Interactive Architecture:

Connecting and Animating the Built Environment with the Internet of Things

Jennifer Stein
Mobile and Environmental Media Lab
USC School of Cinematic Arts
Los Angeles, CA USA
jenstein04@gmail.com

Prof. Scott S. Fisher
Mobile and Environmental Media Lab
USC School of Cinematic Arts
Los Angeles, CA USA
sfisher@cinema.usc.edu

Prof. Greg Otto
USC School of Architecture
Los Angeles, CA USA
Greg.Otto@BuroHappold.com

Abstract

The Internet of Things presents a groundwork for thinking about the implications and applications for connected, animated and interactive architectural spaces. The growing number of ubiquitous and embedded computing technologies introduces a new paradigm for how we interact with the built environment, while mobile and pervasive devices offer new possibilities for sensing and communicating with buildings and objects in the physical world. These technologies are used not only for collecting and providing data, but also as a way to animate and collectively augment the world around us. In thinking about creating hybrid physical and digital architectural spaces, we are presented with new forms of interactivity between humans, computers and the built environment.

In this context, Interactive Architecture explores the possibilities for dynamic, interactive spaces in which people and buildings engage in a mutual relationship with one other. By connecting the data, stories and experiences that develop though this relationship between buildings and their inhabitants, the built environment becomes an interactive, adaptive and animate entity. The paper explores how the Internet of Things not only connects physical and digital spaces, but how these networked spaces and objects might become playful characters that engage people with the built environment in new ways.

Introduction

The Internet of Things presents a groundwork for thinking about the implications and applications for connected, animated and interactive architectural spaces. The growing number of ubiquitous and embedded computing technologies introduces a new paradigm for how we interact with the built environment, while mobile and pervasive devices offer new possibilities for sensing and communicating with buildings and objects in the physical world. These technologies are used not only for collecting and providing data, but also as a way to animate and collectively augment the world around us. In thinking about creating hybrid physical and digital architectural spaces, we are presented with new forms of interactivity between humans, computers and the built environment.

We use the concept "Interactive Architecture" to explore the possibilities for dynamic, interactive spaces in which people and buildings engage in a mutual relationship with one other. By designing interactive systems that consider the daily interactions people encounter with buildings, there is great potential for the development of a relationship between buildings and inhabitants over the lifecycle of the building. This relationship development is an integral part of our research in the Mobile and Environmental Media Lab at USC, and provides the foundation for thinking about how characters and stories can emerge through the collection of data generated by both the building and its inhabitants on a daily basis.

Overview: Interactive Architecture in the Internet of Things

Earlier concepts of *Interactive Architecture* have been synonymous with responsive environments, smart environments, and intelligent architecture. Though all of these concepts rely on the deployment of embedded computation and ubiquitous digital technologies to seamlessly connect physical and virtual spaces, the focus has been on the addition of *intelligence* to architectural spaces. Rather than think of these spaces as intelligent and predictive, our research considers how interactive architecture can become more animate, playful, and conversational. This does not necessitate architecture to become intelligent per se, but it rather engages in an ongoing process of teaching and learning between inhabitants and the built environment.

Some of the earliest and most influential examples of Interactive Architecture were those explored in the 1960's, 1970's and 1980's by cyberneticians and architects interested in cybernetic systems. Cybernetician Gordon Pask was one of the earliest to engage with notions of Interactive Architecture, using his "Conversation Theory" as a way to explain a reciprocal relationship between people, machines and architecture. By engaging in conversations with one another through a feedback loop, inhabitants and buildings would engage in an ongoing process of teaching and learning, allowing inhabitants to have a more proactive role in configuring their environments.

Cedric Price, an architect who adopted these principles of cybernetics, designed one of the best known early experiments in Interactive Architecture, the Fun Palace (1964), for which Pask was a consultant. In collaboration with theater director Joan Littlewood, Price designed a concept for a reconfigurable environment that could be physically manipulated by the users of the space to accommodate their changing needs. Though this project was never fully realized, it stands as one of the most influential projects when considering how buildings and their users could become part of a collaborative architectural system.

Also inspired by cybernetics and by Pask in particular, Nicholas Negroponte approached interactive architecture from the perspective of the design process itself, rather than the actual building. It was his intention to create an architecture machine that could help architects design buildings as an active partner and that was capable of learning from the activity to the extent that it could become a highly personalized collaborator. Around the same time, Warren Brody, another colleague of Negroponte, was presenting his ideas about the built environment that proposed "we teach our environments first complex, then self-organizing, intelligence that could eventually become evolutionary".

Since this early research, much work in Interactive Architecture has been concerned with responsive facades and predictive environments, such as smart homes and intelligent buildings. But a renewed interest into the work of Cyberneticians and Architects of the 1960's has led to more creative and participatory concepts of Interactive Architecture. A number of these projects are discussed below to demonstrate the varying concepts of Interactive Architecture over the past few years. The common thread amongst these projects is an interest in connecting physical and virtual spaces through the Internet of Things.

Furthermore, our current research into Interactive Architecture in the Mobile and Environmental Media Lab focuses on how we can connect and animate the built environment by considering the role of storytelling both in the internet of things, as well as for creating conversational, interactive spaces.

Recent Work in Interactive Architecture

This section presents an overview of different approaches to Interactive Architecture, varying in scale from objects, to rooms, to cities, to the entire planet. These projects all rely on a connective network of enabling technologies such as sensors, actuators and embedded computational devices to people, objects and the built environment, creating hybrid physical and virtual spaces. However, many of these projects have made strides away from "smart buildings" by thinking not only about how architecture might become intelligent and predictive, but how it might also become an active part of a larger and more complex ecosystem of interactions between buildings and the people who inhabit them. These new interactive architectures take the form of art-based projects (Arch-OS), studies in energy efficiency (North House), Citizen Science (Common Sense), and globally connected buildings, people and objects (Pachube).

Ada - The Intelligent Room

An early attempt at designing an intelligent room that also developed a playful personality was "Ada - The Intelligent Room" project at the Swiss Pavilion, 2002. Developed by at ETH Zurich, this project modeled intelligence on neural networks of the brain onto a physical space, a room that would respond to, recognize and learn from its visitors. Ada used responsive light and sound to communicate data, goal achievements and emotions.

Arch-OS

The Arch-OS project was developed by the Centre for Art, Media and Design Research at the University of Plymouth, UK. This project, described as "an evolution in intelligent architecture, interactive art and ubiquitous computing" is an Operating System for architecture that fosters a creative and collaborative environment for artists, engineers and scientists at the University of Plymouth. Arch-OS consists of a number of hardware and software systems that are integrated into the built environment to monitor real-time environmental changes, detect the flow of people, and record, generate and play back audio within the building. The data generated and collected by each system can then be used by inhabitants of the building to create dynamic art installations and interactive experiences in the building.

Always Building: Programmable Environments
The Herman Miller Creative Office has been reimagining the workplace as a programmable, dynamic and personalized environment. By leveraging the sensors and ubiquitous technologies that have become integrated into the fabric of new building construction, *Always Building* aims to extend the life and usefulness of buildings by designing spaces that can adapt and be reprogrammed to accommodate changing needs, rather than considering them obsolete.

Chasing the Negawatt
Simon Fraser University's School of Interactive Arts and Technology(SIAT) approaches Interactive Architecture from the perspective of energy and resource management. By developing pervasive visualization technologies and displays, it is SIAT's goal to promote energy efficiency and behavior change by making inhabitants aware of current activities within buildings. The use of real-time feedback related to energy consumption is communicated through the internet of things, and distributed to inhabitants and neighbors through social networks to encourage shared understanding and conservation. Using energy management dashboards, Ambient Canvases in buildings, and mobile interfaces, *Chasing the Negawatt* presents compelling visualizations towards a shared understanding of one's personal impact on buildings, neighborhoods, and cities.

Common Sense
An ongoing initiative between researchers at UC, Berkeley, Intel Labs Berkeley, and Carnegie Mellon University, *Common Sense* is developing mobile sensing technologies that engage distributed citizens to collect and analyze environmental data, becoming Citizen Scientists. By making citizens part of the collection process and providing visualizations of the collected data, *Common Sense* aims to make communities more aware of air quality and other environmental factors that affect everyday life in cities.

The SENSEable City
MIT's SENSEable City lab has done extensive research into how real-time data generated by sensors, mobile phones, and other ubiquitous technologies within cities can teach us about how cities are used and how new technologies redefine the urban landscape.

Living City
Living City, a design concept by The Living, investigates three possible futures for how cities might be interactive, living entities. The first possible future, and most relevant to our research, considers a platform for enabling buildings to talk to each other, sharing their sensor data and other relevant information about being part of an interconnected city.

Pachube
Finally, Pachube provides an extensive platform for connecting all the various sensor data and visualizations described in the projects discussed above. Through the development of an Extended Environmental Markup Language (EEML), Usman Haque and his team have designed

a web-based and mobile application for easy-to-use and widespread sharing of real-time sensor and environmental data. Pachube has truly fostered a robust connection of objects, devices, people and buildings within a growing internet of things.

Mobile and Environmental Media Lab

USC's Mobile and Environmental Media Lab explores context- and location-specific mobile and spatial storytelling. Our current research projects focus on interactive architecture within the context of environmental media. Through the use of ubiquitous technologies, it is our goal to enhance environmental awareness, augment presence in the physical environment, and enable participation in place making. This research investigates interactive architecture through *ambient storytelling* and how the built environment can act as an animate storytelling entity that engages and interacts with people in specific spaces. Developments of personalized responsive/interactive environments arise as people spend time in and build a relationship with the spaces they inhabit habitually. By designing context-aware interactions through the integration of backstory and real-time data about an environment, ambient stories emerge and can be accessed through mobile and pervasive computing technologies and applications.

A significant part of our research goal has been to connect people through the Internet of Things to the spaces and objects of everyday life using backstory, lifelogging and ambient storytelling. Much of this research has taken place within the new Cinematic Arts Building Complex on the USC campus and is specifically focused on creating an interactive architectural environment within the George Lucas and Steven Spielberg Buildings, in which the buildings themselves become storytelling characters. By inviting inhabitants to engage with both the building and other inhabitants, we have introduced a new paradigm for place making within an animated, interactive environment.

The practice of lifelogging, or documenting and broadcasting one's daily activities with wearable computing devices, has been a recurrent topic of our research. However, instead of people documenting their activities, we are focusing on designing lifelogs for the built environment. Lifelogs for physical spaces combine various building, environmental and human sensor data, as well as collaboratively-authored character development, to create an ongoing presence of a story. Through the integration of these various sensors and collaborative character development, the building itself offers a daily snapshot of both infrastructural behaviors (power and water usage, internal temperature, HVAC usage), but also the behavior of the inhabitants of a building (movement through space, interests in context-specific information, time spent in the building). These elements, when combined, create the groundwork for ambient, mobile storytelling based on contextually relevant information collected and authored throughout the day.

Additionally, backstory, or the extant history of an object or situation, plays a significant role in our conceptualization of mobile and ambient storytelling. By embedding objects with contextual information about what materials objects are made of, where those materials came from, who designed and built the objects, and how the objects was transported, we can deepen the emotional connection of a participant to an object and space. It is our objective to provide a novel way to access an object's backstory using mobile and pervasive technologies and applications, while the overarching goal of our research into ambient storytelling is to merge lifelogging and collaborative character development with these backstories and context-aware interactions.

Furthermore, our research into interactive architecture and ambient storytelling provides a platform for making sensor and environmental data more accessible and playful within the actual context of the information. Rather than simply visualizing the data that is produced and captured throughout the day, this information becomes an ongoing part of the story through both lifelogs and backstory.

Million Story Building Project

The *Million Story Building* (MSB) project introduces the idea of mobile, ambient storytelling within the new School of Cinematic Arts Lucas Building at the University of Southern California. Through the use of the custom MSB mobile phone-based application, inhabitants and visitors become immersed in an emergent, responsive environment of collaborative storytelling. By designing location-specific interactions in the built environment, we have created an interface to the new School of Cinematic Arts Complex through the use of mobile phones, sensor networks, and software applications.

This application is intended to be used by the students, faculty and staff of the School of Cinematic Arts on a daily basis. As these inhabitants begin to interact with and engage in conversations with the building regularly, an ongoing relationship develops between the building and its inhabitants. If inhabitants choose to have an active relationship with the building and begin to interact more frequently, the building can create user profiles by learning names, locations and activities of its inhabitants. This user profile can be used by the building to offer context-specific information tailored to the likes and interests of a specific inhabitant. Furthermore, we have designed mission-based experiences and challenges that deliver a daily surprise to individuals as they spend more time in the building and sustain a playful relationship with the building. Experiences such as tagging movie clips, taking photos of specific elements of the building, and collecting videos from film locations are introduced to inhabitants in the form of missions or quests that the building proposes as a way to help it learn about itself, its inhabitants, and the world around it. These requests are made by the building in a pervasive game-like way in which inhabitants are asked to complete more difficult tasks only after becoming actively engaged with the building over time.

Additionally, as inhabitants begin to interact with the building and provide the requested information, a digital archive of all the collected videos, images, tagged movie clips and other data is created. The resulting database for this collected data will be useful to the School of Cinematic Arts not only as a way of developing a living history of the new Lucas building, but will also provide useful tools that can be used in the classroom. For example, as more movie clips are collaboratively tagged, professors and students will be able to access the database and call up movie clips by keyword in the classroom. Having access to the kinds of information that the building collects and stores will be an invaluable resource to the School of Cinematic Arts.

StoryObjects

The objects of our everyday lives have a backstory, as well as a continuously emerging history, that we might never discover without doing a bit of research. Each object contains a concept, a designer, a fabricator, and materials from which it is made, but the owner/user of that object rarely knows what the story of that object is. At the same time, once objects are acquired and put into use, they take on a life of their own in which they might have experiences and interactions with both people and other objects. These experiences and interactions can be embedded within the object, creating an ongoing contextual history, until the product is finally dismantled, recycled, or repurposed… at which point, it begins this cycle again. Ubiquitous computing technologies provide the tools for embedding information within objects as well as communicating that information to the personal, mobile devices we carry with us every day.

In addition to providing people with information to help them make socially responsible product decisions, the StoryObjects project investigates the potential for new forms of storytelling between people and everyday objects. The current phase of this project consists of a custom-designed table for the new School of Cinematic Arts Lucas Building. The table is sustainably constructed using reclaimed materials from both the old George Lucas Instructional Building and the old MGM Studios Sound Stage 28. This table is embedded with images and information that is accessible when building inhabitants who are using the Million Story Building iPhone application come within bluetooth proximity of the table. The embedded information is transmitted to a user's mobile phone, with more pieces of the story becoming available as the user spends more time with the object.

The Million Story Building and StoryObjects projects have allowed us to explore new ways of interacting with the built environment and the objects within them, as well as to think about storytelling in computationally embedded spaces. By embedding a digital layer of information into buildings and objects, we have created a new kind of space for storytelling in which a mobile phone application invites users to participate in a persistent story world. This current research and development has informed our ongoing design plans for both new projects within the School of Cinematic Arts Complex, as well as for a new Interactive Media Building. Our goal for the new building is to embed interactive systems and backstory elements from the ground up at the beginning of the design and construction process.

Lessons Learned and Next Steps

Our recent research into ambient storytelling, lifelogging and Interactive Architecture has given us the opportunity to imagine an internet of storytelling things and environments. We have just scraped the surface of these possibilities and have realized that our research extends beyond just a single building, but to connected buildings within connected cities made up of connected people, objects, automobiles, and infrastructure. However, this complex interconnectivity of a networked world has lead us to explore three distinct, yet interrelated, levels of engagement between people and interactive architecture.

While continuing along our original research trajectory, we are now shifting focusing on deepening the engagement between inhabitants and the building itself. We have designing three stages of interaction, relationship development and place-making in interactive architecture: Building Transparency, Building Engagement, and Building Objects.

The Building Transparency Phase uses real-time data generated by the building, its inhabitants, and the network that connects them, to provide a dynamic visualization of current building activity. By visualizing the building information system data, i.e., HVAC, temperature, humidity, air quality, noise levels, and power consumption; network activity such as bandwidth usage, wifi access points and the number of devices connected to the network; and building inhabitant data, such as social network check-ins, a complex ecosystem of dynamic data

materializes, making building inhabitants aware of not only the many systems within a building, but also the amount of data that is being generated and collected on a daily basis.
After inhabitants begin to understand the building through its data visualization, the Building Engagement Phase uses the data described above to develop a personalized inhabitant profile. As the building begins to understand specific inhabitants, it uses what it has learned about them to engage them directly in interactions, or conversations, throughout the spaces of building. It is also at this point that the real character of the building emerges, becoming more aware of its inhabitants, using visuals and sonic profiles to let inhabitants know that it recognizes them specifically and would like to engage more deeply with them. The building keeps track of all data and information gathered through these interactions to further develop an ongoing inhabitant profile.

In the final phase, Building Objects, the building uses all of the stored data about itself and inhabitant profile data to generate a 3D object for specific inhabitants who have engaged in ongoing conversations and interactions with the building. This data object is a gift, or totem, created for inhabitants, representing the growing relationship between building and inhabitant, while making visible the invisible interactions and data sets that have become part of a new process of place-making in interactive architecture.

Finally, we have identified three areas of interest for which our research could successfully be applied: Energy, Health and Hospitals, and Museums. Because each of these categories represents a constant evolution of knowledge and learning, we believe that the platform we have created to use the built environment as an animate, storytelling entity would transform the ways in which we can engage and educate people to most efficiently use buildings, to be more healthful, and to enable playful participatory learning environments.

Energy
Working with Professor Greg Otto and USC's School of Architecture, we are working towards the development of a systemic framework for the deployment of ubiquitous computing within the built environment that produces intelligence at the building system level (environmental quality and comfort) and supports bi-directional user feedback. Our proposal presumes that a productive, user-friendly interface can be evolved from the field of media/information sciences, and made available to support user interaction with their immediate environment. It is our intention to seek optimal energy efficiency and environmental quality and comfort at the human level via direct interfacing with building environmental systems and to create new social networks that foster eco-positive behavior, learning and adaptation.

Significant opportunity exists for improved indoor environmental quality and comfort, and energy efficiency – two commonly competing agendas – within the built environment. Advanced system controls coupled with direct sensor feedback have already proven readily able to achieve improved operational performance and hence energy savings. However, the individual and his/her input and engagement within their immediate environment has for the most part been left unexplored and untapped at the behavioral level for potential energy savings. New opportunities exist to bring the individual in direct communication with building environmental management systems to participate in direct feedback and communication through ubiquitous computing with the targeted aim to 'tune' the indoor environment at the individual level for quality, comfort and maximum energy efficiency. The assumption is that the individual, supported by a decision-making framework with targeted goals, will make the 'correct' decisions in tuning their immediate environment and that further energy efficiencies can be achieved.

Technology change within the profession of architecture and building engineering is already underway to support digital, virtual environments. Building Information Modeling (BIM) and interoperable computational platforms already support simulation and animation of energy, power, air, water and occupant systems. However, industry change is not occurring quickly in this frame due to a fundamental lack of understanding of the value of data centric processes – a consequence of architectural education and its failure to evolve beyond visual representation – and the potential for it to extend beyond design to building operation and management. Complex interactions can be modeled, simulated and optimized. Real-time monitoring and adaptive controls can link the virtual environment to the physical world. Real-time data, decision making provisions and control instructions can be supported on ubiquitous computing infrastructure and delivered bi-directionally via smart devices. Data mining and analysis supports adaptive learning and make it is possible to suggest that a building might begin to be sensitive and responsive to people given a complex set of variables. It therefore should not be much of a stretch to assume that the response can be optimized for any number of variables including energy efficiency and environmental conditions (environmental quality and comfort).

The transformative impact of information based, web enabled technologies and small, inexpensive, networked devices are having on human interaction and communication has been significant. Media, gaming and other virtual simulations have begun to explore new ideas about human-environment interaction and engagement. However, none have gone so far to support bi-directional interaction and engagement between buildings and users in a significant way. Ubiquitous computing presents a number of challenges in engineering design, modeling and interface.

Hospitals

Our research can further be extended to the context of hospitals, with Children's Hospitals being of particular interest. By applying these concepts of character and relationship development within storytelling environments to health and wellness facilities, there is a unique opportunity for a building character to learn about its patients and engage them in healthful behaviors. Through networked records and appointment schedules, progress updates and tracking, and vital information about one's health, an animate hospital environment could transform a potentially unpleasant setting into a playful, engaging, experience for young patients. Furthermore, by developing an ongoing patient profile, the hospital-as-character could teach its patients how to engage in healthful lifestyles, like taking their medication and reminding them of future appointments. Finally, hospitals connected to the internet of things could be extended to mobile platforms, which would help monitor and further encourage healing and healthy habits.

Museums

Finally, informal learning settings such as museums provide an ideal application platform for our research. Using Science Museums as testbeds for digital learning experiences, we intend to design an open-source mobile platform that enables an integrative system for teaching and learning between networked spaces. This framework for ambient storytelling includes a real-time Alternate Reality Game (ARG) that invites museum visitors to become an integral part of the learning experience by engaging with the museum and its exhibits using social networking tools, while also contributing to a virtual, web-based experience.

The museum building itself might become a character in the alternate reality game, enlisting visitors' engagement with its exhibits while teaching it what they have learned through their experience in the museum. This enables participants to share what they have learned and become teachers themselves within the context of an engaging ARG experience. Additionally, the complementary web-based experience will allow people to participate virtually as real world agents to museum participants. The learning experience will be assessed through immediate feedback embedded directly into ARG software and web experience.

For example, since the museum building is stationary and cannot discover the world itself, its visitors will act as a street team of citizen scientists who can help the building learn more about the world around it. Though the building might be able to collect sensor data about itself and its external environment, such as energy consumption, air quality, wind data, and water currents, it enlists young visitors to examine environmental exhibits to help the museum building make sense of the information it collects. Participants would therefore teach the building what they have learned, enabling the building to become more knowledgeable about its environmental impact. This cycle of teaching and learning between the building and its visitors could be translated to other thematic exhibits, connecting complex scientific concepts within the museum.

Project Appendix

Ada: The Intelligent Room: http://architettura.supereva.com/interview/20040205/index_en.htm

Arch-OS: http://www.arch-os.com/

Herman Miller Always Building: www.**hermanmiller**.com/MarketFacingTech/.../**Always_Building**.pdf

Adaptive House: http://www.cs.colorado.edu/~mozer/index.php?dir=/Research/Projects/Adaptive%20house/

Chasing the Negawatt, Simon Fraser University: http://www.siat.sfu.ca/news/2010/481/

Lucid Design Group: http://www.luciddesigngroup.com/index.php

Common Sense: http://www.communitysensing.org/technology.php

Living City, The Living: http://www.thelivingcity.net/

Pachube: http://www.pachube.com/

USC Mobile and Environmental Media Lab: http://mobilemedia.usc.edu/

Million Story Building Demo Video: http://vimeo.com/8490038
StoryObjects Demo Video: http://vimeo.com/8489931

Acknowledgements
The Mobile and Environmental Media Lab would like to thank Intel, Nokia, and Amdocs Corp. for their generous support of the Million Story Building and Story Objects.

MEML Team:

Scott S. Fisher
Jen Stein
Jeff Watson
Josh McVeigh-Schultz
Marientina Gotsis
Peter Preuss
Will Carter
Andreas Kratky

Contacts:

Scott Fisher
Professor and Chair
Interactive Media Division
School of Cinematic Arts
University of Southern California
sfisher@cinema.usc.edu
+1 213 821 5219

Jennifer Stein
PhD Researcher
Media Arts and Practice
School of Cinematic Arts
University of Southern California
steinjen@usc.edu