, lighting engineers categorized the city into hierarchical categories of varying brightness from the bright commercial districts to more subtly lit residential districts. Purposefully or not, they were programming the city's footprint at night and the image people could create in their minds of the urban structure. These hierarchies result in a characteristic footprint that distinguishes one city from another. Armengaud et al. (2009) even claim that nighttime increasingly becomes the only time when urban environments can be differentiated because the unique characteristics of place emerge with greater definition.

Overall, infrastructures such as street lighting and display systems affect the "imageability" of the city though as any visitor to a city knows they do not always succeed in improving the legibility of an urban space. Lynch (1960, 1964) studied people's subjective experience of urban spaces and found certain symbols and markers assisted people in navigating complex environments. The configuration of various urban features such as landmarks supported or detracted from the imageability of an urban space according to Lynch.

Infrastructures of imageability in the city are varied and at the service of many interests including public and private, commercial and non-profit, large-scale and small-scale. Marseille's street addressing system emerged from a bureaucratic need to reliably find specific people spread out through the city (Dourish & Bell, 2007; Smail, 1999). The absolutist state installed autonomous lighting in Paris to take control of city streets at night (Schivelbusch 1988). Today, new communication technologies are creating more fluid boundaries between lighting and display systems that are explored in the next section.

Lighting and display technologies transform people's experience of the city because they are infrastructures of imageability (Lynch 1964, 1972). Each new wave of lighting technology – lantern, reflector lantern, gaslight, electric light – increased levels of illumination. The last wave of electrification truly enabled the explosion of light in display technologies. The World's Fairs and the emergence of the Great White Ways in the United States became essential to city identity. (Jakle, 2001)

With a shift towards pixilated narratives about cities, urban footprints will become more dynamic either as a result of preprogrammed content or through interactive/responsive features. The image will become the sum total of individuals' movements in the city as well as large-scale display installations. Positioning people's agency vis-à-vis these infrastructures of imageability will play an increasingly important role. Providing access for content generation and making responsive features more transparent are value-laden decisions that require public dialog. (Struppek, 2006)

Reiterating the Liberated Pixels Vision

The following paragraphs serve to rethink the promise of ubiquitous programmable display and lighting as an emergent sociomaterial landscape of people and liberated pixels. Many visions for future computing environments assume networks of programmable screens and displays. They usually consist of a combination of large-scale, shared and small-scale, personal devices. The preceding analysis attempts to reinstate the emergent and sociomaterial nature of these ubiquitously programmable display and lighting environments. Rather than consisting of "smart" infrastructures they are contingent upon the narratives people overlay onto them as well as the particular arrangements in which they are designed and later used.

When McLuhan writes that "...a light bulb creates an environment by its mere presence." (McLuhan, 1964) he underestimates the importance of how people respond to the light bulb as the central aspect of the environment. It is the performative interventions of people in those lit environments that create urban life (Chase et al., 2008; Lynch, 1972). Kirshenblatt-Gimblett (Chase et al., 2008, p. 19) writes: "Performance is also central to the production of the urban vernacular, for performance produces spatial form. By performance I mean everything from hanging the laundry out to dry to hopscotch or lion dancing during the Chinese New Year holiday." . A performative view of liberated pixels takes the emergent nature of public spaces into account in order to increase the dialog among designers, engineers and users around the image of their cities of the future. The proliferation of certain technologies over others is not a haphazard process, but one being shaped by us. There is a blurring here between everyday, ordinary experiences and actual choreographed performance. The design explorations reflected this tension by engaging with ordinary infrastructure as in the AR Street Light and formal performances as in Light Bodies.

As described in the introduction, urban design partly emerged in response to an increasingly rigid framework for city form which arose from the standards determined by the car. The vehicle's dimensions, safety requirements, speed determined road widths, set backs and signage. In many ways, the pedestrian realm was subordinated to the vehicular realm. Even elaborate traffic calming methods intended to give back space and safety to pedestrians and cyclists ultimately take the vehicle as the basic common denominator. Transportation engineers have used these parameters to establish highly detailed frameworks for design that often leave little space for creative and site-specific solutions. Urban designers have been pushing back, though, to bring back the role of place making into city design. More flexible urban design frameworks and design guidelines rather than rigid, quantitative measures allow designers to provide for the necessary transportation requirements while still producing creative solutions for the public realm.

Like urban design, lighting has been dominated by engineering standards. As we saw through Otter's analysis of nineteenth century England, engineers have focused on improving their ability to accurately measure and determine quantitative measures for lighting. The increased ability to measure and specify exact lighting levels and conditions for optimal physiological responses dominate most city codes. Of course these advances are invaluable. No one would claim that such photometric measures are not essential for our understanding of spaces. However, we have reached a moment – like in urban design – when revolutionary technologies should allow designers to break open the frame and consider more design options. Ideally, these options would take place in concert with engineers. The push towards more holistic approaches such as urban lighting master plans in the face of proliferating urban media facades and screens depends on this dialog.

A manifesto of sorts, liberated pixels (LPs) are more than just a material technology. They are a way of understanding the emerging narratives around display and lighting that are taking place all around us in connection with new systems being deployed in cities. Rather than presenting a break with the past, however, they are in many ways a continuation of historical trends and struggles around brightness, control, and image.

One of the central areas, though, for exploration and contribution rests with designers and engineers in considering how to program for the emergent landscape of LPs. Three aspects of programming will play a role. First, more than ever, the architectural and urban context will play an even more important role. These systems should not cover up the existing environment, but rather work in concert with it. Second, the types of patterns, animations, images whether high-resolution or low-resolution will need fine-grained curation and careful design. Finally, these systems will be contingent ones where the individual's role in meaning-making becomes a constitutive element of the end result. In other words, LPs are embedded within a performative notion of public space that requires a deeper engagement among urban stakeholders.

Future Work

Most of the technical limitations of the design explorations can be resolved in future development cycles. For example in Urban Pixels, the lack of localization could be remedied in future implementations. Various solutions using local masters and beacons with known positions or external devices such as cameras could be imagined. In AR Street Light, a more effective tracking technology could also be implemented rather easily. Overcoming these technical shortcomings is not as essential for proving the liberated pixels vision as experimenting with more content ideas, flexible programming strategies and evocative form factors (refer to the discussion on new shapes for Light Bodies) in the future.

The two most important domains of content development are more user-generated content and the interaction with spatial context that take advantage of the three-dimensional space. Using the spatial relationships among different systems as an exciting input to the systems would lead to a more cinematic redesign of urban screens. In combination with user-generated content or inputs (by triggering sensors, for example), these screens would be extensions of the public realm rather than animated billboards or flashy architectural statements.

In order to test the proposals, long-term and larger-scale deployments at the city scale are essential. Either by deploying more systems like Urban Pixels or appropriating existing environments like Times Square it would be possible to test some of the design proposals at full scale. Going beyond simulation into a real world context is essential in exploring this domain. The complexity and subjectivity of lighting further increases the importance of full-scale implementations and experiments. As stated at the outset, the sum total of display and lighting comprise our lightscapes in the city. Designers and engineers should test more provocative proposals in these real world contexts to demonstrate the value of multiple, alternative narratives to enrich everyone's experience of the city.

List of Images

(Images are by the author unless noted otherwise.)

Chapter 1

Fig. 0.1. Milla Digital Zaragoza, Spain. Visualization by Franco Vairani. (Frenchman, Mitchell, 2006) ... 17
Fig. 1.1. Definitive publication on LED technology by E. Fred Schubert (2006). 20
Fig. 1.2. I/O Bulb diagram by John Underkoffler (1999). 20
Fig. 1.3. Engineering specification from the early 20th century for a proposed luminaire. General Electric Review 22 (December 1919), p. 1044. (Jakle, 2001, Figure 5.3) 22
Fig. 1.4. Diagram illustrating the five dimensions of liberated pixels. This representation is used in subsequent chapters to map the design explorations. 37
Fig. 1.5. Three design explorations. From left to right: AR Street Light, Urban Pixels, Light Bodies. 38

Chapter 2

Fig. 2.1. Adapted from the Outdoor Lighting Guide (2005). 44
Fig. 2.2. Photopic and scotopic visibility curves. (Mann, M. D. (1997-2010). The nervous system in action. Chapter 7. Fig. 7-9. Winton FR, Bayliss LE: Human Physiology, 5th ed. Boston, Little, Brown, 1962. www.unmc.edu/physiology/Mann/mann7.html) 45
Fig. 2.3. Drawings of different types of lanterns. (O'Dea, 1958, Fig. 21. Lanterns) 49
Fig. 2.4. Watchman (1820), New York Public Library ID#1168473. 50
Fig. 2.5. Reflector lantern from Paris. (Schivelbusch, 1995, p. 92) 50
Fig. 2.6. Ardwick, Manchester, 1904. (Otter, 2008, Fig. 2.7) 52
Fig. 2.7. Liverpool Street Station, London, 1909. (Otter, 2008, Fig. 5.4) 52
Fig. 2.8. London, 1878-82. Holborn viaduct subways. (Otter, 2008, Figure 6.1) 53
Fig. 2.9. Advertisement for the Star Iron Tower Company of Fort Wayne, Indiana, Electrical Review 13, Feb. 10, 1889. (Jakle, 2001, Fig. 2.4.) 54
Fig. 2.10. Arc lamp, Madison Square, New York, NY. (Jakle, 2001, Fig. 2.3.) 55
Fig. 2.11. Leipzig Street Lighting Scene, 1702, Leipzig, 1891 (Koslofsky, 2002, p. 758). 57
Fig. 2.12. Temple of Music and Machinery, Panamerican Exposition, Buffalo, NY, 1901. (Neumann, 2002, p. 91) 58
Fig. 2.13. Krollgarten at night, Berlin, 1900. (Neumann, 2002, p. 18) 58
Fig. 2.14. De Volharding Building. (Neumann, 2002, pp. 132-133) 60
Fig. 2.15. Franz Niklaus König, The St. James Fires at Lake Brienz, ca. 1815, watercolor, display case for diaphanoramas, Kunstmuseum Bern. (Blühm & Lippincott, 2000, p. 97) 61
Fig. 2.16. Erwin Blumenfeld, 1946, reprinted 2008, City Lights, C-type print, 40x30 cm. 62

Fig. 2.17. Alfred Stieglitz, Icy Night, New York, 1898. Photogravure, 5 x 6 3/8" (12.7 x 16.2 cm). Transferred from the Museum Library. © 2010 Estate of Alfred Stieglitz / Artists Rights Society (ARS), New York. (MoMA, The Collection, www.moma.org/collection/browse_results.php?object_id=51840) 63
Fig. 2.18. Laszlo Moholy-Nagy. Licht-Raum Modulator. 1922-30, replica 1970. Eindhoven Design Museum, The Netherlands. 65
Fig. 2.19. The duck and the decorated shed. Venturi, Brown, & Izenour (1998, 1972) 66
Fig. 2.20. Exhibit design by Gyorgy Kepes, Thomas McNulty, with Mary Otis Stevens, La forma della città di notte. Palazzo dell'Arte, XIV Milan Triennale May-July 1968. (Zardini, 2005, p. 46-47) 71
Fig. 2.21. Lights zones of a fictional city with bright zones and moderately lit zones differentiating the busy commercial districts from quieter residential areas, 1930. (Jakle, 2001, Figure 5.7.) 72
Fig. 2.22. Visual comparison of some contemporary display and media projects. 74
Fig. 2.23. Electrical Review and Wester Electrician 56, May 21, 1910, p. 1053. (Jakle, 2001, Figure I.1.) 78
Fig. 2.24. Sester, M. (2002-2003) ACCESS, Ars Electronica, September 2003. Photo by: Marie Sester. http://accessproject.net/archives/pictures/pictures1.html 79
Fig. 2.25. Louis XIV Medallion (1667). (Schivelbusch, 1988, 1995, p. 86) 80
Fig. 2.26. Visions for mobile street lighting. Lyon workshop. (Philips , City, People, Light, 2007, p. 37) 80

Chapter 3

Fig. 3.1. Diagram of the AR Street Light responding to the presence of a person. 83
Fig. 3.2. Various existing LED luminaire designs. 84
Fig. 3.3. Philips LED luminaire which responds to different ambient light conditions. 85
Fig. 3.4. Ross Lovegrove solar lights. www.rosslovegrove.com 86
Fig. 3.5. Colorblast 6 donated by Philips ColorKinetics. 88
Fig. 3.6. Street light prototype in cardboard on display in the Smart Cities lab space. 88
Fig. 3.7. Color pools created by the light. 89
Fig. 3.8. Shadow Playground mounted to a street light in on December 2, 2009 in Kendall Square, Cambridge, MA. Wayne Higgens. 91

Chapter 4

Photographs of installation in Scotland by Matthew Karau and Richard Wilson.
Fig. 4.1. Urban Pixels scenario showing a person placing or removing pixels in any ad-hoc configuration on a fence. 96
Fig. 4.2. Table describing the general parameters for designing sensor networks. Adapted from Akyildiz (2002) specifically for small-scale lighting and sensing units such as Urban Pixels. 98
Fig. 4.3. Table describing the differences among physical and screen-bound pixels. Adapted from table by Heaton (2000). 100
Fig. 4.4. Design iterations of hardware for Urban Pixels. 101
Fig. 4.5. Rendering of how unbounded pixels might look on a building facade. 104
Fig. 4.6. Detail of the units mounted on the facade of Eden Court Theater, Inverness, Scotland. 104
Fig. 4.7. New wing of Eden Court Theater, Inverness Scotland, with Urban Pixels mounted on the facade. 106

Fig. 4.8. Visitors pointing to Urban Pixels displayed on Eden Court Theater, Inverness Scotland........106
Fig. 4.9. Solar urban pixels (see chapter 6 for a rendering of a floating pixel unit which uses wind and waves to power the device). 108
Fig. 4.10. Rendering of floating Urban Pixels in the River Ness, Inverness, Scotland. 109
Fig. 4.11. Various urban pixels prototypes shown on the I.M. Pei Media Laboratory building (1985). 111

Chapter 5

Fig. 5.1. Diagram of Light Bodies as they were prototyped and implemented. 113
Fig. 5.2., Fig. 5.3., Fig. 5.4. Self-organizing lanterns scenario drawings........114-115
Fig. 5.5. "Excuse me, Miss, your bag is on fire!" A passerby made this comment as we were carrying the bag of Light Bodies shown in this photograph to a performance in Vienna, Austria........116
Fig. 5.6. Table showing the color space. Table by Daniel Taub........118
Fig. 5.7. Light Bodies unit up close. 118
Fig. 5.8. Performance at the Technical University of Vienna. Photograph TU Wien. 121
Fig. 5.9. Play me, I'm yours! Photograph by Abigail Sellen. 122
Fig. 5.10. Interacting with Light Bodies. Photograph by Daniel Taub. More images available at www.flickr.com/photos/tentacles/sets/72157608649677169. 124
Fig. 5.11. Interaction diagram showing the three deployments of Light Bodies. 126
Fig. 5.12. Three alternative form factors for Light Bodies that might evoke different interaction patterns and relations between the environment and the devices. 127

Chapter 6

Fig. 6.1. Mapping the dimensions of liberated pixels onto the AR street light design exploration.....130
Fig. 6.2. Mapping the dimensions of liberated pixels onto the urban pixels design exploration. 132
Fig. 6.3. Mapping the dimensions of liberated pixels onto the light bodies design exploration. 134
Fig. 6.4. Rendering of floating pixels in the Arno River, Florence, Italy. 136
Fig. 6.5. Three proposed floating light artifacts powered by wave movements. (Renderings by Peter Schmitt) 137
Fig. 6.6. Visualization of pixels placed along a building facade for a temporary guidance system guiding people to a museum. 138
Fig. 6.7. Visualization of pixels placed on a building facade for a temporary light show........138
Fig. 6.8. Diagram illustrating the continuity of content and display information across scales and technologies. 140

Appendix

Fig. A.1. Schematic circuit diagram of final Urban Pixels unit. Designed in collaboration with Daniel S. Perry based on Texas Instruments-Chipcon CC1010 board layout recommendations. 176
Fig. A.2. Final Urban Pixels board layout showing top (red) and bottom layers (blue) as well as holes (green). 177
Fig. A.3. Graphical user interface used to interact with Urban Pixels in Inverness, Scotland. Created by Richard Wilson, Distance Lab, Fores, Scotland. 177
Fig. A.4. Diagram illustrating the set-up used in the installation on Eden Court Theater in Inverness, Scotland. GSM set-up created by Richard Wilson, Distance Lab, Fores, Scotland. 178
Fig. A.5. Code excerpts from Urban Pixels created with Daniel Perry. 179
Fig. A.6. Light bodies LED and sensor expansion board for Funnel I/O. 183

Fig. A.7. Final Light Bodies board layout showing top (red) and bottom layers (blue) as well as holes (green). 184
Fig. A.8. Light bodies code created with Daniel Taub. 184
Fig. A.9. Augmented reality street light construction details. 188
Fig. A.10. Augmented reality street light code excerpt. Code created with Joshua Robles. 189

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Abowd, G. D., Mynatt, E. D., & Rodden, T. (2002). The human experience. IEEE Pervasive Computing, 1(1), 48-57. DOI= http://dx.doi.org/10.1109/MPRV.2002.993144

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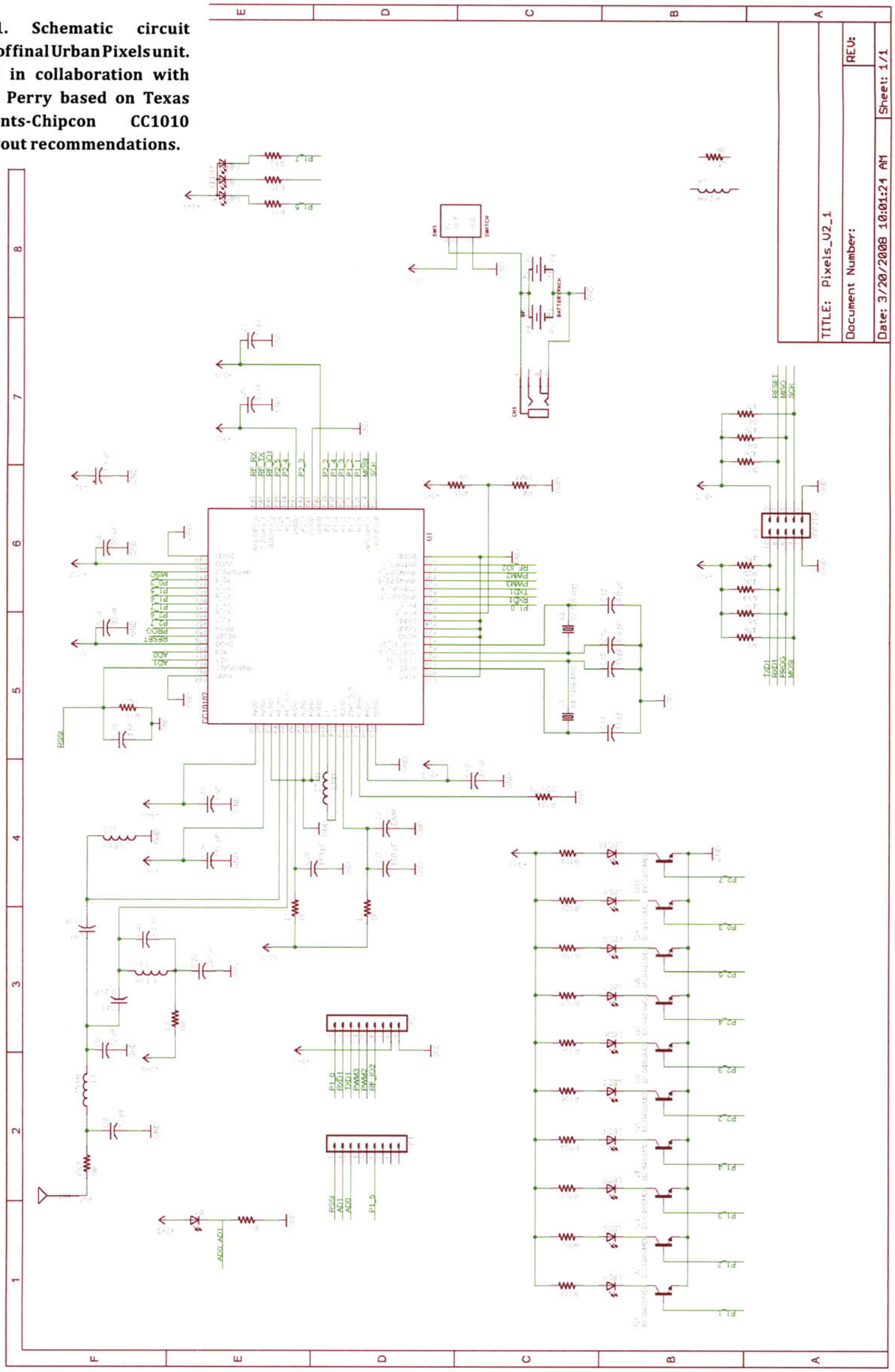
Appendix

Fig. A.1. Schematic circuit diagram of final Urban Pixels unit. Designed in collaboration with Daniel S. Perry based on Texas Instruments-Chipcon CC1010 board layout recommendations.



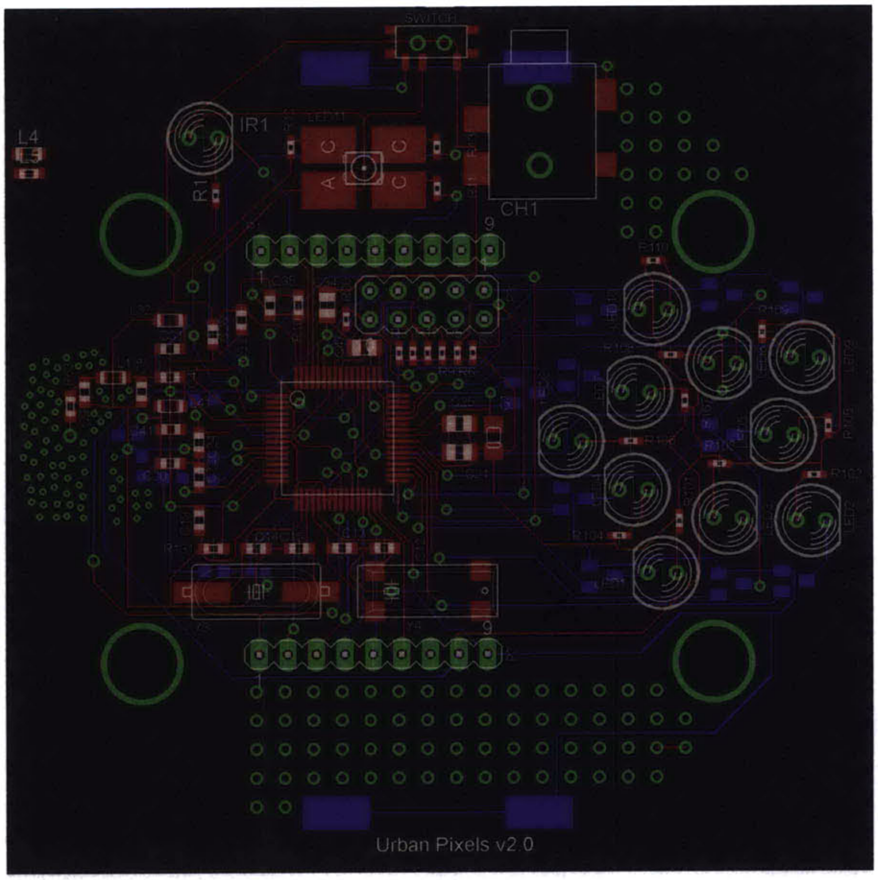


Fig. A.2. Final Urban Pixels board layout showing top (red) and bottom layers (blue) as well as holes (green).

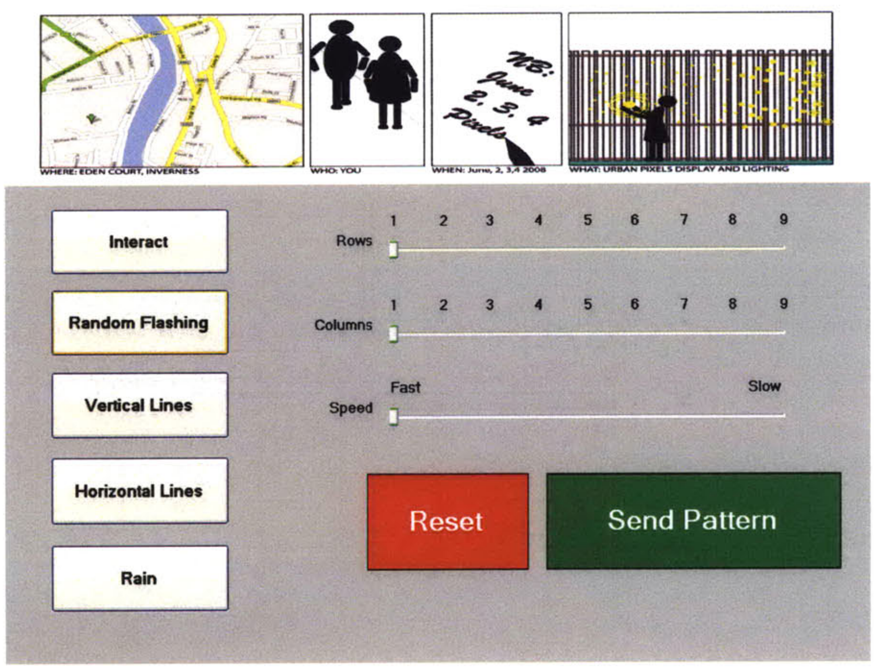


Fig. A.3. Graphical user interface used to interact with Urban Pixels in Inverness, Scotland. Created by Richard Wilson, Distance Lab, Fores, Scotland.

Fig. A.4. Diagram illustrating the set-up used in the installation on Eden Court Theater in Inverness, Scotland. GSM set-up created by Richard Wilson, Distance Lab, Fores, Scotland.

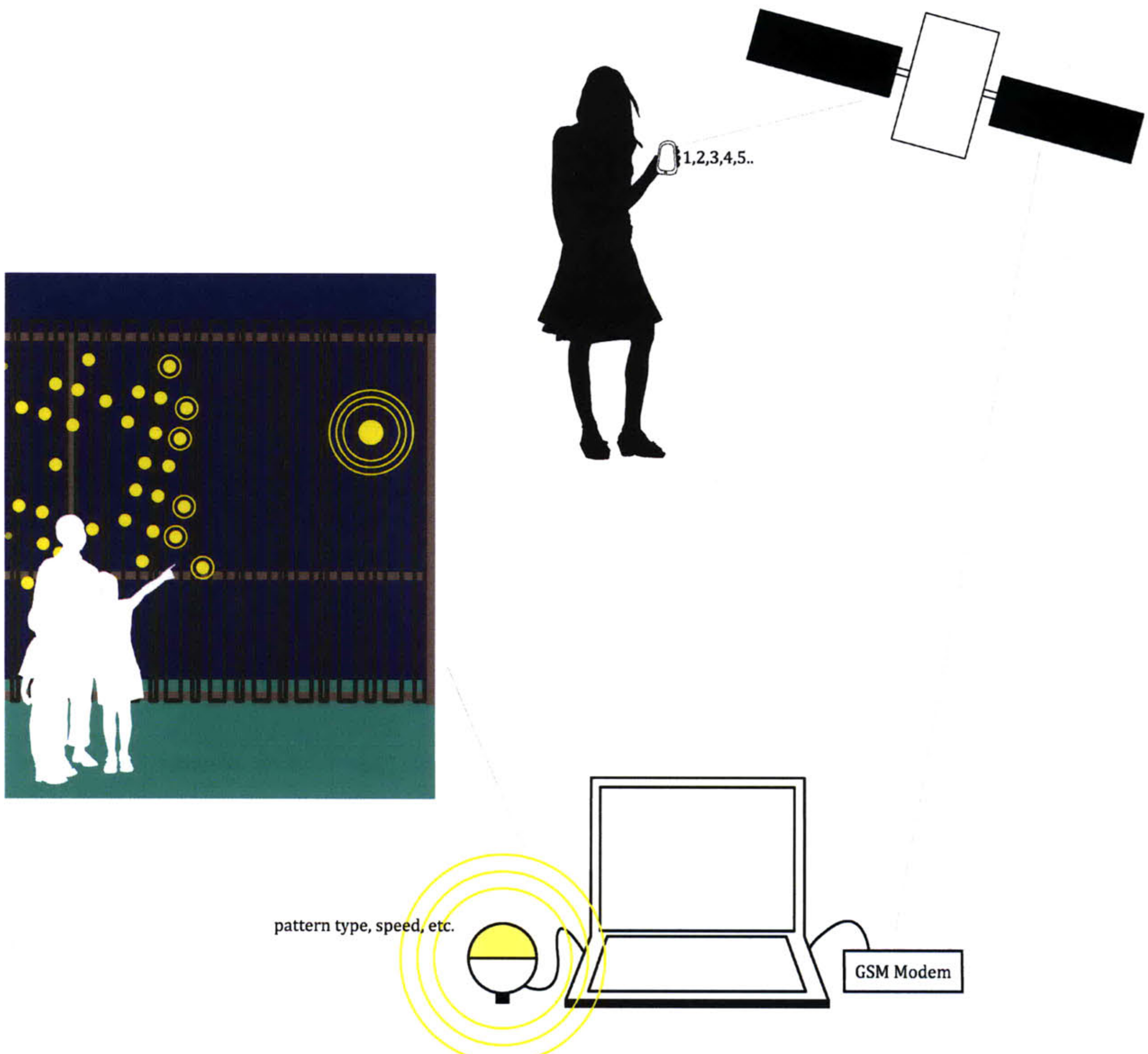


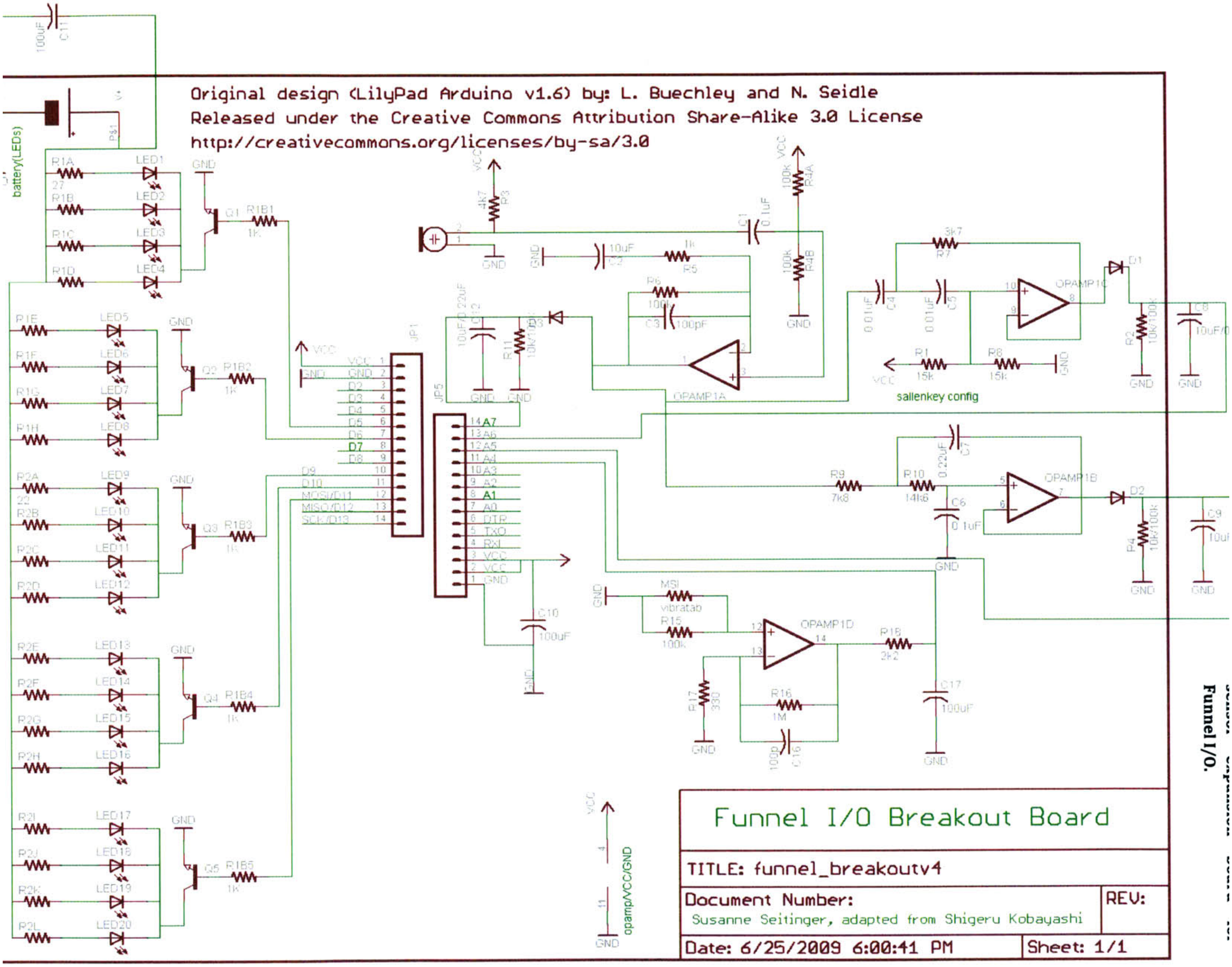
Fig. A.5. Code excerpts from Urban Pixels created with Daniel Perry.

```
#include "CC1010DC.h"
#include "cul.h"

// Define Address and Pattern Here
 char my_address = 0x03;
 char my_pattern = 0xDB;

// Flags
 char Flags_Receive;
 char Flags_Master;
 char Flags_Timeout;
 char Flags_Reset;

// General Variables
 char message_type;
 char my_master_number;
 char pattern;
 char number_frames;
 int my_frames;

// Master Function Prototypes
 char MasterCheck(char my_master);
 char MasterMode(void);
 void SlaveMode(void);

// Radio Function Prototypes
 void Broadcast(char broadcast_length);
 char ReceivePacket(void);
 void SetupRadio(char timeout);

// Transmitting Function Prototypes
 void SendMasterNumber(char master);
 void SendReset(void);
 void SendStart(void);

// Display Function Prototypes
 void LEDS_OE(void);
 void AllOff(void);
 void AllOn(void);

// Pattern Function Prototypes
 void SendPattern(char this_pattern);
 int GetPattern(char address, char modifier, char index);
 char NumberFrames(char pattern_data);
 void Display(char this_number, char this_pattern);

// Radio Variables
 SPP_RX_INFO xdata RXI;
 SPP_TX_INFO xdata TXI;
 char xdata pRXData[0x0A];
 char xdata pTXData[0x0A];
 SPP_SETTINGS xdata sppSettings;

void main(void) {

#define FREQ433
#ifdef FREQ433

// X-tal frequency: 14.745600 MHz
// RF frequency A: 433.302000 MHz         Rx
// RF frequency B: 433.302000 MHz         Tx
// RX Mode: Low side LO
// Frequency separation: 64 kHz
// Data rate: 2.4 kBaud
// Data Format: Manchester
// RF output power: 10 dBm
// IF/RSSI: RSSI Enabled

RF_RXTXPAIR_SETTINGS code RF_SETTINGS = {
  0x4B, 0x2F, 0x0E,  // Modem 0, 1 and 2
  0x58, 0x00, 0x00,  // Freq A
  0x41, 0xFC, 0x9C,  // Freq B
  0x02, 0x80,        // FSEP 1 and 0
  0x60,              // PLL_RX
  0x48,              // PLL_TX
  0x44,              // CURRENT_RX
  0x81,              // CURRENT_TX
  0x0A,              // FREND
  0xFF,              // PA_POW
  0xC0,              // MATCH
  0x00,              // PRESCALER
  };
#endif

 RF_RXTXPAIR_CALDATA xdata RF_CALDATA;

// Disable Watchdog Timer and ADC
 WDT_ENABLE(FALSE);

// Set Optimum Setting for Speed and Low Power Consumption
 MEM_NO_WAIT_STATES();
 FLASH_SET_POWER_MODE(FLASH_STANDBY_BETWEEN_READS);

// Initialize LEDs
 LEDS_OE();

RESET:
// Turn on Orange LED (Red and Green LEDs simultaneously)
 AllOff();
 RLED = RGB_OFF;
 GLED = RGB_OFF;
 BLED = RGB_ON;

// Clear All Flags
 Flags_Receive = 0;
 Flags_Master = 0;
 Flags_Timeout = 0;
 Flags_Reset = 0;

// Assign Unit a Random Master Number
 halRandomNumberGen(&my_master_number,1);

// Setup Radio with Random Master Number Timeout
 SetupRadio(my_master_number);
 sppSetupRF(&RF_SETTINGS, &RF_CALDATA, TRUE);
 sppStartTimer(CC1010DC_CLKFREQ);
 SPP_INIT_TIMEOUTS();
 TXI.flags = 0x00;

INITIALIZATION:
// Receive a Packet
 //Flags_Receive = //ReceivePacket();

// If Unit Received a Packet, Parse Message
 if(Flags_Receive) {
   message_type = 0x40;//pRXData[0];
```

```
  // If it is a RESET Message, Reset
  if(message_type&0x80) {
    goto RESET;

  // If it is an INITIALIZATION Message, Check Master Number
  } else if(message_type&0x40) {

    // See if Master Number is Smaller
    //Flags_Master = MasterCheck(my_master_number);

    // If it is Smaller, Send Master Number
    if(Flags_Master) {
      SendMasterNumber(my_master_number);
      goto INITIALIZATION;

    // If it is Larger, Become Slave, Go to Record
    } else {
      SlaveMode();
                        goto RECORD;
    }

  // If it is a RECORD message, Become Slave, Save Pattern
  } else if(message_type&0x20) {
    SlaveMode();
    pattern = pRXData[1];
    my_frames = GetPattern(my_address,pattern,0);
            number_frames = NumberFrames(pattern);
    goto DISPLAY;

  // If it is a DISPLAY message, Reset and Sync all other Units
  } else if(message_type&0x10) {
    SendReset();
    goto RESET;
  }

// If Unit did not Receive a Packet
} else {

  // If There Have not Been 3 Rounds of Silence, Continue Transmitting
  if(Flags_Timeout<3) {
    Flags_Timeout++;
    SendMasterNumber(my_master_number);
    goto INITIALIZATION;

  // If There has Been 3 Rounds of Silence, Unit is Master
  } else {
    my_master_number = MasterMode();
            goto RECORD;
  }
}

RECORD:
// Receive a Packet
// Flags_Receive = ReceivePacket();

// If Unit Received a Packet, Parse a Message
if(Flags_Receive) {
   message_type=pRXData[0];

  // If Unit Received RESET Message, Reset
  if(message_type&0x80) {
    goto RESET;

  // If Unit Received INITIALIZE Message, Ignore It
  } else if(message_type&0x40) {
    goto RECORD;

  // It Unit Received RECORD Message, Get Pattern, Go to Display
  } else if(message_type&0x20) {
    pattern = pRXData[1];
    my_frames = GetPattern(my_address,pattern,0);
    number_frames = NumberFrames(pattern);
            Flags_Timeout = 0;
    goto DISPLAY;

  // If Unit Received DISPLAY Message, Reset and Sync Other Units
  } else if(message_type&0x10) {
    SendReset();
    goto RESET;

  // If not a Valid Message Type, Ignore it
  } else {
    goto RECORD;
  }

// If Unit did not Receive a Packet,
} else {

  // And is a Master, Send Pattern, and Display it
  if(Flags_Master) {
            //SendPattern(my_pattern);
            my_frames = GetPattern(my_address,my_pattern,0);
            number_frames = NumberFrames(my_pattern);
            //SendStart();
            Display(number_frames, my_frames);
            goto RESET;

  // And is a Slave, Check Timeout
  } else {

    // If Unit has not Exceeded Timeout, Increment it
    if(Flags_Timeout<10) {
      Flags_Timeout++;
      goto RECORD;

    // If Unit has Exceeded Timeout, Reset
    } else {
      goto RESET;
    }
  }
}

DISPLAY:
// Receive a Packet
Flags_Receive = ReceivePacket();

// If Unit Received a Packet, Parse it
if(Flags_Receive) {
  message_type = pRXData[0];

  // If it is a RESET Message, Reset
  if(message_type&0x80) {
    goto RESET;

  // If it is a DISPLAY Message, Start Display
  } else if(message_type&0x10) {
    Display(number_frames,my_frames);
            goto RESET;

  // If it is any other Message, Ignore It
  } else {
    /* Do Nothing */
  }
```

```
// If Unit did not Receive a Packet, Increment Timeout
 } else {
   if(Flags_Timeout<10) {
     Flags_Timeout++;
     goto DISPLAY;

   // If Unit has Exceeded Timeout, Reset
   } else {
     goto RESET;
   }
 }
}

/* ------------------------------------------------ *
 * Master Functions                                *
 * ------------------------------------------------ */

char MasterCheck(char my_master) {
  char master_check = 0;
  if(my_master<pRXData[1]) {
    master_check++;
  }
  return master_check;
}

char MasterMode(void) {
  char master_number;
  Flags_Master = 1;
  halRandomNumberGen(&master_number,1);
  SetupRadio(master_number);
  BLED = RGB_OFF;
  GLED = RGB_ON;
  RLED = RGB_OFF;
  while(1){
  }
  return master_number;
}

void SlaveMode(void) {
  Flags_Master = 0;
  Flags_Timeout = 0;
  SetupRadio(LONG_TIMEOUT);
  BLED = RGB_OFF;
  GLED = RGB_OFF;
  RLED = RGB_ON;
  while(1){
  }
}

/* ------------------------------------------------ *
 * Radio Functions                                 *
 * ------------------------------------------------ */

void Broadcast(char broadcast_length) {
  TXI.destination = SPP_BROADCAST;
  TXI.flags |= SPP_ACK_REQ;
  TXI.pDataBuffer = pTXData;
  TXI.dataLen = (1+broadcast_length);

  if(sppSend(&TXI)==SPP_TX_STARTED) {
    do{/*nothing*/} while(SPP_STATUS()!=SPP_IDLE_MODE);
  }
}

char ReceivePacket(void) {
  char data_ready = 0;
  RXI.pDataBuffer = pRXData;
  RXI.maxDataLen = 0x0A;
  if(sppReceive(&RXI)==SPP_RX_STARTED) {
    do {/*nothing*/} while(SPP_STATUS()!=SPP_IDLE_MODE);
          if(RXI.status==SPP_RX_TIMEOUT) {
            return data_ready;
          } else if(RXI.status==SPP_RX_FINISHED) {
            data_ready++;
                  return data_ready;
          } else {
            return data_ready;
          }
  }
}

void SetupRadio(char radio_timeout) {
  sppSettings.myAddress = my_address;
  sppSettings.rxTimeout = radio_timeout;
  sppSettings.txAckTimeout = 0x10;
  sppSettings.txAttempts = 1;
  sppSettings.txPreambleByteCount = 7;
}

/* ------------------------------------------------ *
 * Transmitting Functions
 *
 * ------------------------------------------------ */

void SendMasterNumber(char master) {
  pTXData[0] = 0x40;
  pTXData[1] = master;
  Broadcast(0x01);
}

void SendReset(void) {
  pTXData[0] = 0x80;
  Broadcast(0x00);
}

void SendStart(void) {
  pTXData[0] = 0x10;
  Broadcast(0x00);
}

/* ------------------------------------------------ *
 * Display Functions
 *
 * ------------------------------------------------ */

void LEDS_OE(void) {
  RLED_OE(TRUE);

  GLED_OE(TRUE);
  BLED_OE(TRUE);
  LED1_OE(TRUE);
  LED2_OE(TRUE);
  LED3_OE(TRUE);
  LED4_OE(TRUE);
  LED5_OE(TRUE);
  LED6_OE(TRUE);
  LED7_OE(TRUE);
  LED8_OE(TRUE);
  LED9_OE(TRUE);
  LED10_OE(TRUE);
}
```

```
void AllOff(void) {
  LED1 = LED_OFF;
  LED2 = LED_OFF;
  LED3 = LED_OFF;
  LED4 = LED_OFF;
  LED5 = LED_OFF;
  LED6 = LED_OFF;
  LED7 = LED_OFF;
  LED8 = LED_OFF;
  LED9 = LED_OFF;
  LED10 = LED_OFF;
}

void AllOn(void) {
  LED1 = LED_ON;
  LED2 = LED_ON;
  LED3 = LED_ON;
  LED4 = LED_ON;
  LED5 = LED_ON;
  LED6 = LED_ON;
  LED7 = LED_ON;
  LED8 = LED_ON;
  LED9 = LED_ON;
  LED10 = LED_ON;
}

/* ------------------------------------------------ *
 * Pattern Functions
 *
 * ------------------------------------------------ */

void SendPattern(char this_pattern) {
  pRXData[0] = 0x02;
  pRXData[1] = this_pattern;
  Broadcast(1);
}

int GetPattern(char address,char modifier,char index) {
  int output;
  char rws = ((modifier&0x38)>>3);
  char cls = (modifier&0x07);

  if(modifier&0x80) {
    if(address>cls) {
      address -= cls;
      GetPattern(address,modifier,index);
    }
    if(modifier&0x40) {
      output = ((1<<(2*cls+1-address)) | (1<<(address-1)));
    } else {
      output = ((1<<(cls+address)) | (1<<(cls-address)));
          }
  } else {
    if(address<=((rws-1)*cls)) {
      rws--;
            index++;
      modifier &= 0xE7;
      modifier |= (rws<<3);
      GetPattern(address,modifier,index);
    }
    if(modifier&0x40) {
      output = ((1<<(2*index+rws+1)) | (1<<(rws-1)));
    } else {
      output = ((1<<(2*rws+index)) | (1<<index));
    }
  }
  return output;
}

char NumberFrames(char pattern_data) {
  char frames;
  char rows = ((pattern_data&0x38)>>3);
  char cols = (pattern_data&0x07);
  if(pattern_data&0x80) {
    frames = (2*cols + 1);
  } else {
    frames = (2*rows + 1);
  }
  return frames;
}

void Display(char this_number, char this_pattern) {
  while(this_number) {
    char i;
          char frame = 0;
    char mask = (1<<(this_number-1));
    frame = (mask&this_pattern);
    if(frame) {
      AllOn();
                  for(i=0;i<15;i++) {
              halWait(100,CC1010DC_CLKFREQ);
            }
    } else {
      AllOff();
          for(i=0;i<15;i++) {
              halWait(100,CC1010DC_CLKFREQ);
            }
          }
          this_number--;
  }
}
```



Original design (LilyPad Arduino v1.6) by: L. Buechley and N. Seidle
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battery(LEDs)
sallenkey config
OPAMP1A
OPAMP1B
OPAMP1C
OPAMP1D
opamp/VCC/GND
Funnel I/O Breakout Board
TITLE: funnel_breakoutv4
Document Number:
Susanne Seitinger, adapted from Shigeru Kobayashi
REV:
Date: 6/25/2009 6:00:41 PM
Sheet: 1/1

Funnel I/O.

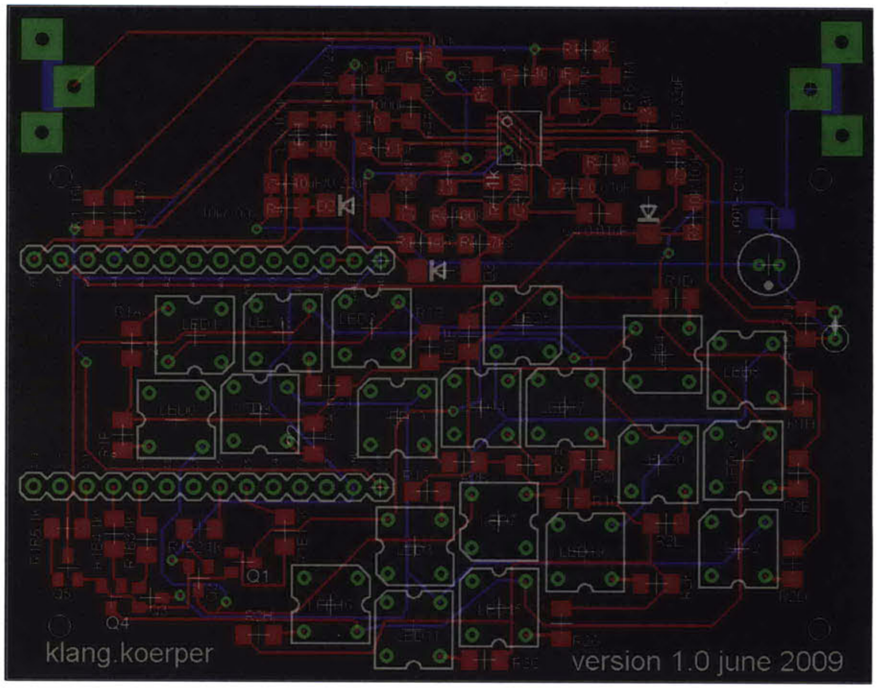

Fig. A.7. Final Light Bodies board layout showing top (red) and bottom layers (blue) as well as holes (green).

Fig. A.8. Light bodies code created with Daniel Taub.

```
....removed set up and pin declarations

//////////////////////////////////////////////////////////////////
// FUNCTIONS /////////////////////////////////////////////////////

// Turn off all the LEDs
void ledsOFF ()
{
  digitalWrite (redLEDs, LOW);
  digitalWrite (amberLEDs, LOW);
  digitalWrite (whiteLEDs, LOW);
  digitalWrite (blueLEDs, LOW);
  digitalWrite (greenLEDs, LOW);
}

// Turn on all the LEDs
void ledsON ()
{
  analogWrite (redLEDs, MAX_LED_VAL);
  analogWrite (amberLEDs, MAX_LED_VAL);
  analogWrite (whiteLEDs, MAX_LED_VAL);
  analogWrite (blueLEDs, MAX_LED_VAL);
  analogWrite (greenLEDs, MAX_LED_VAL);
}

int getAmplitude ()
{
  amp = analogRead (pinMic);
  return amp;
}


boolean ambArrived(int rand, int val, int inc)
{

  if (inc >> 15 )          //    (   incblue>>15 // if 1 is negative)
  {
    if (val <= rand)
    {
      return true;
    }
    else {
      return false;
    }
  }
  else
  {
    if (val >= rand)
    {
      return true;
    }
    else {
      return false;
    }
  }
}

// setting the value to which the LEDs fade, up or down depending on
the current value
void setRandBlue()
{
  // randBlue = random(MAX_LED_VAL>>2,MAX_LED_VAL-20);
  if (blueValue <= (MAX_LED_VAL >> 1)) // currently low
  {
    randBlue = random(MAX_LED_VAL>>2,MAX_LED_VAL-22);
  }  //set high
  else


  {
    randBlue = random(MIN_LED_VAL,MAX_LED_VAL>>2-20);
  }  //set low
}
```

```
void setRandGreen()
{
 // randGreen = random(MAX_LED_VAL>>2,MAX_LED_VAL-20);
 if (greenValue <= (MAX_LED_VAL >> 1)) // currently low
 {
  randGreen = random(MAX_LED_VAL>>2,MAX_LED_VAL-33);
 }  //set high
 else
 {
  randGreen = random(MIN_LED_VAL,MAX_LED_VAL>>2-20);
 }  //set low
}

void setRandWhite()
{
 if (whiteValue <= (MAX_LED_VAL >> 1)) // currently low
 {
  randWhite = random(MAX_LED_VAL>>2,MAX_LED_VAL-44);
 }  //set high
 else
 {
  randWhite = random(MIN_LED_VAL,MAX_LED_VAL>>2-20);
 }  //set low
}

//setting the random value to which each color will fade
void startCandle()
{
 candleCountdown = START_CANDLE-1;

 if (ambArrived(randBlue,blueValue,incBlue))
 {
  setRandBlue();
 }
 if (ambArrived(randGreen,greenValue,incGreen))
 {
  setRandGreen();
 }
 if (ambArrived(randWhite,whiteValue,incWhite))
 {
  setRandWhite();
 }

 //magnitude of the step for fading
 incBlue = random(-1,3);//(randBlue-blueValue) >> 3 ;
 incGreen = random(-1,3); //(randGreen-greenValue) >> 3;
 incWhite = random(-1,3);//(randWhite-whiteValue) >> 3;

 /*   Serial.print("blueVal: ");
  Serial.println(blueValue);
  Serial.print("blueInc: ");
  Serial.println(incBlue);
  Serial.print("randBlue: ");
  Serial.println(randBlue);   */

}

//adding the increment/decrement or fade value to the current value of the LED
int incrementLED(int val, int inc)
{
 return min(MAX_LED_VAL, max(MIN_LED_VAL, val+inc));
}

// ambient candle mode which takes over in periods of inactivity when the other hp, lp, piezo threhshholds are not triggered
void candle ()
{
 //red and amber values are still just responding to amplitude
 redValue = (amp-512)>>4;
 amberValue = (amp-512)>>4;

 /*  Serial.print("redVal: ");
  Serial.println(redValue);   */
 analogWrite (redLEDs, redValue);
 analogWrite (amberLEDs, amberValue);

 // only fading the white/blue/green LEDs in and out in candle mode
 whiteValue = incrementLED(whiteValue,incWhite);
 blueValue = incrementLED(blueValue,incBlue);
 greenValue = incrementLED(greenValue,incGreen);

 analogWrite (whiteLEDs, whiteValue);
 analogWrite (blueLEDs, blueValue);
 analogWrite (greenLEDs, greenValue);

 if (candleCountdown <= 0)
 {
  candleCountdown = START_CANDLE;
 }
 /*    else if (candleCountdown <= (START_CANDLE << 1 ))
  {
  incWhite = -2;
  incGreen = -2;
  incBlue = -2;
  }
  */
 //}
}

// using this to make the overall brightness proportional to the sound levels
int scale(int amp)
{
 //return (amp-512)/4;
 amp-=512;
 return map(amp,0,512,0,MAX_LED_VAL);
}

int decAndWrite(int LEDSet, int LEDVal, int dropoff) //writes the value AFTER decrementing
{
 if (LEDVal >= MIN_LED_VAL)
 {
  LEDVal -= dropoff;
  /*if (LEDSet == whiteLEDs) //Because the white LEDs are being set to a brighter initial point
   {
   LEDVal -= dropoff*2;
   } */
 }
 delay(1);
 analogWrite (LEDSet, LEDVal);
 return LEDVal;
}

// setting the clusters of LEDs that respond to different inputs
void setPiezoLEDs(int LEDVal)
{
 greenValue = LEDVal;
 blueValue = LEDVal;
 whiteValue = LEDVal; // *1.4;
}
```

```
void setHpLEDs(int LEDVal)
{
 redValue = max(redValue,LEDVal);
 amberValue = max(amberValue,LEDVal);
}

void setLpLEDs(int LEDVal)
{
 redValue = max(redValue,LEDVal);
 blueValue = max(blueValue,LEDVal);
}

// resetting the counters for the ambient candle mode
void resetAmbient()
{
 //ambientOn = 0; // don't think we used this variable
 countInactive = 0;
}

// setting the dropoff, i.e. speed of fade
int setDropoff(int thresh)
{
 if (thresh > 800)
 {
  dropoff = 4;
 }
 if ((700 > thresh) && (thresh < 800))
 {
  dropoff = 3;
 }
 if ((600 > thresh) && (thresh < 700))
 {
  dropoff = 2;
 }
 if (thresh < 600)
 {
  dropoff = 1;
 }
 return dropoff;
}

// Get the average of the previous mic amplitude values/////////
// setting the threshhold for amplitude////////////////////////

int setAmpThresh(long sum)
{
 ampThresh = 1.1*(sum/64);
 if (ampThresh > 1024)
 {
    ampThresh = 1024; // in case the threshhold exceeds the 1024
possible in the 10-bit ADC
 }
 //Serial.print("ampThresh: ");
 //Serial.println (ampThresh);
 return ampThresh;
}

int setHpThresh(long sum)
{
 hpThresh = max(1.2*(sum>>6),absoluteHpThresh);// scale factor for
the threshhold trigger, anything under 1.2 gets spastic
 return hpThresh;
}

int setLpThresh(long sum)
{
 lpThresh = max(1.2*(sum>>6),absoluteLpThresh);//bit shifting to the
right by 6 = dividing by 64
 return lpThresh;
}

//////////////////////////////////////////////////////////////////
// VOID LOOP ////////////////////////////////////////////////////
void loop()
{
 /*  Because the piezo sensor was not working properly we added
  this section to enable or diable the piezo sensor.
  */

 // "button" used to control enable/disable
 digitalWrite (pinButton, HIGH);
 if (digitalRead(pinButton) == LOW)
   MODE = ((MODE+1) % 3);

 // mode 0 is disable
 if (MODE == 0)
 {
 }

 // in some units the piezo was going low on vibration and in other it
was going high
 // set the threshhold here based on this difference
 else
 {
  if (MODE == 1 )
  {
   piezoThresh = 750;
  }
  else
  {
   piezoThresh = 350;
  }

  // read the piezo sensor if it is enabled
  piezo = analogRead (pinPiezo);
  // Serial.print ("Piezo: " );
  // Serial.println (piezo);
  // digitalWrite (pinPiezo, LOW);
 }

 // read the ADC high pass pin
 hp = analogRead (pinHp);
 //Serial.print ("HP: " );
 //Serial.println (hp);

 // read the ADC low pass pin
 lp = analogRead (pinLp);
 //Serial.print ("LP: " );
 //Serial.println (lp);

 // read the ADC amplitude/microphone
 amp = analogRead (pinMic);

 // cumulative sums for calculating the averages over 64 cycles
 sumAmp = sumAmp + amp;
 sumHp = sumHp + hp;
 sumLp = sumLp + lp;

 // adaptive threshholding
 // every 64 cycles, recalculate the trigger threshholds
 if (counter == 64)
 {
  setAmpThresh(sumAmp);
```

```
 setHpThresh (sumHp);
 setLpThresh (sumLp);

 Serial.print ("Amplitude: " );
 Serial.println (amp);
 Serial.print("ampThresh: ");
 Serial.println (ampThresh);

 Serial.print("hp: ");
 Serial.println (hp);
 Serial.print("hpThresh: ");
 Serial.println (hpThresh);

 Serial.print("lp: ");
 Serial.println (lp);
 Serial.print("lpThresh: ");
 Serial.println (lpThresh);

 // the speed of the fade is also dependent on the overall amplitude
 setDropoff (ampThresh);
 Serial.print("Dropoff: ");
 Serial.println (dropoff);

 // reinitialize the variables and counter
 sumHp = 0;
 sumLp = 0;
 sumAmp = 0;
 counter = 0;
}

// two conditions for triggering piezo
if (  ((MODE == 1)&&(piezo < piezoThresh))  ||
  ((MODE == 2)&&(piezo > piezoThresh))  )
{
  // setPiezoLEDs(scale(piezo)); // scale doesnt work well for piezo
therefore just set them to the maximum
  setPiezoLEDs(MAX_LED_VAL);
  resetAmbient();
}
else  // if no knock
{
 // incrementing to determine when to trigger ambient candle mode
 countInactive++;
 /*if (amp > ampThresh)
  {
  setDropoff (amp);
  }*/

 // testing condition for high pass response
 if (hp > hpThresh)
 {
  //setHpLEDs(scale(amp));
  setHpLEDs(scale(hp));
  resetAmbient();
  //setHpLEDs(MAX_LED_VAL);
 }

 // testing condition for low pass response
 if (lp > lpThresh)
 {
  //setLpLEDs(scale(amp));
  setLpLEDs(scale(lp));
  resetAmbient();
  // setLpLEDs(MAX_LED_VAL);
 }
}

// testing condition for starting ambient mode
if (countInactive > MAX_COUNT_INACTIVE)
{
 startCandle();
}

// counting down from ambient mode
if (candleCountdown < START_CANDLE)
{
 candleCountdown--;
 candle();
}

// analogWrite (redLEDs, redValue);
// analogWrite (greenLEDs, greenValue);
// analogWrite (blueLEDs, blueValue);
// analogWrite (amberLEDs, amberValue);
// ledsOFF();

// setting the LEDs
if (candleCountdown == START_CANDLE)
{
 //Serial.println("in dec-----------");
 amberValue=decAndWrite (amberLEDs, amberValue, dropoff);
 redValue=decAndWrite (redLEDs, redValue, dropoff);
 greenValue=decAndWrite (greenLEDs, greenValue, dropoff);
 blueValue=decAndWrite (blueLEDs, blueValue, dropoff);
 whiteValue=decAndWrite (whiteLEDs, whiteValue, dropoff);
}

  // incrementing counter for counting cylces for adaptive
threshholding
 counter ++;

 // oldCode();

}// end of main loop
```

Fig. A.9. Augmented reality street light construction details.

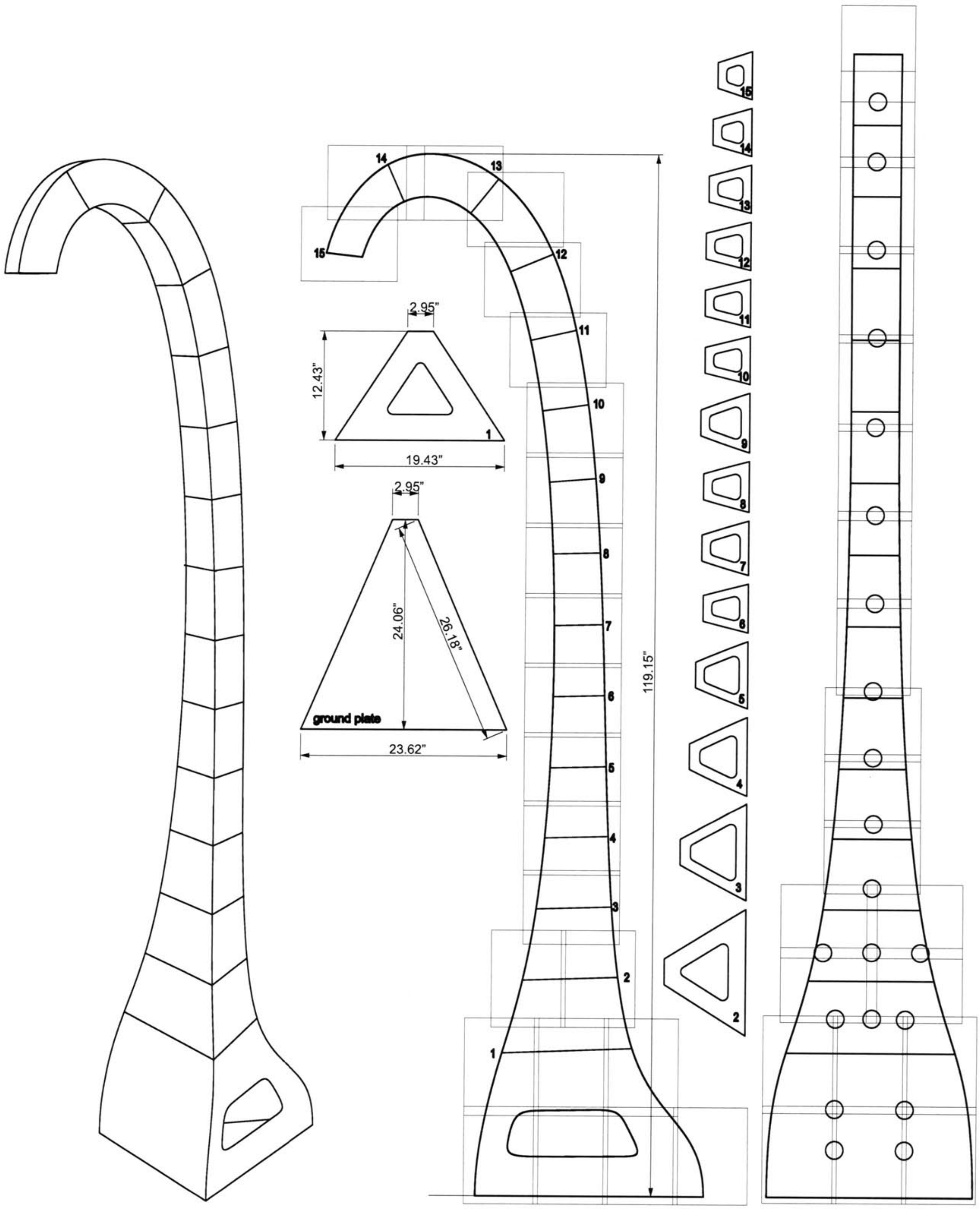

Fig. A.10. Augmented reality street light code excerpt. Code created with Joshua Robles.

```
....removed set up and pin declarations


void loop()
{
 rangeVal = analogRead(RANGEFIND); // read the value from
 // the rangefinder
 if(rangeVal>20)
 {
  if (timeOff > 20)
  {
   analogWrite(RLED, 1023);  // Write white to LED pins
   analogWrite(GLED, 1023);
   analogWrite(BLED, 1023);
  }
  if (timeOff <= 20)
  {
   analogWrite(RLED,   redVal);  // Write current values to LED pins
   analogWrite(GLED, greenVal);
   analogWrite(BLED,  blueVal);
   timeOff = timeOff + 1;
   delay (300);
  }

 }
 else
 {
  posBottom = random(70, 110); // generates random position
  posTop = random (50, 130);
  int pos1 = lastRandPosBot;
  int pos2 = lastRandPosTop;

  redVal = random (0, 1023);
  greenVal= random (0, 1023);
  blueVal = random (0, 1023);


  analogWrite(RLED,   redVal);  // Write current values to LED pins
  analogWrite(GLED, greenVal);
  analogWrite(BLED,  blueVal);



  if (posBottom >= lastRandPosBot)              //decide which way to
go to next position,
    // towards positive degree or negative (next if)
    //BOTTOM forward
  {
   for(lastRandPosBot; pos1 < posBottom; pos1 += 1)
   {
    bottomServo.write(pos1);
    delay(7);
   }
   lastRandPosBot = posBottom;
  }

  if (posBottom < lastRandPosBot)              //BOTTOM Backward
  {
   for(int i=0; i <= lastRandPosBot-posBottom; i++)
   {
    bottomServo.write(lastRandPosBot-i);
    delay(7);
   }
   lastRandPosBot = posBottom;
  }

if (posTop >= lastRandPosTop)              //TOP Forward
  {
   for(lastRandPosTop; pos2 < posTop; pos2 += 1)
   {
    topServo.write(pos2);
    delay(12);
   }
   lastRandPosTop = posTop;
  }



  if (posTop < lastRandPosTop)              //TOP Backward
  {
   for(int i=0; i <= lastRandPosTop-posTop; i++)
   {
    topServo.write(lastRandPosTop-i);
    delay(12);
   }
   lastRandPosTop = posTop;
  }
  timeOff = 0;
  delay (1000);
 }


 Serial.println("");

}
```