Integrating Physical Objects Into Digital Displays: Design of a 3D Campus Map for the MIT Atlas Center

by

Tiffany T. Lu

S.B., EECS, Massachusetts Institute of Technology (2015)

Submitted to the Department of Electrical Engineering and Computer Science
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Author . . . .
Department of Electrical Engineering and Computer Science
May 20, 2016

Certified by . . . .
Prof. Federico Casalegno
Associate Professor of the Practice, CMS/W
Thesis Supervisor

Accepted by . . . .
Dr. Christopher J. Terman
Chairman, Masters of Engineering Thesis Committee

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Abstract

An emerging trend in consumer technology has been to build smarter technology into physical objects and to control those objects through digital interfaces. This blend of different interfaces for the internet of things reflects a response to a need for integrating technology more deeply into everyday life and providing more intuitive and natural interfaces. As these technologies advance, the line between digital information and physical objects will blur. This project explores how physical objects can be integrated into digital interfaces through the development of an interactive 3D campus map, a component of the new MIT Atlas Service Center. The installation combines physical objects with a large touch screen table in order to create a blended engaging experience. Through the design of both the experience and interface of the installation, we explore how digital information and physical objects can work together to help people understand spatial and contextual information. The campus map allows users to explore various aspects of MIT culture from basic navigational information to the latest MIT research to what's going on around campus right now, and also provides a modular platform for any location-based data visualization.

Thesis Supervisor: Prof. Federico Casalegno
Title: Associate Professor of the Practice, CMS/W

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Chapter 1

Introduction

The 3D interactive MIT campus map will be an installation in the new MIT Atlas Service Center to serve as a central source of information for students, employees, and visitors. The map will provide a wide range of information including events around campus, shuttle routes, recent MIT news, and interesting places to see for visitors to the Service Center to explore. The map uses tangible interaction components as well as a three-dimensional visualization of the campus to make the experience more engaging and natural for new users. The physical map combined with the multi-touch screen creates a multi-modal experience in a simple engaging interface for users of all backgrounds.

1.1 Motivation

As part of an initiative by MIT to develop a new Service Center, the MIT Design Lab designed a completely new and hi-tech service center experience for students, employees, and visitors at the new MIT Atlas Service Center. The newly designed MIT Atlas Service Center aims to provide a space to better serve the MIT community by making it easy to get administrative tasks done efficiently, strengthening connections within MIT, and communicating MIT's mission to advance knowledge and promote innovation. Along with providing more than nineteen services, the service center is meant to act as a place to get inspired by MIT technology and innovation and to learn more about that culture. In order to accomplish these goals, the service center design includes many engaging features to make the space more welcoming and inviting for students, faculty, and visitors to campus.

The interactive 3D campus map was one concept that was proposed in the design of the new center and meant to educate students, employees, and visitors about various aspects of MIT and the MIT campus. Not only will the campus map serve as a helpful installation in the service center, but it also poses interesting interaction problems that have yet to be explored in depth such as how to visualize a wide range of information on a map or how a 3D map can enhance the experience. Much of the information and features that the campus map will include could be done on a two-dimensional touch screen with much greater simplicity, but this project aims to explore how physical objects can be integrated to create a better experience for the user. The physical 3D map poses many interesting explorations such as how physical objects can be used with digital information in order to help the user orient themselves in space and to make the experience more interactive or intuitive. These broad human-computer interaction questions will push the development of the campus map forward in interesting new ways.

1.2 Vision

With the current movement towards a world of connected objects, the internet of things is becoming more prominent and mainstream. Experts estimate that by 2020 there will be 20 to 50 billion connected objects in existence, excluding smartphones and computers, increasing from approximately 5 billion today [4][9]. Smart home products such as light bulbs and thermostats are already very common, but the trend is leaning towards making more basic items like books or keys "smart" by attaching sensors and chips to them. As these technologies advance and more products become connected, the line between digital information and physical objects will blur. Before getting to that stage, however, we must understand how to incorporate physical objects into digital interfaces. Most existing smart objects use a smartphone as the primary interface for controlling the object and exchanging information, so this interaction is key to designing the useful connected objects of the future. This thesis hopes to explore the relationship between physical objects and information architecture through the development of the campus map. The map will be used to explore how to design a tangible interface and connect it to a display to attempt to understand how users perceive space and the relationship between objects. Our map design proposes that a combination of touch, light, and visual feedback will be effective in sharing digital information with users. This project will examine how this particular model works towards helping users understand spatial information and aims to understand how future connected objects can improve the user experience with everyday objects.

1.3 Thesis Summary

- Chapter 2 describes the project background and relevant research done in the area of tangible interactions.
- Chapter 3 describes the design and prototyping process.
- Chapter 4 describes the overall design of the map interface.
- Chapter 5 describes the technical components of the project.
- Chapter 6 describes the final prototype, contributions, and conclusion.

Chapter 2

Background

2.1 Previous Work

In 2015, the MIT Mobile Experience Lab was tasked with designing the new MIT Atlas Service Center - a new center for students, employees, and visitors to get administrative tasks done and to get access to campus resources. While the existing service center offers just four services, the new center was re-imagined to offer more than nineteen different services, making it a one-stop-shop for all administrative needs. This center was designed with both visitors and employees in mind, with an open, bright flow in order to maximize both efficiency and visits.

The completed design offers an elegant combination of architectural and digital features to enhance the space. The space was designed to reduce lines and crowds and to make the center an inviting and engaging place. The digital features were designed to streamline waiting times and make all processes more efficient and flexible. These features included tools like digital check-in, kiosks, and private video-conferencing rooms, whose goals were to offer more flexible forms of support for a variety of use cases.

The 3D campus map is one of those features and aims to serve as a point of interest within the service center to show visitors what is going on around campus. The initial mockup of the campus map is shown in Figure 2-1. The scale-model of campus gives users a better sense of the layout and look of the buildings around campus, and the

Figure 2-1: 3D Campus Map concept mockup.

embedded screen allows users to learn more about nearby events or other areas of interest. The design has since changed greatly, as described in section 3.5, but this was the initial concept proposed by the Lab.

2.2 Related Work

The 3D campus map utilizes key concepts from tangible interface research done over the past few years since "smart" objects have become more common. The physical interactive buildings act as the main interface with which users interact with digital information. This work is influenced by work done in tangible interfaces, smart objects, and spatial memory research.

2.2.1 Tangible Interfaces

Many research studies have reported increased user engagement and fun user experiences with using everyday objects to interact with digital systems. These are great advantages for applications in learning and gaming systems. Research has shown that tangible interfaces produce some sort of cognitive advantage over more abstract representations of information, but where these advantages come from are not well understood. Researchers have proposed that "the advantages come from increased sensory engagement - tactile, proprioceptive and kinesthetic, the true 3D visual space, our social norms of collaboration and turn-taking and our understanding of the physical world" [8]. Physical objects that people use in everyday life to explain ideas make those concepts more concrete and put these ideas into a tangible context and real space.

A study from 2013 researched these cognitive advantages by comparing support for mental projection in tangible and virtual representations of the Four-in-a-row game [3]. The results did not offer any clear indications of specific cognitive advantages, but the biggest difference in results between the two interfaces was the time to play metric where the tangible interface was much improved over the virtual interface. The study concluded that in order to better understand the direct advantages of a tangible interface over a virtual one would require developing a more robust virtual system to provide as much freedom of movement and flexibility as a physical system, but this statement itself reveals some of the benefits of a physical interface over a digital one, where users are able to create and understand their own ways of interacting with a system and do not have to learn the interface.

In a 2015 study from the San Francisco Exploratorium, researchers compared user behavior at an interactive exhibit when using physical objects versus virtual objects to explore a large scientific dataset [5]. The exhibit took the form of a large multi-touch table, visualizing the world's oceans; one version of the table used physical rings to explore the data while the other version used virtual rings. The study found that users were more inclined to touch and manipulate the physical rings as opposed to the virtual rings, which led to more interaction, attracted more groups, and encouraged further exploration. However, they did not see a difference in the thoroughness of a user's interactions and explorations; users did not seem to learn more in either version of the exhibit.

These studies indicate that while there may not be a clear cognitive advantage to a tangible interface, there is a clear difference in level of engagement and freedom of interaction with physical interfaces. With the 3D buildings, users are able to better understand the physical context and will be more likely to engage with the installation.

2.2.2 Smart Objects

Tangible interfaces as they currently exist are fairly basic, utilizing simple embedded sensors into familiar everyday objects to demonstrate to users how the objects connect to the digital information. However, looking five years into the future, one can imagine that eventually all interfaces will become "tangible"; interfaces will move beyond the constraints of specific devices like smartphones or touch screens and become ubiquitous through smart, integrated materials. As the technology becomes more advanced, it is likely that the objects will act as the interface, so that the information and the object are indistinguishable.

Today, smart objects are primarily designed by embedding sensors into objects that can communicate wirelessly with other more powerful devices, which do the majority of the analysis. Developments in this field can be seen in the 3D printing industry, where advanced printers are able to print a wide range of materials including conductive material and circuits, so that the printed objects have sensors embedded within them. For example, Voxel8 has developed a highly conductive printable ink with extremely low resistance and high conductivity that can be used with their printers to print objects with embedded circuits [10]. At the 2016 CHI conference, xPrint, a modular liquid printer, was presented, with the ability to print a wide range of liquid-based smart material in order to give designers and researchers more flexibility when prototyping new materials and designs [11]. These printers allow for objects to be printed with sensors and circuits embedded within them in order to allow the objects to interact with their surroundings.

More extensive research has begun to explore how to make these objects standalone interfaces and systems. In a 2014 paper, researchers proposed the term Soft User Interfaces (SUI), which refer to interfaces integrated into fabrics and clothing to create new experiences. More recently, MIT created the Advanced Functional Fabrics of America partnership, dedicated to the research and development of intelligent and

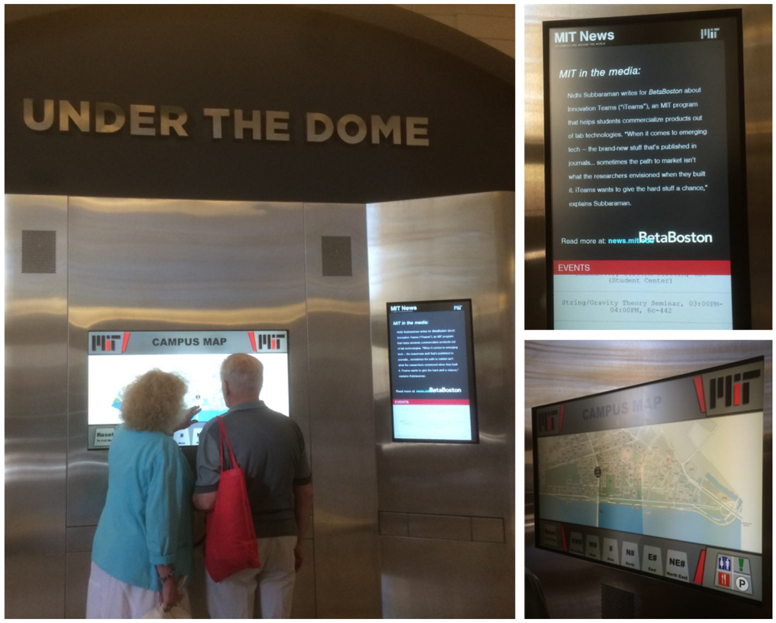


Figure 2-2: Lobby 7 "Under the Dome" map kiosk.

integrated textiles and fabrics as well as of the actual manufacturing process as well [2].

While the field still is in its early stages, this 3D Campus Map project takes the idea of integrated sensors into static objects to create a more interactive and intelligent experience.

2.2.3 Three-Dimensional Maps

There are many maps around the MIT campus for tourists and students to use when they are not sure where to go or where their next class is. One example of this is the "Under the Dome" kiosk in Lobby 7 as seen in Figure 2-2. This kiosk displays all the buildings around campus as well as other relevant information like bathroom locations, handicap-accessible entrances, and bike racks. The kiosk is often seen crowded with visitors waiting for their turn to inspect the interface, with its maximum capacity at around 2 people. The 3D campus map aims to improve upon some of these downfalls by using a 3D model of the map to help users orient themselves easier.

There has been much research into the difference in a user's ability to learn or remember a space with a two-dimensional versus a three-dimensional map, and while none of the relevant studies have been able to come to conclusive results, they all can agree that both the 2D and 3D maps each have their own pros and cons. A 2009 study compared users' performance when navigating a space using a 2D map versus a 3D representation of the map on mobile devices [6]. Because of the first-person perspective and display of a more realistic point of view, allowing for ego-centric alignment, the study hypothesized that users would have an easier time of navigating the physical space with the 3D tool. However, it was found that users spent a lot more time manipulating the 3D view of the map in order to orient themselves in the space, and that they were actually much more comfortable with the 2D maps, where they primarily used street names and other labels to find where they were going. This difference indicates that the actual perspective of the view is less useful to the user than the additional indicators on the maps that help them locate where they are, such as street labels and visual landmarks. This hypothesis was confirmed in another study, which compared the use of different navigation aids (maps vs. instruction lists) and the use of landmarks [7]. It demonstrated that maps with landmarks were the most effective teaching tool for users to actually gain an understanding of the space, though the learning curve was steeper than in the other cases.

The 3D campus map for the Atlas Center combines the benefits of both 2D and 3D maps. The top-down layout and overall view of the map is similar to that of a 2D map, where a user is free to orient themselves from any angle and can get the overall picture of the space, as well as have access to street labels. With the 3D buildings, users can also take advantage of an ego-centric perspective if they wish. Additionally, the 3D buildings better represent some of the obvious landmarks around campus, such as Killian Court or the Stata Center, which allows them to learn the layout of the campus more easily and efficiently.

Chapter 3

Design Process

This section describes the design process for the campus map installation. It describes the desired functionality of the campus map, the initial design and prototype, user tests, and the final design.

3.1 Desired Functionality

The desired functionality of the 3D campus map can be described with four main concepts:

- The Five Schools: This concept focuses on celebrating the five schools at MIT. Information on people, events, news and the school's history will be the centerpiece.

- Campus Buzz: This concept is centered around the idea of a dynamic, resourceful community. Several streams of information are combined to produce a near real-time map of the goings-on at the campus.

- Discover: This concept is directed at an audience interested in discovering the campus. Navigation and utilitarian information are the focus points.

- The Institution: This concept aims to present MIT's best people, research and contribution. Curated highlights that tell the story of MIT are key for this concept.

3.1.1 The Five Schools

The goal of the concept of the Five Schools is to allow users to explore the five different schools of MIT: School of Architecture and Planning, School of Engineering, School of Humanities, Arts, and Social Sciences, Sloan School of Management, and School of Science. In each of these schools, users are able to explore the people and labs, relevant events and lectures, school history, and highlights and achievements.

3.1.2 Campus Buzz

The Campus Buzz concept aims to encapsulate a real-time view of what is going on around campus through social media feeds, trending events, and user input. The core of this concept is to give users a sense of what life is like around campus throughout the day. Layers on this map will be made up of Twitter and Instagram updates, live traffic and public transportation information, and other user-generated content.

3.1.3 Discover

This concept focuses entirely on helping users find basic information about the space and the school. The key feature in this concept is navigation, so that users are able to take advantage of indoor hallways and paths that traditional navigation systems are not able to provide. The Discover concept also provides basic utilitarian information like bike rack locations, places to eat, lab information, and points of interest around campus, so that users are guided in what they can explore on campus.

3.1.4 The Institution

This concept consists of a curated series of highlights about MIT through people, research, and general institute history. The purpose of this concept is to immerse users into the MIT experience and its mission and values.

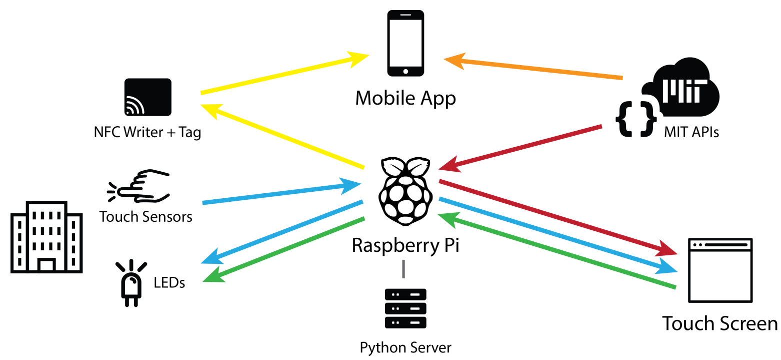


Figure 3-1: System diagram of the first physical map prototype.

3.2 Early Prototype

The initial idea was to build a complete 3D replica of the campus with interactive physical buildings and an accompanying information screen or media wall. In order to test this concept, a small-scale prototype using LEDs, conductive material, and a Raspberry Pi was developed and user tested. This section describes the technical implementation of the prototype and the corresponding user tests and results.

3.2.1 Technical Implementation

In order to build a system that would allow users to tap on buildings, illuminate buildings, and select information on the touch screen, the system had to connect the web application on the touch screen to the LEDs and touch sensors on the physical map. A Raspberry Pi was used to link the hardware and software, and the overall system diagram is seen in Figure 3-1. All of the components are driven off the Raspberry Pi Python server. Capacitive touch inputs and individually addressable LEDs are embedded into the 3D-printed buildings and are connected to the Pi via its GPIO pins.

The buildings are 3D printed in translucent filament in order to allow light to shine through and with black conductive filament, so that touches on the building can be detected. The touch input from the buildings is registered through the capacitive touch sensor breakout board, which detects changes in capacitance that occurs when a conductor (i.e. a hand) comes into contact with the input. The buildings are then illuminated using an individually addressable LED (LPD8806 driver) strip embedded underneath. The Raspberry Pi uses the Biblipixel Python library [1] to control the color and power of the LEDs. Finally the screen interface pulls everything together and takes the form of a web application running on the lightweight Flask server framework. The application pulls in MIT data from MIT APIs about events, food, shuttles, and people. Additionally, external APIs for social media feeds and non-MIT related food or events information is pulled from the Twitter and Factual APIs.

3.2.2 User Tests

After the prototype was assembled, user tests were conducted to gather initial qualitative feedback on the aesthetic, layout, features, and quality of the prototype. The prototype used for testing is seen in Figure 3-2: the prototype was built on a foam board, which the small-scale buildings were glued to and which had LEDs and wires embedded on the underside to connect all the components back to the Raspberry Pi. The appendix includes a time-lapse video of the prototype construction (A.1) as well as the script and questions used for the user tests (A.3).

When introducing the interface, the basic functionality was explained before asking users to complete the tasks. The user test included three tasks for the user to complete, which were chosen such that the user could explore the different parts of the interface. These tasks were:

1. Find an interesting event in E15 and add it to your calendar
2. Learn more about Building 10
3. Explore the interface and share your thoughts and feedback.

The goal of Task 1 was to observe how users thought to look for events and get them to use the mobile app component. The goal of the second task was to push the user to actually touch the interactive buildings and see if that action came naturally to them. Finally, the last task offered the chance to observe what features the users

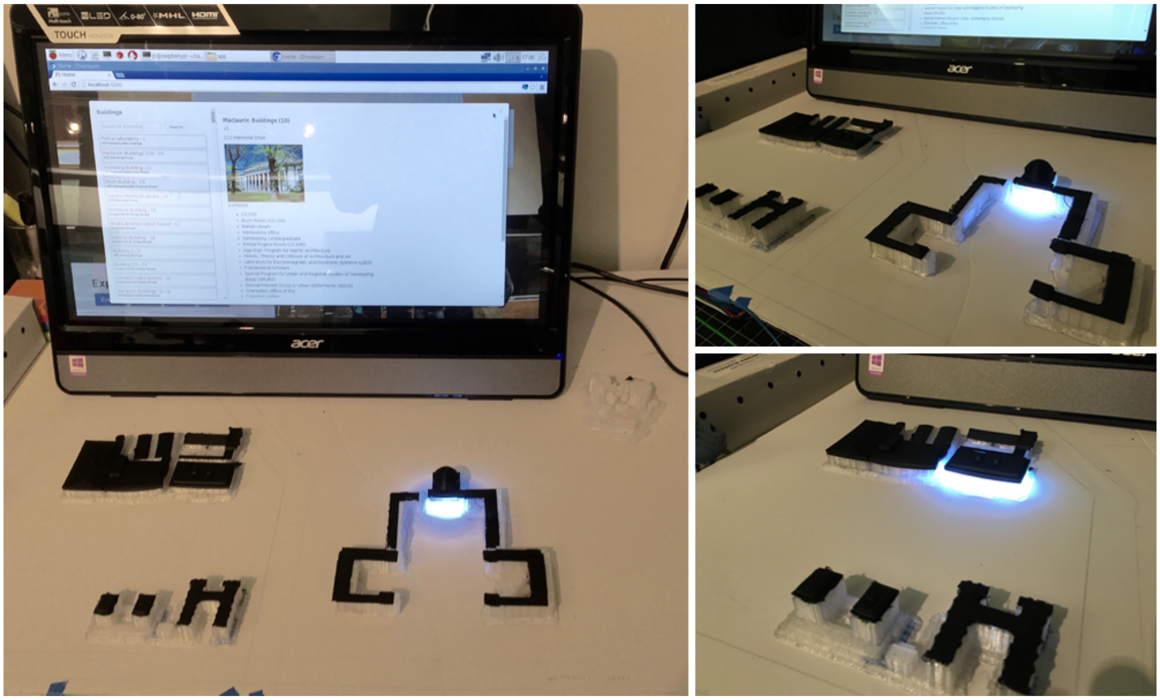


Figure 3-2: The completed prototype used for user testing.

liked and longed for and to see what other pieces of information they could pull from the interface.

The collected feedback was organized into four different buckets: the screen interface, the 3D-printed buildings, the map, and the map/screen relationship, and these were compiled into design guidelines for the next iteration.

3.3 User Feedback

3.3.1 The Screen Interface

The feedback collected for the screen interface primarily focused around information architecture. The interface separated Building, Food, Event, and Shuttle information into four different menus, but users wished that each of these categories were integrated since their primary use case would be exploration, and they did not always know what they were looking for. Filtering information was another common request to make it easier to find information relevant to the user's interests. Finally, users thought the interface was not very interesting: it was extremely text-heavy, and while the information seemed useful, it was not very engaging, and users did not feel like they were getting much value from it.

3.3.2 The Map

Users enjoyed the 3D map the most out of all the components; many users spent most of their time exploring and experimenting with the touch sensitivity of the different buildings. Beyond this initial excitement though, there was mixed feedback on the utility of this type of map.

Some users thought that the 3D map made the campus feel more real and recognizable: "If I'm at MIT, and I've seen the dome, I now have a better sense of where it is. It is much more relatable for spotting which buildings are where if I'm a visitor," indicating that the 3D models of the buildings made them easier to identify and gave them more recognizable landmarks to work off of. However, others expressed concern that as someone unfamiliar with campus, it was difficult to tell what building was what, and that street and building labels would help. Another concern was that with a regular 2D map on a smartphone, for example, users are able to zoom and pan around the map to view more details, and this was something that was important but missing in a map designed for visitors and new students. Finally, users also thought that, although the interactive buildings gave off a "wow" factor, after a few minutes, they were underwhelmed with the map and were searching for something more lively, suggesting different color lights and more movement.

3.3.3 3D Printed Buildings

The 3D printed buildings definitely had the desired effect of drawing users into the map and making it feel more engaging. Users all felt that the building illumination looked great and was very responsive to the touch. However, the combination of the semi-transparent and black conductive filaments made it difficult to see the building details. The transparent filament made it easier to see the defects in the 3D prints, and the black filament made it hard to pick out any details as well as difficult to see the building illumination in denser building areas. Finally, while the scale of the map was manageable since all buildings were in reach, users unanimously agreed that they were too small and would have a bigger impact if the scale was increased.

3.3.4 Map / Screen Relationship

The final category of feedback, the map and screen relationship, garnered the biggest problems and had the largest negative effect on the user experience. None of the users could get the hang of the connection between the physical map and the accompanying screen; they felt that the touch screen and the map were very separate. When a user touched a building, they often did not notice that relevant information appeared on the screen despite being aware of the screen's existence.

As a new student, one user stated "I don't understand the use of touch because I don't know where anything is." Despite the building interaction being the most exciting part of the interface, most users would likely first go to the touch screen to find information since the physical map contains no information beyond the layout of the campus. Users suggested that both the screen and the map should offer the same information rather than require users to use both to learn anything.

The relationship between the map and screen was the most difficult part for users; all users were more comfortable interacting with only one or the other and suggested that the information were more deeply integrated with the actual map.

3.4 Design Considerations

The main pieces of feedback are summarized as follows:

- The screen information and the 3D map are too separate.
- The screen information needs to be better organized to better facilitate discovery.
- The 3D printed buildings are too small and do not show enough detail.

- The 3D map looks boring and is not very engaging.

From this feedback, key design considerations were identified and developed for each component.

The Screen Interface

- Create a clear information architecture to facilitate discovery and exploration
- Engage users with more visuals and less text

The Map

- Context is very important for a map, so geographical context or street labels might help
- Buildings need more energy through colors or movement

3D Printed Buildings

- Higher resolution buildings in a slicker material
- Larger buildings

Map / Screen Relationship

- Deeper integration and connection between the information and the physical map

3.5 Final Design

This resulted in a redesign of the system, the layout of which is shown in Figure 3-3, where the 3D printed buildings would be placed directly on top of a large touch screen table, such that the table's pixels would illuminate the buildings, and the associated information would be displayed directly on the map. The 3D printed buildings would now no longer be wired to the Raspberry Pi, and instead would transmit touch

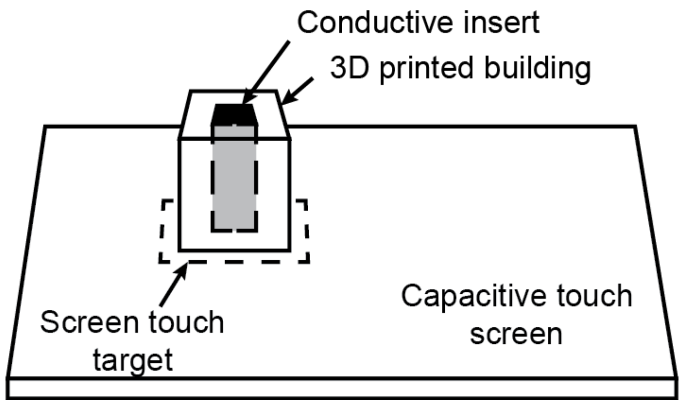


Figure 3-3: The concept diagram behind the system redesign.

information through the capacitive touch screen. The touch screen surface would allow information to be more dynamic and displayed alongside the buildings, so the user's focus will be concentrated on one interface.

This new design addresses the four feedback points above by superimposing the information with the map, organizing information by location rather than by category, increasing the size of the map, and by re-evaluating the 3D print method. This design follows tangible interaction and three-dimensional map theory more closely, creating a better experience for the user.

3.5.1 Tangible Interaction

With this tighter coupling of physical object and digital information, users have more context to place these objects into and will be able to better understand these objects in both their real physical context as well as their context within the interface. The design takes more advantage of tangible interaction benefits because the physical buildings are directly linked to the digital information associated with them as opposed to the separation between interface and information in the original prototype. The integration of the digital screen with the transparent buildings gives the objects more movement and life, and these features will increase user engagement and excitement towards the installation.

3.5.2 Three-Dimensional Maps

The redesigned map utilizes the benefits of both 2D and 3D maps by combining the two into one interface. The map on the screen provides more map and environment details that users are familiar with when looking at a traditional map. Because the map is a touch screen, users are able to interact with the entire map, not just the buildings, which gives the user more freedom and flexibility to explore and manipulate not just the MIT campus, but the pieces of information associated with campus. The 3D buildings embedded into the interface provide users with recognizable landmarks and different perspectives to allow them to understand the space even more.

Chapter 4

Interface Design

4.1 Information Architecture

With the new design in mind, the desired functionality was pared down to more closely fit the building and location-based focus of the map. This new information architecture focuses on the Campus Buzz concept described in section 3.1 and is illustrated in Figure 4-1. The three categories in Figure 4-1, Real Time Buzz, Info Showcase, and Around Me, are focused on giving users a sense of what is going on around campus at the current moment.

"Real Time Buzz" is a data visualization layer with multiple data streams. These visualizations are location-based with the popular pedestrian routes displayed as a density map, and the devices connected to Wi-Fi shown as a network graph. Active shuttle routes are just shown as live paths on the map, and social media chatter is displayed as a constantly updating feed. The visualizations are displayed based on the location data attached to each of the data points, so there is room for other types of data to be displayed as well.

The info showcase is a layer focused on showing off MIT research and innovation and is based on content that is updated from MIT public APIs as well as curated by hand and regularly updated. This information takes the form of news articles, featured faculty or researchers, and featured events. This information can be explored interactively through the map or it can be shown in ambient mode as a means for

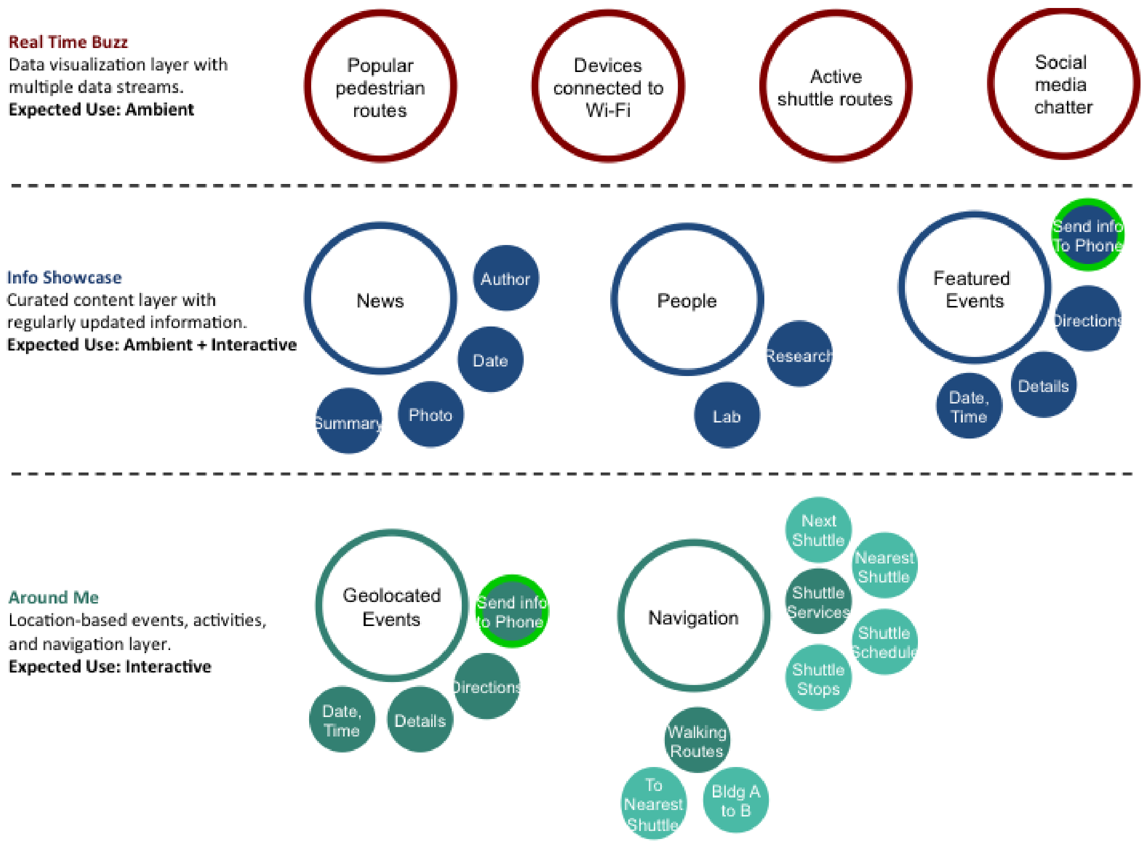


Figure 4-1: The information architecture for the campus map interface.

discovery.

"Around Me" is the main interactive layer of the map, focusing on location-based events and activities around campus as well as a custom navigation layer that provides both indoor and outdoor navigation across campus. This layer is geared towards users of all backgrounds. Visitors are able to learn more about what is currently going on around them, and they can navigate themselves to different places on campus, and current students and employees who are already familiar with the layout of campus can see relevant events or activities that they may not have heard about otherwise. This layer combines location and time sensitivity to provide a real-time picture of MIT.

4.2 User Interface

The interface for the campus map focuses on the buildings as the main interactive point. The main component is a card-based interface feature, which displays all relevant information. Other components include navigation, a dashboard, and ambient mode.

4.2.1 Cards

Each piece of information shown in Figure 4-1 has a corresponding card, and these cards are associated with a specific building. Examples of these cards can be seen in Figure 4-2. Figure 4-2a displays the building label card, which includes the building name and number, the associated school or department, and a photo of the building. Next is the events card, which provides a list of upcoming events either in the building selected or nearby; this card can be expanded to reveal the actual details, and if the event is selected, a QR code can be revealed. Part c of the figure shows the shuttle card, which displays the next upcoming shuttle at the nearest shuttle stop; users can bring up the schedule on their phone by scanning the associated QR code. Part d displays the various states of the news cards, which are presented in an expandable stack. The news articles are categorized by school or department and can be opened on the user's phone through the QR code. Finally, part e displays featured researchers in the associated building's departments.

The card model was chosen to mimic a feeling of tangibility for each piece of information, which follows the physical buildings placed on top of the map. The cards are also modular, which allows each type of information to have its own form, the card layout to change based on what information is available, and new types of information to be easily added.

Lastly, there is also a Social Media chatter card that is statically placed at the top of the map. This card continuously updates its content with status updates and photos from official MIT Twitter accounts (e.g. department accounts, Alumni Association, etc.).

4.2.2 Navigation

Users can use a long-press gesture to view navigation via streets and indoor or outdoor campus pedestrian paths between locations. When a user long-presses a location, the interface draws the path from the location of the Atlas Service Center (building E17) to that location as displayed in Figure 4-3. When a building is already selected, users can use the navigation card shown in Figure 4-2f to view navigation to that building as well. To view navigation between two specified locations, the user selects the origin first then long-presses the destination. The interface displays a time estimate on a card as shown in Figure 4-3.

4.2.3 Dashboard

For more basic utilitarian information that users might expect from a campus map, there is a dashboard which allows users to toggle on and off locations for bike racks, restrooms, campus art, and free food. The campus art and free food pins also can provide more information if selected. Figure 4-4 shows the corresponding icons for each of these features. Part a shows an example of free food; the icon is customized to what type of food it is, and the corresponding description is shown if the icon is

Figure 4-2: The various information cards: (a) building label card, (b) events card, (c) shuttle card, (d) news cards, (e) people cards, (f) navigation card.

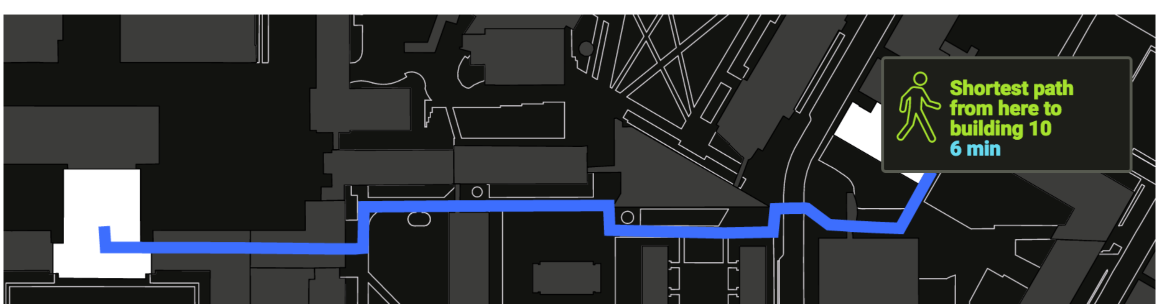


Figure 4-3: Navigation from the Atlas Center to Building 10.

Figure 4-4: Icons for dashboard menu items.

selected. Part b shows a similar mechanism for art around campus.

4.2.4 Ambient Mode & Visualizations

Finally, the last components of the interface are the ambient mode and data visualizations. Ambient mode is activated after a period of inactivity on the campus map; it cycles through the various pieces of information as a means for passive discovery for users who are just passing by or observing. For example, it can display events that are occurring in the next half an hour, interesting pieces of recent news, free food that recently got posted, or a live display of where the shuttles are on campus.

The ambient mode not only displays the information accessible in the interactive mode but also displays data visualizations. These visualizations take MIT data such as the most popular pedestrian paths or the Wi-Fi activity around campus and display them in easy-to-understand and engaging ways. This gives users a sense of the activity around campus.

Chapter 5

Technical Approach

The 3D campus map is built as a Node.js web application that runs on a large touch screen augmented with interactive 3D printed buildings. The web application allows the system to be built in the most versatile and modular way: it can be run on any operating system, the back and front ends will be reusable and separate components, and it makes updating and expanding the system for more installations or personal devices easier. This section describes the physical setup of the map and the various components of both the back and front-end software.

5.1 Physical Setup

The 3D campus map takes the form of a large touch screen with interactive 3D printed buildings placed on top. The touch screen is 55" large diagonally and can handle up to 60 distinct touch points. The screen is large enough to allow 4 to 6 people to fit comfortably around it; however, the size and resolution of the screen restricts the amount of information that can be displayed at one time, so the system is designed for one user's interaction.

The 3D printed buildings are printed in clear resin on a Formlabs Form 2 printer with conductive pieces embedded. The inserts are printed in conductive filament on an additive printer. The conductive inserts allow users to interact with the physical buildings and have their touch be transmitted and detected by the capacitive

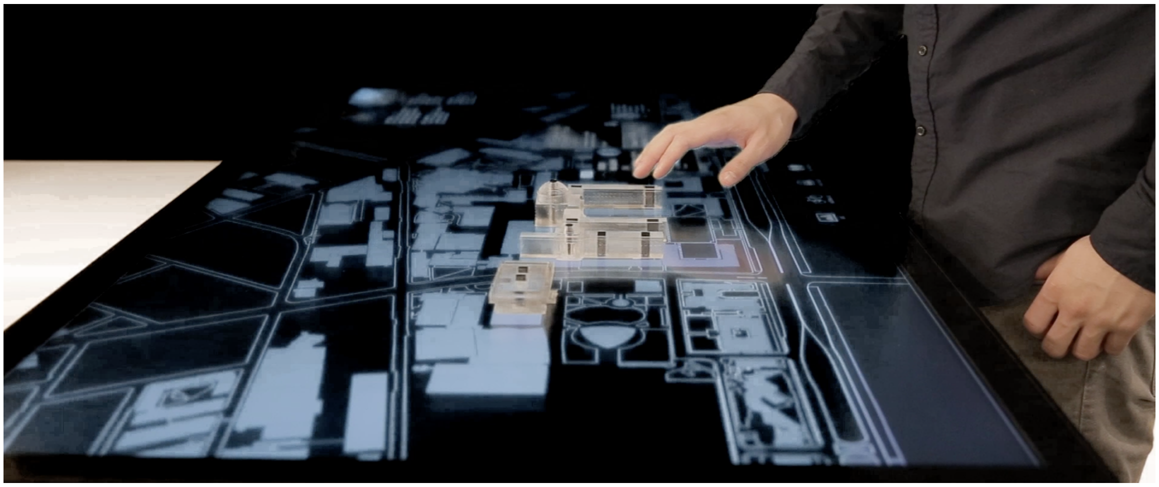


Figure 5-1: The physical setup of the 3D Campus Map.

touch screen underneath. Figure 5-1 shows the touch screen with a small selection of buildings printed and placed on top.

5.2 Back-end Software

The back-end system is a Node.js Express server with a MongoDB database for data storage. The Information Systems and Technology department (IS&T) at MIT provided access to many MIT resources to back up the system including MIT APIs for access to the events calendar, shuttle tracking system, news, dining, tours, courses, and departments, and Facilities' building and campus information. IS&T also provided suggestions for external APIs and example sets of data that are not publicly accessible that were used for testing.

The following APIs are used to collect information to serve to the front-end:

- MIT Mobile APIs, `http://m.mit.edu/docs/`
  - Events Calendar
  - Shuttle tracking (NextBus)
  - News
- MIT Facilities Campus Map, `http://whereis.mit.edu/`

  - Restrooms
  - Bicycle Racks

- Twitter API, `https://dev.twitter.com/`
- OpenStreetMap data with Mapzen Valhalla API, `https://mapzen.com/projects/turn-by-turn/`
  - Indoor/Outdoor Navigation

There are many resources that are integrated into the system and available in the system's internal API but are not surfaced in the interface, including:

- MIT Mobile APIs, `http://m.mit.edu/docs/`
  - Dining
  - Tours
- MIT Developer APIs, `http://developer.mit.edu/`
  - Courses
  - Subjects
  - Departments

Information that does not change often is stored in the MongoDB database and updated on a recurring schedule (i.e. everyday for Events and News) through Cron jobs. Live information such as the shuttle schedules, Twitter updates, and navigation are requested from the APIs directly because of the time-sensitive nature of those pieces of data. The varying types of information are stored in similar uniform ways to make the system as flexible for new data as possible. Each update function is written in a modular and reusable way so that new data sources can be simply and easily integrated.

Since the primary interaction with the interface is through MIT buildings, most of the data are associated with specific buildings and are served together. For example, if a user selects Building 7, the cards shown in Figure 4-2 are displayed, so information such as the nearest shuttle stop and its tracking information, upcoming events, related news articles, and related people are all pre-computed, bundled together, and served to the front-end.

5.3 Front-end Software

The front-end of the web application is built on top of the Node.js app primarily with JQuery. The front-end uses the following frameworks:

- JavaScript / JQuery: animations, event callbacks, queries to the back-end
- Embedded JavaScript (EJS) Templates: data display
- Snap SVG: map display, animations, building labeling
- Hammer JS: touch-screen gestures and callbacks

JQuery is used to integrate interaction into all the pieces of the user interface while EJS templates are used to display the actual data in reusable and customizable HTML templates. Since the actual campus map is in SVG form, Snap SVG is used to display and manipulate the map and building outlines. Finally, more customized and complex gestures are enabled through Hammer JS, which adds touch and gesture support to web pages.

In order to maintain modularity and code readability, each component of the front-end is separated into its own module; these modules are compiled together using a tool called Browserify (`http://browserify.org/`), which bundles together all required components and allows the use of NPM modules in the front-end as well.

5.3.1 Modules

There are two groups of front-end modules, ones for general module use, and others that are specific to pieces of the UI. The general modules include:

- Main module: calls the document setup functions and initializes all modules
- Model module: tracks the state of the user interface
- Snap module: provides abstracted functions for manipulating and understanding the map SVG
- Utils module: general helper functions (e.g. converts latitude and longitude coordinates to pixel locations onscreen)

The more specific modules each have their own interface responsibilities.

Setup

There are two modules whose purpose is for general setup: the map and buildings modules. The map module loads the map SVG using the general Snap module and sets up listeners for each of the pieces. The buildings module sets up each building on the map to be listening for interaction. Each building is labeled with an ID corresponding to its building number, and these IDs are used to identify which building is being selected. These setup modules are used at page load and never again.

Card Layout & Display

The bulk of the user interface is done in the card layout and display modules, whose responsibilities are to find and display the relevant cards for each building that is selected. The Buildings-Info module is the main driving module that calls each of its submodules. When a building is selected, the module retrieves the data from the back-end, generates the corresponding UI fragments, sets up any required listeners, and lays out the cards according to the building's specifications.

The cards are generated using the Card-View and Card-Stack modules, which generate custom EJS templates depending on what type of data was requested (events, news, people, shuttles, etc.). The Card-Stack module is called by the Card-View module for News and People data since those are displayed as a stack of cards. There is also a set methodology laid out to add a new data type, but there is also a default

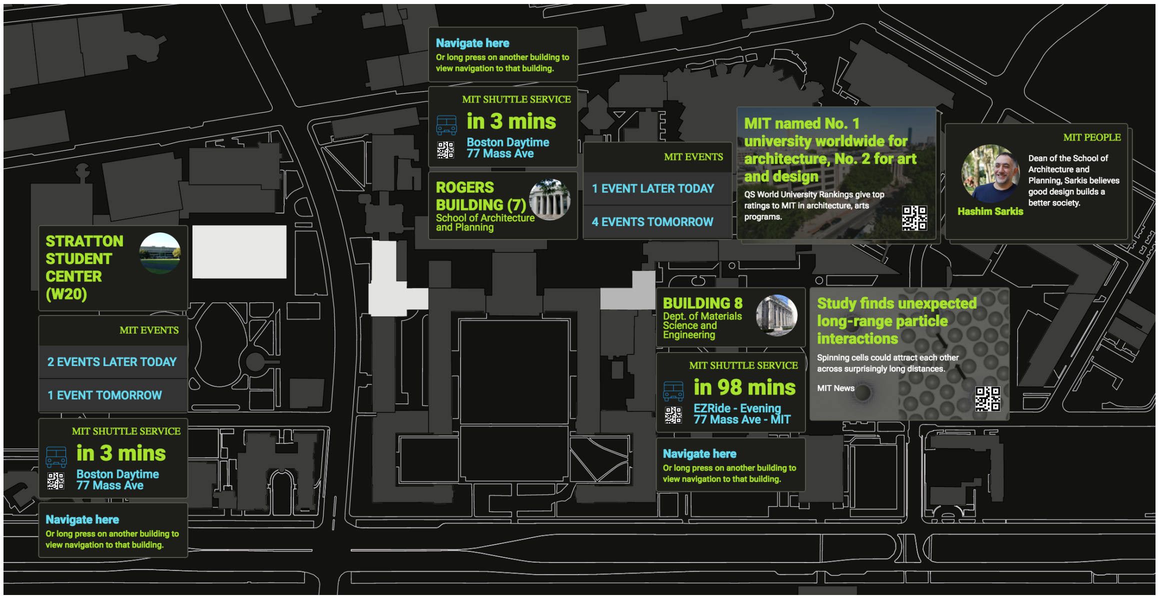


Figure 5-2: Card layouts for three buildings: W20, 7, and 8.

template designed especially for unspecified types of data, so that any additional information can be easily added and displayed. These modules determine which cards should be displayed for each building depending on what information is relevant and available for the current time.

The actual layout of the cards is handled by the Card-Layout module. Because of the 3D printed buildings that are augmented onto the touch screen, not all of the screen space is available for information display, and the cards must adapt to fit around displayed buildings. A static data module knows which buildings are 3D printed, and each building has specified corners and sides that are open for card display. The Card-Layout module uses these specifications to determine where to place the cards. Example layouts that are arranged to avoid covering the 3D printed main Killian Court building cluster are shown in Figure 5-2.

Dashboard

The dashboard modules take care of requesting the relevant information from the back-end, displaying the locations of each of the features (free food, campus art, restrooms, and bike racks), and adding tap listeners. This module is also designed to be easily expanded to include other types of data since the only required pieces of information per data type are location (latitude/longitude coordinates) and a caption.

Ambient Mode

The final module is the Popups module, which takes care of starting, looping through, and stopping ambient mode. This module has an internal timer that resets itself every time there is an interaction on-screen; after a certain period of inactivity tracked by that timer, the popups module begins "ambient mode", which loops through information that is usually available in interactive mode such as upcoming events, nearby free food, or shuttle schedules. It also includes abstract visualizations of pedestrian density and Wi-Fi network usage. The module uses the Card-View and Card-Layout modules to access and display this data.

5.4 Content Management System

The final component of the software is the Content Management System (CMS). The CMS allows for data entry and tagging for the database collections that are automatically populated from their respective APIs.

As described in Section 4.1, the Info Showcase layer of the Information Architecture is partially hand curated. This is done through a simple create-read-update-delete (CRUD) interface.

Specifically, the components that are curated by hand include: which events are trending or featured, profiles of professors or researchers of recent note, and tags for news articles, so that they may be displayed alongside the relevant departments or labs. The interface for events and news only allows editing of the tags that are associated with those objects since the information is automatically populated from the APIs. Since there is no back-end source for MIT people, the content management system allows for full CRUD operations on all fields for these featured researchers.

In the future, it is imagined that the sources for each of these APIs may include the information that requires hand curation, so that the process may be fully automated and require no use of the CMS.

Chapter 6

Contributions & Conclusion

6.1 Contributions

The final prototype is demoed in a video attached in Appendix A.1, and images of the prototype in action are shown in Figure 6-1.

Feedback was gathered from users through a series of demo sessions. Users found the campus map to have a lot of information that they had not seen aggregated into one context before. Information such as news and featured researchers can be found alongside upcoming events and nearby free food; before using the campus map, users were either unaware of these features or had to visit various places to get all this information. Users also found that the physical buildings gave them a new perspective of the campus, and they were more interested to explore surrounding buildings and features of the campus that were new to them.

6.1.1 Vision

Although there are strong elements of tangible interfaces and integrated interfaces in the campus map, there is still a lot of work to be done to build interfaces that do not require external displays like the touch screen that is used in this system. The physical buildings with embedded conductive inserts are primitive predecessors of future smart objects, which will potentially be able to sense touches and movement and act as

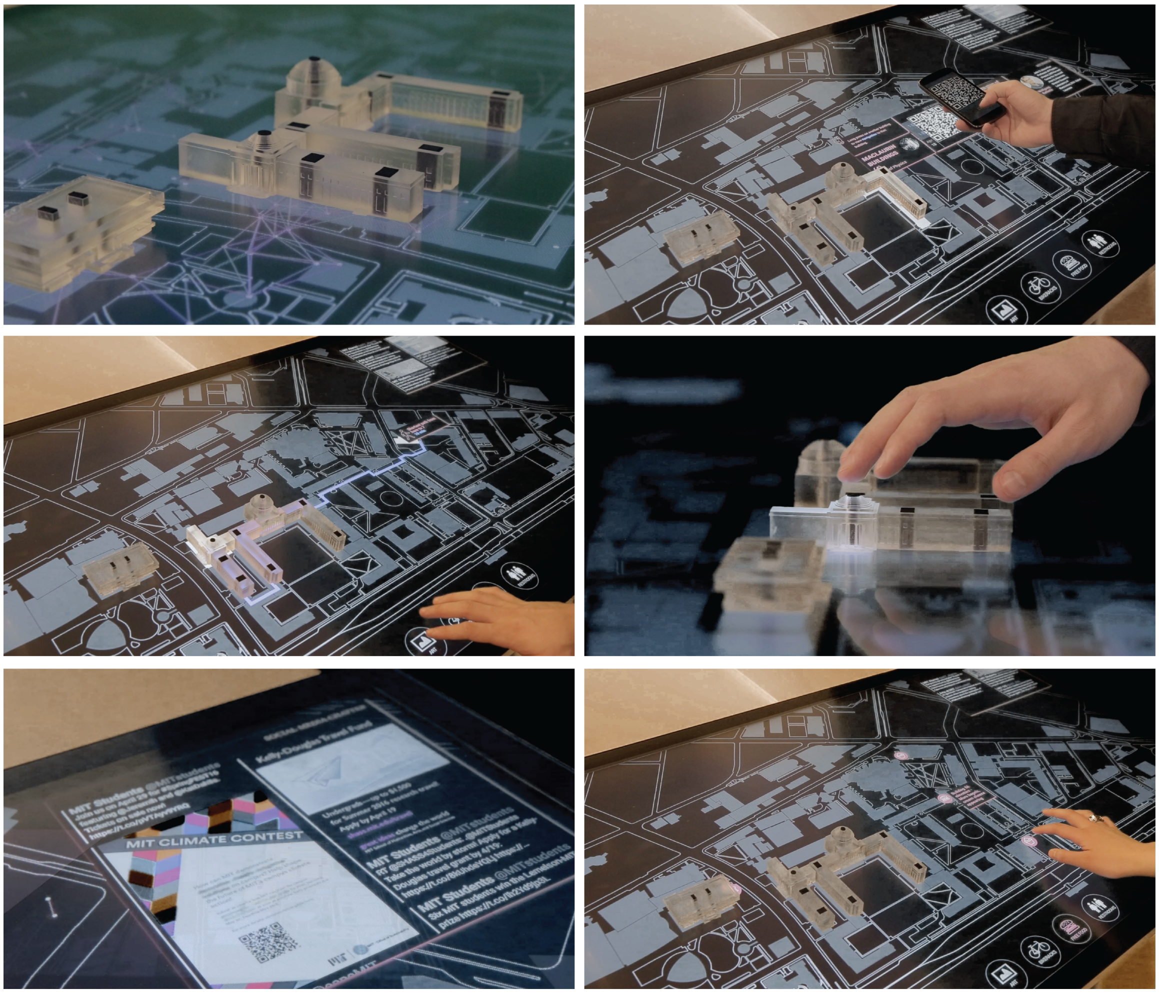


Figure 6-1: The final prototype in action: the Wi-Fi visualization, QR code event sync, indoor navigation from the Atlas Center, building selection and illumination, social media chatter, dashboard free food icons.

displays themselves. While simple, the touch screen and augmented physical buildings demonstrate how powerful these connected objects can be for both interface design as well as for education and collaboration.

Through the development of the 3D Campus Map, how physical objects can be integrated into digital displays to increase engagement, spatial awareness, and interactivity was explored. The resulting installation is an engaging and unique platform with many opportunities for expansion and further development. The system is an open platform on which more MIT visualizations, services, and data can be aggregated to develop a tool to help build a more connected and integrated campus.

6.2 Future Work

The current prototype is fully functional and fairly robust, and has the potential to be deployed as a real installation as it stands, but there are many areas for improvement and expansion moving forward.

6.2.1 Mobile Information Sync

The prototype gives users the option of syncing information to their phones via a QR code; users can add events to their calendar, read full news articles, or view live shuttle schedules and tracking on their personal devices. However, these features are limited and do not cover the whole experience. For example, one big feature that is missing from the existing mobile-sync functionality is being able to sync indoor MIT navigation directions to a user's phone. Because the system navigation uses an open-source mapping system, bringing that information to the user's phone would require a custom mobile application that uses the same mapping system. In the future, this feature could be integrated into the MIT mobile app, which most students and employees have, and which could be suggested to visitors to download as well.

Besides these missing features, the method by which the information sync occurs is also not optimal. While QR codes are universal and can be used by any smartphone, they are not very common or popular and feel a bit old-fashioned. A potential area for expansion could be to update this syncing method to use near-field communication (NFC), so that a user just has to tap his phone on the installation, and his phone automatically gets the information. Users are more familiar with this mode of interaction due to the increasing use of mobile wallets, so this experience would be an improvement upon the existing system.

6.2.2 Widespread Access

Throughout the user testing process, users expressed interest in being able to explore the information available through the campus map on their own or on the regular campus map (`http://whereis.mit.edu/`). Designing the interface for smaller dimensions and personal devices would be an interesting expansion to tackle.

6.2.3 Other Data Sources

This prototype already aggregates quite a few sources of MIT data; however, there are many more sources that are integrated but not surfaced or that can still be plugged in. Further research and development is required to figure out what other data sources exist within specific MIT departments to make the Campus Map a more unique and useful tool.

6.2.4 Multi-User Design

The system is currently only designed for a single user interacting with it at one time and does not take advantage of the touch screen's 60 touch point capabilities. Explorations into how multiple users can use the map simultaneously and collaboratively may greatly increase engagement and utility of the installation.

6.2.5 Alternative UX

There is still room to explore alternative experiences for interacting with the campus map. One option was to potentially use auxiliary iPads as a means to navigate through the information. There is not a lot of flexibility in the current interface for exploring or searching for specific people or events around campus, and these iPads could allow users to run more advanced queries. This would also allow more users to use the system at one time and would provide more screen real estate for information display.

Another possibility was to have an additional screen that is displayed behind and at an angle to the campus map, whose primary job is to display information, so that in the case that the entire campus is 3D printed, there is still room to display all the relevant information.

The best layout will depend on the actual Atlas Service Center space and how many users are expected to flow through the space at one time, so further experimentation is required to determine the best experience.

6.2.6 Physical Buildings

The 3D physical buildings are functional and engaging, but much work can still be done to improve their interactivity and aesthetic. Currently, the buildings are not permanently affixed to the screen, which could potentially result in misplaced or broken buildings if the installation were deployed. Additionally, the touch points are large and black as can be seen in Figure 6-1, which takes away from the sleek resin building prints.

Opportunities to enhance the buildings include embedding clear conductive touch points to make the buildings more visually appealing, connecting them together or to the screen to increase durability, altering the material to increase building illumination capabilities, and integrating more sensors to create more interesting interactions beyond touch.

6.3 Conclusion

The future of interfaces will definitely move beyond two dimensions as users become more accustomed to deeply integrated systems into everyday objects. The development of the campus map leads a push for more unique and engaging interfaces that provide genuine value to users. The 3D Campus Map prototype is an interactive and engaging tool for all visitors to the Atlas Service Center to explore and learn more about MIT. The augmented touch screen creates a unique experience that enhances users' ability to contextualize themselves geographically and identify buildings. The dynamic information that is displayed aggregates a variety of MIT data not previously done before, and the location and department-based content is a unique way of exploring the information. The physical buildings and location-based information encourage exploration and discovery.

While there is much room for future expansion and development, the modular system provides an open platform to integrate more data and services as well as to build more interesting visualizations of MIT data, so that the installation is useful for users of all backgrounds and to keep users coming back to learn more.

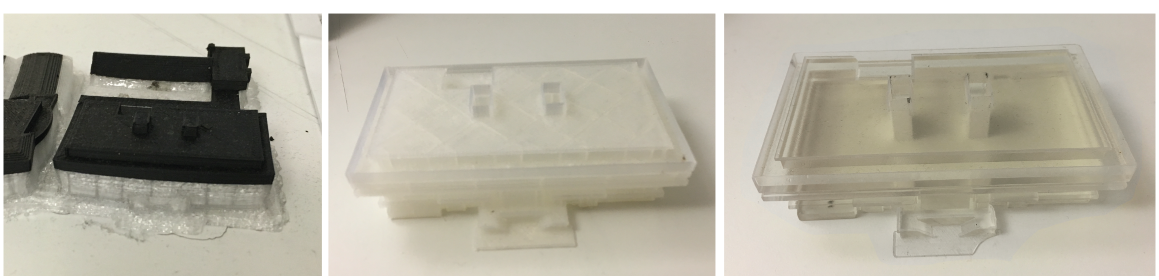
Appendix A

Prototype

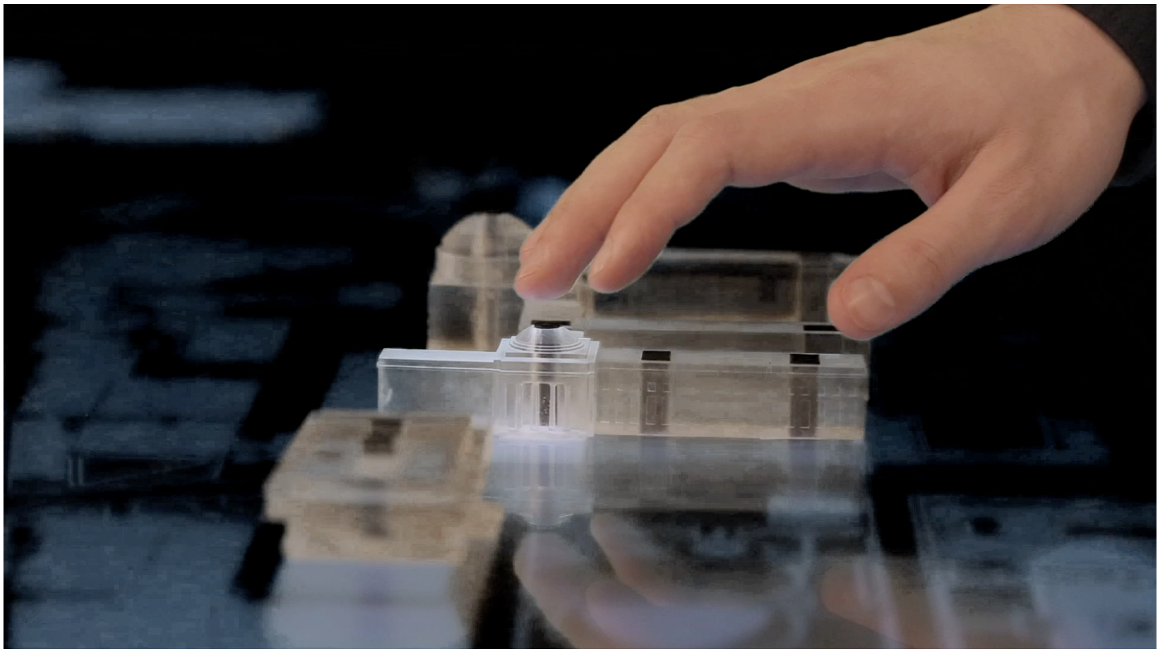
A.1 Videos

- Prototype assembly: `https://youtu.be/WIIuK1ST608`
- Final demo: `https://vimeo.com/164745667`

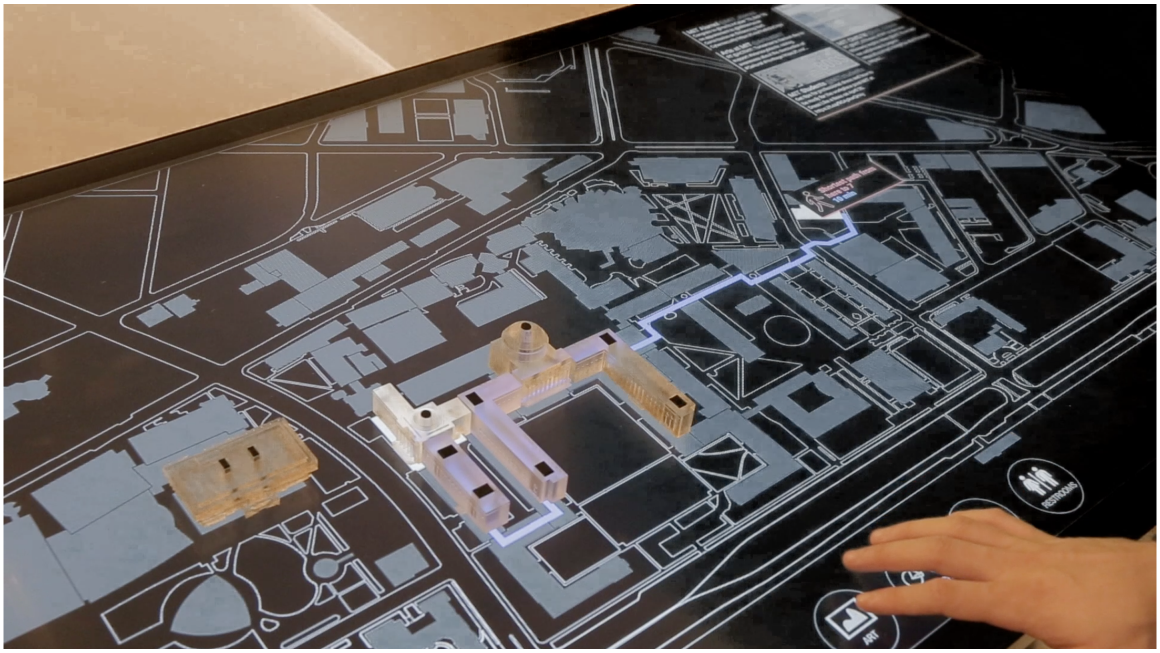
A.2 Photos



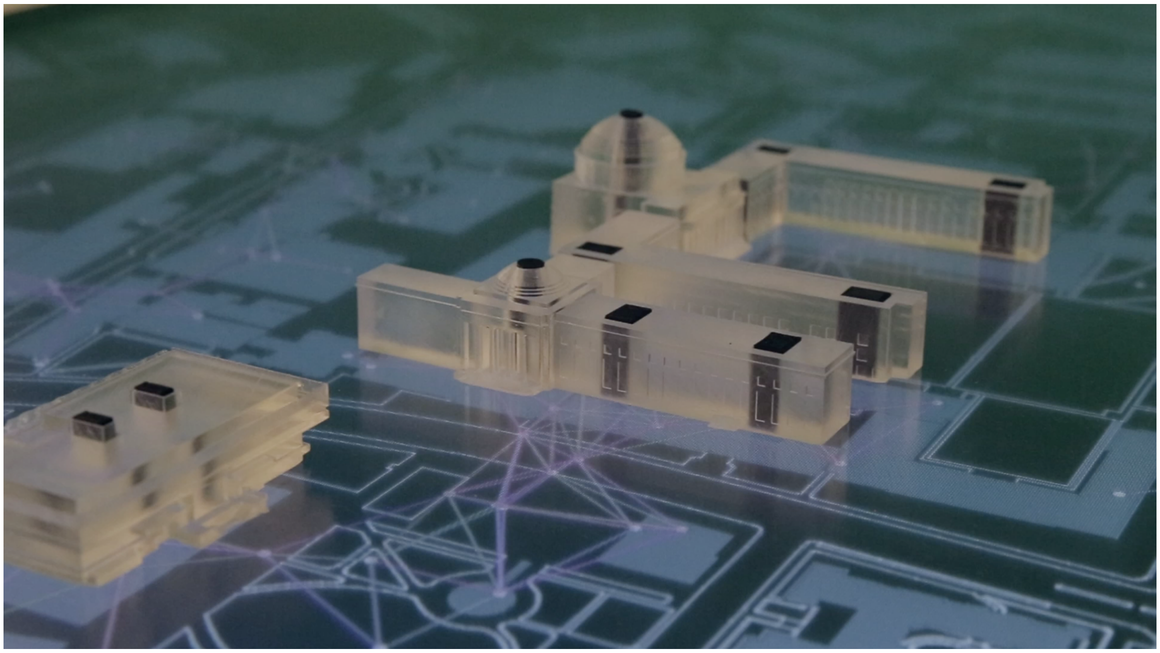
Three versions of the building prints. From left to right: additive printing with conductive layer, additive printing with holes for conductive inserts, resin printing with holes for conductive inserts.



Building illumination in the final prototype.



Navigation display in the final prototype.



Wi-Fi visualization in the final prototype.

A.3 User Test Script

Introduction

Thank you for helping out with our initial user tests. We wish to gather thoughts and suggestions on our first prototype of the 3D campus map. The map will be a tool to help students and visitors get to know MIT, learn more about the school, and to find out what's going on around campus. We would like you to perform some basic tasks and provide feedback on how it works. Note, only four buildings are touch-sensitive currently: E14, Stata, Building 10, and the student center.

Tasks

- Find an interesting event in building E15 and add it to your calendar
- Learn more about Building 10
- Explore the interface and tell us what you think

Questions

- How do you feel about the aesthetic of the buildings?
- How do you feel about the layout and scale of map and screen together?
- What do you think of the range of features that the map provides?
- Any other general comments or suggestions?

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