Toward a Multi-Scale Participatory Urban Policymaking Platform:
Co-Designing Mass Transit using LEGO Bricks, Open Data, and Interactive Pixels

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Abstract  
Rapid urbanization and industrialization around the globe have brought urban policymakers complex challenges such as chronic congestion, environmental pollution and socio-economic inequalities. With the rising adoption of and sophistication of social media and personal electronic devices, citizens are increasingly voicing their expectations and hearing those of others from near and afar on what they expect of their city governments. The planning and policymaking of the urban environments and transit systems, due to their complexity and traditional dependence on proprietary tools, have been, by-and-large, a process restricted to those who are deemed as “domain experts”. As citizens demand more transparency of, and participation, in the urban planning process, how might policymakers reshape their traditional decision-making processes, to not just align the expectations of diverse interests, but also to make more informed policies by harvesting relevant data from the collective intelligence?  

This paper documents the creation and evaluation of an interactive, multi-scale, dual-interface transit information system that combined a LEGO-based Tangible User Interface (TUI), Augmented Reality (AR), and cloud computing-based, and interactive data visualizations into a new type of interface aimed at enabling the process of participatory planning. The prototype system used Bus Rapid Transit (BRT) planning in Boston as a pilot case and allowed trial users to see, create, compare and evaluate new transit scenarios. We found potential in the systems to not just convey knowledge related to the chosen topic, but also support social learning and induce change in behavioral intention.
ACKNOWLEDGEMENTS

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INTRODUCTION

Over the course of the 20th century, cities have emerged as veritable centers of social, economic, political and cultural activities. Globally, cities service 3.9 billion residents, daily, which is more than double of the monthly active users (1.6 billion) of the most known online service, Facebook (Facebook, 2016). Cities compete internally to attract and support human capital in order to boost their economies. In cities, time is a critical resource for both productivity and leisure. The planning and design of urban policies and services have real impact on the socio-economic wellbeing of cities and their inhabitants.

Despite being one of the most pervasive service providers, local governments as an industry in the US trails behind every private sector in user satisfaction (2016) (Figure 1A). Why do private sector organizations continue to set the bar for people’s expectation and aspiration for services? One main reason is that it is not atypical for private sector organizations to spend several million dollars to engage their users and co-create with them in order to develop a new product or service that responds the needs and aspirations of their intended users. By both scale and user diversity, cities are comparable to most leading private sector organizations. The co-creative approach to design and planning in the public sector, however, has historically been more of an enterprise of “theories” than one about technology that scales.

Take for example, a public transit service that might costs hundreds of millions of dollars to serve and affect thousands of daily users. What is a one-million-dollar budget that could be used to ensure that the design of the user experience is developed to respond to the mutual needs and aspirations of the user communities? According to former deputy mayor of New York Stephen Goldsmith, “government’s authority comes from its cooperation with a vibrant community, and the community’s respect for that authority flows from government’s responsiveness.” The resulting condition, adds Goldsmith, is a “continuing loop of respect and efficiency”(Goldsmith, Crawford, 2014). The opposite state of respect and efficiency, if one infers further, would be an impending crisis of legitimacy in the Habermas sense of the word.
(Habermas, 1975), where citizens no longer see the institution in which they bestow their trust and the authority to exercise administrative power and allocate taxes as an effective vehicle to help the society achieve its shared goals and values.

With the proliferation of mobility-on-demand services such as Lyft, Uber, Bridj and Fasten, citizens’ expectations for the commuting experience are undoubtedly evolving faster than traditional public transportation services. Meanwhile, the public sector increasingly finds itself in a reactive position in allowing private sector organizations to influence its policy. Compounding these disproportional speeds of innovation between the public and private sectors are the increasingly common fiscal constraints—in Boston as elsewhere—and the evermore diverse voices of interests. Faced with such a multitude of pressures and considerations, how might cities improve their existing services and innovate ones that are more convenient, equitable, and resilient than what has come before?

Fortunately, this great gap between citizen expectations and public service delivery is not entirely unbridgeable. Today, the tradition of participatory planning, which emerged out of the despair of the 60’s top-down urban planning orthodoxy, arguably finds a new partner: the IT revolution driven by the culture of open source development and the decreasing costs of data collection and computation. Before, urban policymakers, compartmentalized by bureaucratic structure and blinded by out-of-date information, often made decisions on behalf of a large citizenry with, at best, an only partial picture of the true underlying complexity and mix of stakeholder demands and interests. Today, however, increased access to data, open source tools and affordable cloud-based computing mean new opportunities for public sector institutions to fulfill their social contract with their citizen stakeholders through a more efficient, informed and inclusive decision-making process. That is the main topic of this thesis.

This thesis project explores the effectiveness of a new type of interactive, multi-scale representational system for participatory urban planning. The platform was built by a coalition of students, researchers and faculty from MIT with the goal of testing their viability for improving participation methods for transportation planning. Chapter one begins with an introduction of the contemporary origin of participatory planning tradition as the socio-political driver of participatory policymaking. It then discusses the theory of Persuasive Technology and outlines its potential applicability to the creation of a participatory policymaking and planning support system. In addition, several university-based experiments are discussed as precedents and technological drivers for the new tool. From there, some general research questions are raised and turned into hypotheses of the research.
Chapter two provides the necessary description of the technologies being adopted to form the prototype of a multi-scale, participatory urban planning platform, and the research developed to measure the effectiveness of its features and overall design. Chapter three evaluates the performance of the platform, both as a whole and comparatively across the different tools, and ends by proposing two design considerations to inform the future iteration of the tool. Finally, chapter four discusses the research finding more broadly in the context of integrating the tools into the future workflows of engagement, planning, policy design, and evaluation, and of maintaining and innovating urban services.
CHAPTER ONE

1.1 SOCIO-POLITICAL DRIVERS OF PARTICIPATORY URBAN PLANNING & POLICYMAKING

1.1.1 Post-60s Drive for Holistic & Inclusive Planning

“We are basically having a referendum on every single thing that we do every day”

– Michael Bloomberg

In just a half-century, the world population has doubled, and the urban share of the global population increased from 33.7% in 1960 to 53.9% in 2014 according to the World Health Organization. These increases are challenging the allocation of land and water, as well as the production of energy and food. They are also changing the way we travel and shelter. As a result, planning problems have become what Rittel and Webber (1973) describe as "wicked", as opposed to "soluble" in the classical scientific sense. In the old planning paradigm from the turn of the 20th century, political and economic elites regarded city planning as a cure to the social ills and pollution that came with decades of rapid industrialization in large American and European cities. This expectation of environmental intervention as solution manifested most famously in Ebzener Howard's Garden City, David Burnham's White City in Chicago, Le Corbusier's Cite Radieuse and Oscar Niemeyer's Brasilia. What these projects and proposals had in common were centralized decision-making among the designers, planners, and the socio-economic elites. Nonetheless, the result of these centralized approaches, and the sheer lack of opportunity to realistically implement entire new city plans from scratch, showed that the top-down approach was unable to resolve the socio-economic imbalance that was beginning to appear across cities. As Michael Batty describes it:

“the notion that there are optimal products in the form of ideal cities to be designed has given way to the possibility that there might only be optimal processes to be used in negotiating futures that are in some general sense ‘acceptable’... In fact, we are living through a time where theories have fragmented and where there is much less consensus about what represents the
key ways in which cities evolve and grow than there was fifty years ago” (Batty, 2007, p. 3).

In addition to the myriad socio-economic and environmental issues, Batty’s description reflects the gradual departure—in both theory and practice—of urban planning from the top-down, urban renewal of the 50s and 60s. In part driven by the rise of cultural politics, immigration, environment concerns, and federal budget reduction in the US (Friedmann, 2005), a new planning tradition commonly referred to as “participatory planning” today, has emerged over the past four decades in various manifestations. This tradition includes the notion of planner as “consensus builder” and “communicator.”

Planning as consensus building, or negotiating conflicting public interests, is championed most prominently by Lawrence Susskind and John Cruiskshank (1987). As a response to the limitation of American judicial capacity and public administration rules and electoral processes in resolving distributional disputes, the approach is concerned primarily with the process that leads to action that complements conventional/accountable decision-making. Thus, Susskind and Cruiskshank envision planners as boots-on-the-ground, embedded at the informal, face-to-face level among stakeholders with an aim to broker win-win outcomes.

While Susskind and Cruiskshank’s notion of the planner takes form more as an Impartial Party, in John Forester’s “Critical Pragmatist” (1989) and Innes & Bookers’s “Authentic Collaborator” (2010) we find the role of Communicative Planner, a relatively more immersed, reflexive facilitator who participates in the actual problem-identification and problem-solving process with participating stakeholders. “Make sense together” is the core proposition. Recognizing that the institution where planners work is a constraint itself (e.g. legacy, ideology, culture and capital), Forester proposes that planners should fully exploit their human agency to immerse themselves into the project and actively (re)formulate problems and arguments to influence opinions. Citing the experience from the design review for a northeastern city park project—where residents helped define the problems of vandalism and littering, and challenged the architect’s legitimacy to determine the final outcome—Forester highlights the productive and transformative nature of the process whereby planners/architects engaged the residents without a clear goal and fixed structure. From such instances, Forester formulates the role of the planner as one who listens, asks, reads and corrects distortions; while at the same time, as one who is able to organize attention, generate hope, build relationships, manage expectations, and anticipate conflicts.
1.1.2 Opportunities for ICT in Participatory Policy Making

In the field of Planning Support Systems, as a parallel to the changing concept of the planner, Batty observes a shift from planning's rigid professionalism toward a practice of collective negotiation, where its "methods have been increasingly used to communicate and disseminate a multitude of ideas to many constituencies" (Batty, 2007, p. 3). Moreover, adds Batty, the advancement in Information and Communications Technology (ICT) has also made the communication of planning information more visual, forming the typical starting point for planning speculation and review.

The desire to introduce a more dynamic and democratic experience to decision-making has most recently, and partly, culminated in the use of social media as a participatory planning tool. However, as Chen and Krakty (2013) note, online comments and criticisms that are formulated remotely can suffer from "dissociation from the actual geographic site and its immediate dynamics." They add, "in order to criticize and judge a planned intervention the commentator has to be able to gain a comprehensive understanding of it. This normally involves a mental representation of the planned and thus not yet existent structures integrating the various aspects of information available" (Chen, Krakty, 2013, p. 313).

Given the above trends that represent a general shift toward a more dynamic and collaborative planning practice, as well as the limitation of virtual participation in geographically situated and often complex planning scenarios, we can formulate three opportunities related to Planning Support Systems:

- **Communication:** How might ICT help improve the quality of conversations and motivate greater diversity of participation in the urban planning and policymaking process?
- **Generation:** How might ICT stimulate collective exploration, discovery or even reframing of ideas and problems?
- **Integration:** How might ICT, given its replicable nature, become both accessible and relevant to designers, planners and policymakers operating within different institutional cultures, workflows and resource constraints?

To answer these questions, it is necessary to develop a more in-depth understanding of the changing role of ICT and the extent of its impact and influence on contemporary lives. The following section borrows from *Persuasive Technology* (2003), B.J. Fogg's seminal book on the rising role of the Computer as a Persuasive Technology, and discusses early attempts that sought to introduce Augmented Reality (AR) and Tangible User Interface (TUI) into Planning Support Systems (PSS).
1.2 PERSUASIVE TECHNOLOGY

1.2.1 The Emergence of Computers as Persuasive Technology
The rise of Internet, desktop, and mobile computing has brought irreversible changes to the way we conduct our daily social and productive affairs. This section, using B.J. Fogg's framework of Persuasive Technology, seeks to uncover the mechanisms by which modern computing enters the realm of shaping human decisions, attitudes, and behaviors. Then we discuss how tool developers might further extend these mechanisms to create a participatory urban policymaking tool that responds to the three opportunity areas identified in the previous section.

Persuasion, as Fogg defines it, is the attempt to change attitudes or behaviors or both (Fogg, 2003, p.13). With the arrival of the Internet and mobile computing, Fogg observes and predicts the emergence of persuasive technology being created for diverse occasions and across services to influence human activity, such as Amazon's product recommendation system and "one click" technology. It represents non-human influences that actively shape and guide shoppers' preference and motivate purchases. "Today computer technology is being designed to apply traditional human techniques of interactive persuasion, to extend the reach of humans as interactive persuaders," (Fogg, 2003, p.6), notes Fogg. He further identifies six advantages that computers have over humans as a persuader; they:

1. Are more persistent than human beings,
2. Offer greater anonymity,
3. Manage huge volumes of data,
4. Use many modalities to influence,
5. Scale easily, and
6. Go where humans cannot go or may not be welcome (Fogg, 2003, p.6-7).

1.2.2 Opportunities for Persuasive Technology in Participatory Urban Policymaking
Since the 1960s, theories and practices that fall under the umbrella of Participatory Planning have become a mainstay in planning education. However, as seen in documented cases, they focus on humans as the main social actor in the process of widening participation and driving consensus. This emphasis on human facilitation opens an opportunity to uncover areas where computers might provide a useful supplement to the approach. From Fogg's framework (Fogg, 2003, p. 255-261), we elicit 13 potentially relevant mechanisms for the design of PSS:
<table>
<thead>
<tr>
<th>SELECTED PERSUASIVE PRINCIPLES</th>
<th>POTENTIAL IMPACT ON PSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>REDUCTION: Using computing technology to reduce complex behavior</td>
<td>PSS can simplify the modification of forms and shapes from</td>
</tr>
<tr>
<td>to simple tasks increases the benefit/cost ratio of the behavior</td>
<td>multiple mouse clicks to fewer, quicker hand gestures.</td>
</tr>
<tr>
<td>and influences users to perform the behavior.</td>
<td></td>
</tr>
<tr>
<td>TAILORING: Information provided by computing technology will be</td>
<td>Enables every participant to directly operate the PSS to</td>
</tr>
<tr>
<td>more persuasive if it is tailored to the individual's needs,</td>
<td>visualize and simulate scenarios relevant to one's interest.</td>
</tr>
<tr>
<td>interests, personality, usage context, or other factors</td>
<td></td>
</tr>
<tr>
<td>relevant to the individual.</td>
<td></td>
</tr>
<tr>
<td>SUGGESTION: A computing technology will have greater persuasive</td>
<td>Monitor participants’ choices and offer reminders when</td>
</tr>
<tr>
<td>power if it offers suggestions at opportune moments.</td>
<td>participants overlook certain important parameters.</td>
</tr>
<tr>
<td>CONDITIONING: Computing technology can use positive reinforcement</td>
<td>PSS can monitor and remind the dominant participants to hear</td>
</tr>
<tr>
<td>to shape complex behavior or transform existing behaviors into</td>
<td>out the perspective of the more silent participants.</td>
</tr>
<tr>
<td>habits.</td>
<td></td>
</tr>
<tr>
<td>CAUSE &amp; EFFECT: Simulations can persuade people to change their</td>
<td>PSS provides live feedback of design impacts based</td>
</tr>
<tr>
<td>attitudes or behaviors by enabling them to observe immediately</td>
<td>participant input.</td>
</tr>
<tr>
<td>the link between cause and effects.</td>
<td></td>
</tr>
<tr>
<td>ATTRACTIVENESS: A computing technology that is visually</td>
<td>PSS’ hardware and graphics can adopt forms and user-friendly</td>
</tr>
<tr>
<td>attractive to target users is likely to be more persuasive as</td>
<td>interfaces that lure non-experts to engage with the tool.</td>
</tr>
<tr>
<td>well.</td>
<td></td>
</tr>
<tr>
<td>EASE-OF-USE: A Web site wins credibility points by being easy to</td>
<td>PSS can have integrated TUI to enable intuitive participant</td>
</tr>
<tr>
<td>use.</td>
<td>control &amp; expression.</td>
</tr>
<tr>
<td>PERSONALIZATION: Web sites that offer personalized content and</td>
<td>PSS can enable each participant to choose the vantage point</td>
</tr>
<tr>
<td>services get a boost in credibility</td>
<td>of one’s choice and supplement with relevant information.</td>
</tr>
<tr>
<td>INFORMATION QUALITY: Computing technology that delivers current,</td>
<td>PSS with integrated TUI can display data about the physical</td>
</tr>
<tr>
<td>relevant, and well-coordinated information has greater potential</td>
<td>world in 3D form.</td>
</tr>
<tr>
<td>to create attitude or behavior change.</td>
<td></td>
</tr>
<tr>
<td>SOCIAL FACILITATION: People are more likely to perform a</td>
<td>PSS that brings participants of multiple backgrounds together</td>
</tr>
<tr>
<td>well-learned target behavior if they know they are being</td>
<td>can create a greater level of empathy and behavioral</td>
</tr>
<tr>
<td>observed via computing technology, or if they can discern via</td>
<td>adjustment among the group.</td>
</tr>
<tr>
<td>technology that others are performing the behavior along with</td>
<td></td>
</tr>
<tr>
<td>them.</td>
<td></td>
</tr>
<tr>
<td>SOCIAL LEARNING: A person will be more motivated to perform a</td>
<td>PSS that gathers multiple participants creates a condition</td>
</tr>
<tr>
<td>target behavior if he or she can use computing technology to</td>
<td>of where participants can easily observe each other's</td>
</tr>
<tr>
<td>observe others performing the behavior and being rewarded for it.</td>
<td>behavior.</td>
</tr>
</tbody>
</table>
COMPETITION: Computing technology can motivate users to adopt a target attitude or behavior by leveraging human beings' natural drive to compete.

COOPERATION: Computing technology can motivate users to adopt a target attitude or behavior by leveraging human beings' natural drive to cooperate.

The development of computerized PSS is still in its infancy, restricted largely to 2D interfaces and single-user interaction as exemplified by the popular desktop software ArcGIS. It is therefore difficult to fully envisage how Fogg’s principles of persuasive technology will be fully applied to the design of Planning Support Systems. In the following section, however, as we look at some early attempts of combining AR and TUI with PSS, such as the Luminous Planning Table (LPT) and Illuminating Clay (IC), we can uncover some design motivations that parallel several of Fogg’s principles of persuasive technology.

1.3 TECHNOLOGICAL DRIVERS OF PARTICIPATORY URBAN PLANNING & POLICYMAKING

1.3.1 Tangible User Interface (TUI)

TUI began with Mark Weiser’s vision to interweave digital technology with the physical environment. Hiroshi Ishii and Brygg Ilmer from the Tangible Media Group at MIT Media Lab officially launched the project in 1997 with the goal to "change the 'painted bits' of Graphical User Interface (GUI) to 'tangible bits' in order to take advantage of the richness of multimodal human senses and skills developed through our lifetime of interaction with the physical world" (Ishii, 1997). In technical terms, TUI employs the physical surface or object itself as both the input and output channel of computation, whereby the physical form embodies the digital information itself, giving the possibility for providing feedback to the user that a keyboard and mouse do not. The keyboard and mouse are scalable and easily adopted, but their user interactions do not offer users tactile and kinesthetic feedback to users, which aid spatial cognition (Loomis & Lederman, 1986). The advantage of TUI over 2D interaction is in fact widely exhibited in the control design of complex systems such as trains, power plants and aircrafts. Pilots use tangible interfaces— that is, one switch or one handle per action — to most
efficiently manipulate the aircraft performance. In these affordances of direct manipulation and feedback the creators of TUI-enabled PSS saw the opportunity for a potentially more efficient, rewarding and participatory design experience.

1.3.2 Overview of TUI Applications

The Urban Planning Workbench (“Urp”) at MIT was the first attempt in the field of design and planning to revolt against the paradigm of the Graphical User Interface (GUI). The GUI, first developed at Xerox PARC in 1981, became the standard of Human Computer Interaction (HCI) when Microsoft Windows and Apple Macintosh popularized it throughout the 80s and 90s. Nonetheless, Bill Mitchell saw a significant gap between human’s motor skills and dexterity in manually manipulating physical objects and the dominant design tools used in design and planning that are largely brokered by the keyboard & mouse. As Mitchell illustrates (Figure 1.3A), the creation process of buildings and environment is largely dispersed across three streams of activities and representations: drawings, digital models, and physical models. The fact that mice, keyboards, and 2D screens are divorced from the physical world of the built environment, and impose on designer’s additional cognitive load of switching between medium of representation, motivated the team at MIT to build its first TUI and AR-enabled PSS.

In addition to streamlining the design process, the design team believed that TUI would serve to not only enrich the communication and learning of the design process, but also serve as a more universal medium of interaction to help widen participation in design and planning beyond professionals and experts.

The Urp, or the Luminous Planning Table consists mainly of a table-top projector that casts light and digital shadows downward on the table top surface, and a table-top sensor that monitors the physical blocks placed on the table surface to represent buildings. As users adjust the location and orientation of physical blocks, the shadow follows the building, based on the time of the day. At the same time, users can adjust a physical representation of a clock that
accompanies Urp to see the dynamic changes of the shadow. In addition, Urp visualizes the wind flow condition based on the building orientation. The creators of Urp tested the tool against CAD in a classroom experiment in 2000. They gave a group of students the same set of design exercises with a single computer as they gave the group of students using Urp. They found that the team using CAD soon evolved into a group where one user controlled the computer while receiving uncoordinated directions from the other students lurking behind the designer's back. The student group that used the Urp, on the other hand, designed through consensus.

But the research team soon discovered that despite the ability to enable direct manipulation of digital model through physical objects, the Urp was unable to change the forms of physical objects as users interacted with them. In other words, participants were limited to working with a set of predefined fixed-form objects (Ishii, 2008). As a result, Illuminating Clay was created in 2003 to enable a more fluid representation of the physical dimension. The team studied one student group's performance on designing a golf course using the newly created "digitized" clay, versus another group that used a non-digitized clay model along with pen and paper. The result showed that the students using "digitized" clay explored more "what-if" scenarios than the other group. The study also found that the TUI contributed to greater ease in concept prototyping, touching, and learning. In particular, students were able to discuss and explore the drainage system in greater depth compared to students using paper & pen and clay. Unanimously, students expressed preference for using "digitized" clay as a presentation platform over a physical model or GUI (Shamonsky, 2003). Building on the results of these early TUI developments, Maher and Kim from the University of Sydney sought to understand the difference between GUI and TUI (Maher 2005). In their study, designers who used TUI were found to:

- perform multiple cognitive actions in a shorter time,
- re-visit a previous design frequently while coordinating design ideas,
- create and attend to spatial relations such as local and global relations,
- discover a space or feature of an existing object unexpectedly, and
- produce more re-interpretation actions.
In another recent study, though not with a TUI-based PSS, Robert Goodspeed (2013) compared the performance of Interactive PSS vs human-mediated PSS and the traditional paper-based tools. Goodspeed was specifically interested in the effect of interactive PSS on what Chris Argyris & Donald Schon (1976) theorized as two forms of organizational learning: 1) single-loop learning that “does not question the fundamental design, goals, and activities” of the organization; 2) double-loop learning that involves the questioning of the underlying assumptions, values and goals of the organization (Argyris, 1976, p. 367). Goodspeed’s study found indications that the usage of Interactive PSS elicits learning related to his proxy measures of “imagination” (changed perception), “alignment” (other perspectives) and “engagement” (shared views, others listened). As a result, Goodspeed proposed that interactive PSS would lead to greater social learning outcomes and, by implication, planning outcomes (Goodspeed, 2013, p. 164). In Goodspeed’s study, we can begin to see the potential of the computer acting as a facilitator of problem reformulation, which is consistent with the role of the planner as imagined by Forester and Innes & Boohers. His study also indicates the attitude and behavior-changing potential of the PSS.

For a more specific application on helping professionals and laypeople alike to understand design parameters such as zoning regulations in a more coherent way, a group of students from the City Science workshop at MIT Media Lab built a LEGO-based TUI PSS embedded with both a physical and digital model of Kendall Square on the east side of the MIT campus. They compared the performance of two groups of students who were given the task of redesigning the site based on a revised zoning plan. One group used the TUI PSS, and the other paper and map. Compared to the group using the TUI PSS, the group using the paper-based tool created proposals with lower practical accommodation and with no alternatives as backup proposal. In addition, the proposal violated multiple historical and new regulations (K. Larson, City Science workshop, December, 2014).
1.4. MULTI-SCALE USER INTERFACE HYPOTHESIS

1.4.1 Research Question
While the precedents of TUI-based and interactive planning support systems discussed in the previous section demonstrate a promising outlook for the future of urban planning and policymaking, the scale of their test cases consistently remained sub-regional. In other words, a tool proven useful for the design of a building site, a golf course or a neighborhood is not necessarily useful for addressing issues at the metropolitan level. Governments, however, often devise and implement policies and services at the regional scale. At the same time, they are held accountable by the citizens who experience the policies and services at the street and neighborhood level. Transportation planning is an issue par excellence that very often requires simultaneous, systematic considerations of benefits and costs at multiple scales: the regional level and at every level under it. Given the real-life demands for problem-solving across scales, it becomes natural to imagine the possibility of a multi-scale planning support system. Would multi-scale representation be an effective means of communication for conveying planning and policy choices that are complex and have large scale impacts?

1.4.2 Hypotheses
If a successful public engagement is broadly defined as having induced certain levels of change in forms of knowledge acquisition (learning, social learning & double-loop learning), attitude (attitude change) and/or behavioral intention (e.g. mode-shift), this study is an attempt to develop an in-depth understanding of the effect of a multi-scale interactive data visualization system on these three types of changes. To measure that, we broadly borrow from BJ Fogg's persuasive design principles to form two performance measures of usability and relevance. All the measures, or constructs, and their indicator questions are as the following:

**Usability** (answered once for each scale)
- "[the tool] was easy to understand"
- "was encouraging for me to use it"
- "was engaging when I used it"

**Relevance** (answered once for each scale)
- "reflected my unique issues & concerns"
- "raised important issues for my team to discuss"
- "used data & simulations that seemed credible"
“helped me imagine alternative travel scenarios”

**Social Learning**
- “I had helpful conversation with others while using the tool”
- “I helped others learn”
- “I learned through listening”
- “I learned through observing others using the tools”

**Double-loop Learning**
- “I was able to get answers to the questions I asked”
- “Workshop participants discussed issues in an open way”
- “Participants were open to differences in opinion”
- “I would support recommendations created by the participants of the workshop”

**Attitude Change** (pre-, post-workshop comparison)
- “I can play an active role in the planning of the community where I live”
- “Public participation in planning advances the interests of my community”

**Mode Shift** (pre-, post-workshop comparison)
- Pre-workshop: “in the last week, how many times did you travel by: car; subway/train; bus” to the post-workshop question”
- Post-workshop: “if corridors like we discussed today are implemented, do you imagine yourself changing the way you travel”

In this thesis I test the following specific hypotheses:

1. Because the system can represent the topic of BRT at multiple scales, as opposed to the traditional single-scale representation, it can minimize the amount of knowledge lost in translation, and maximize the users’ comfort level, and therefore lead to an overall positive engagement outcome.
2. Adequate usability of the tool invites and sustains user interaction with the tool, which in turn provides opportunities for the present users to observe, discuss and learn through the interaction. Therefore, I hypothesize that usability has a positive effect on social learning, which in turn has an indirect positive effect on learning and double-loop learning.
3. Relevance is a proxy measure of how well the design of the information in each tool supports the participants’ level of mental engagement with the issue the tool seeks to represent. Therefore, relevance is hypothesized to have a positive effect on a deeper form of learning (double-loop learning) and on transformation (attitude change).
4. Different scales of representation will differ in their effectiveness on the users, therefore we expect some varying levels of effect of each scales’ relevance and usability on learning and transformation.

Building an understanding of how a multi-scale representational system affects learning, attitude change and behavioral intention has the potential to enable both better communication about and more integrative design of future urban policies, especially when the issues at stake are at a scale
and complexity level that challenge easy comprehension by ordinary citizens and policymakers. BRT planning in Boston is one such thorny category of public investments where multi-stakeholder deliberation, collaboration, and concession are needed in order to lead to any sort of “acceptable” outcome. The various impacts of BRT such as physical changes to the streetscape (e.g. curbside parking, media), reduced number of bus stops, traffic impact, and accessibility to opportunities (e.g. jobs) have been difficult to visualize and articulate by citizens and policymakers alike. This study aims to shed light on how a multi-scale interface might enable better communication and participation in the process of urban planning. The following two chapters provide an in-depth description of the system design and research setup.
CHAPTER TWO: RESEARCH DESIGN

2.1 TOOL DEVELOPMENT & INTEGRATION

The multi-scale platform used in this research consists mainly of two existing technology tools developed at MIT: CoAXs, an interactive public transit accessibility mapping and editing system, and CityScope, a LEGO-based Tangible User Interface system for simulating urban information. For this research, CoAXs was used to represent the regional scale, to facilitate the discussion of BRT. CityScope was used to represent neighborhood and street scales (Figure 2.1A).

2.1.1 CoAXs

CoAXs is a web-based interface visualized on a large touchscreen display that allowed workshop participants to explore transit system performance at the regional scale. During the period of the project, the tool was under active development at the Mobility Future Collaborative at MIT’s Department of Urban Studies and Planning.

CoAXs consists of two key modules. The accessibility impact modeling module helps visualize an estimated public transit travel time map based on transit scenarios that are existing, hypothetical or combinations of the two (Figure 2.1B Top-Left). The accessibility map serves to depict the travel time boundary from users’ chosen points on the map, with which users can evaluate accessibility from any point on the map by relocating the pin. The computation underlying the map generation utilizes transportation consulting firm Conveyal’s Transport Analyst, which conducts the calculation of travel distance/time based on a given transit network. The transit network is represented using General Transit Feed Specification (GTFS) files either obtained through local public transit agencies or generated by users using the route editing module of CoAXs. The resulting accessibility maps are rendered on the open-source mapping platform Open Street Map.
The second module is the transit route editor module that allows users to (de)activate and modify preselected bus corridors and save the routes for accessibility map visualization (Figure 2.1B Lower-Left). Modifications open to user adjustment include bus service frequency during peak and off-peak hours, as well as station types such as traditional bus stop, platform station without dedicated lane, and full-BRT station. Once modified and saved, each new version of the bus corridor is “cached” in the GTFS file format and becomes available for selection in the scenario management panel (Figure 2.1 Lower-Right) of the accessibility-mapping module, where users can build hypothetical transit networks and evaluate their impacts.

Figure 2.1B: Regional scale simulation key features

While users modify bus corridors and create transit network scenarios, they can refer to an on-demand dashboard available to each module that depicts metrics related to the chosen corridor service and network scenario. In the transit route editor, users can evaluate the service based on estimated operating cost, station construction cost, dedicated lane construction cost, percentage of shared lanes, and round-trip travel time during peak-hour (Figure 2.1C). In the scenario impact visualization part, users can evaluate their chosen transit network based on the estimated costs of constructing stations and lanes, operating cost, length of bus lines, and the number of vehicles and stations. In addition, users can compare two chosen scenarios and see
the difference in accessibility coverage, and in access to different types of opportunities across the region, such as jobs (Figure 2.1B top-right). For this research, we tailored CoAXs to enable depictions of accessibility scenarios based on Boston’s existing MBTA service network and of scenarios based on users’ addition or modification of bus services.

Figure 2.1C: On-demand dashboard for transit route editor

A CoAXs feature worth noting is the geo-bookmarking feature in the accessibility impact modeling module. Users are able to bookmark and tag their points of interests (POI) (e.g. home, grocery store) through a mini browser-based survey that includes a google map (Figure 2.1D Left). Those geo-bookmarks in turn are made available as icons with users’ name initials for turning on/off their POIs on the map. The purpose of this design feature was to have the POIs serve as a visual reference to help users better relate to the map and orient themselves relative to the region. (Figure 2.1D Right).

Figure 2.1D: Point-of-Interest Geo-bookmarking
2.1.2 CityScope

CityScope is an interactive urban simulator composed mainly of physical LEGO bricks for user interaction, a set of webcam for sensing LEGO placements, and one or a few projectors for projecting static or dynamic digital information onto the physical LEGO model. The tool was created originally at the MIT Media Lab to help illustrate urban flows, like vehicular and pedestrian traffic, as well as any information that is geo-locatable, such as Twitter activity. Users interact with the tool by moving LEGO bricks to alter urban design and/or land uses; the urban flow implication of those changes are calculated via simulation, and then projected back onto the LEGO model using Processing, an open source programming language popular for data visualization. For the purpose of transit planning, we adapted the CityScope to be able to display predicted traffic performance, based on outputs of an open source microscopic traffic modeling software SUMO ("Simulation of Urban Mobility") that we used to model the traffic conditions in the Boston Area.

In order to test the multi-scale hypothesis, we created two separate versions of the CityScope to complement CoAX’s the regional scale simulation. One version depicted a specific
intersection, of Washington Street and Massachusetts Avenue (Figure 2.1E), and another version the neighborhood surrounding Dudley Square (Figure 2.1F). For the neighborhood model, users could select from different LEGO pieces representing different types of bus stations and activate different corridor alignments. Corridor alignment in the neighborhood-scale roughly followed 4 of the 5 corridors proposed by a study group convened by the Barr Foundation (Figure 2.1G). With that, we made 7 possible configurations: Dudley Sq-to-Downtown, Dudley Sq-to-Mattapan, Dudely Sq-to-Sullivan Sq, Dudley Sq-to-Harvard Sq, Mattapan-to-Downtown-via-Dudley Sq, Mattapan-to-Sullivan Square via Dudley Sq, and Mattapan-to-Harvard Square via Dudley Sq. Based on a user’s selection, traffic simulations pre-generated in SUMO for the

*Figure 2.1G: Map of potential Gold Standard BRT corridors identified by the Barr study group (Image: Barr Foundation)*

specific selection would be visualized onto the the LEGO model. At the same time, corresponding summary statistics would be displayed on a TV screen located next to the LEGO model. In the neighborhood model, summary statistics include number of cars shifted per day,
miles of dedicated lanes, number of passengers riding on dedicated lanes, number of parking spaces removed, average speed of BRT bus/regular bus/car, and cost of implementation (Figure 2.1H).

For the street-scale, users could select from three types of bus stations: regular stations on curbside, BRT stations on curbside, and BRT station on the median. In addition, they could add/remove a bike lane to replace on-street parking. Based on users’ choice of station and curbside program, corresponding traffic simulations pre-generated in SUMO were visualized on to the LEGO model. Similar to the neighborhood model, a matching set of summary statistics would appear on an adjacent TV screen. In the street model, the calculated statistics was based on the assumption of implementation along the entire road segment between Dudley Square and South Station; indicators included the number of parking spaces, hourly throughput of bicycles, bus dwell times at stations, and total travel times by bus and by car.

2.2 EVALUATION DESIGN

2.2.1 Surveys
To evaluate the system’s overall performance and its different scales’ comparative performance, we devised a set of survey questions administered before and after each workshop. In the pre-workshop survey (Appendix A), the questions focused on gathering participants’ background, prior experience and attitudes related to community planning events and the topic of BRT. The background questions covered the following topics:

- Number of public planning meetings attended and the level of involvement [public participation experience]
- Past week’s travel frequency by car, subway/train and bus [mode preference]
- Familiarity with the concept of BRT [prior knowledge]
- Familiarity with digital graphical representation of information [data literacy]
- Level of agreement with the phrase: “I can play an active role in the planning of the community where I live”. [agency]
- Level of agreement with the phrase: “Public participation in planning advances the interests of my community”. [impact]
- Naming four important elements of BRT [prior knowledge]

In addition to the questions, we asked people to input their POIs on the touch screen TV and observed each user’s ability to interact with the Google map while they were asked to geo-bookmark their living and frequented locations. The observation was turned into a rating as a proxy measure of map literacy.

The post-workshop survey (Appendix B) covered a range of questions, most of which were organized by themes of usability, relevance, social learning, learning, double-loop learning and attitude change, and answered based on a 1-5 Likert scale. The 7 questions related to usability and relevance were repeated 3 times, once for each scale model, to provide comparative data on the performance of each scale. In addition to measuring engagement outcome by users’ perceived experiences, we repeated four questions from the entry survey to observe possible changes in the users’ ability to name from one to four different BRT elements, in their attitude (belief in impact and agency), and in their intention to travel more/less by different modes (Table 2.2A). Lastly, we asked for qualitative feedback using the following three questions:

1. How do you think corridors like those discussed today might impact your travel?
2. How do you think corridors like those discussed today might impact others’ travel in the region?
3. What was the most interesting part of this workshop?
### Table 2.2A: Engagement indicators

#### Engagement indicators: perceived vs measured

<table>
<thead>
<tr>
<th>Perceived</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Usability</strong></td>
<td><strong>Relevance</strong></td>
</tr>
<tr>
<td>- [the tool] was easy to understand</td>
<td>- [the tool] reflected my unique issues &amp; concerns</td>
</tr>
<tr>
<td>- was encouraging for me to use it</td>
<td>- raised important issues for my team to discuss</td>
</tr>
<tr>
<td>- was engaging when I used it</td>
<td>- used data &amp; simulations that seemed credible</td>
</tr>
<tr>
<td>- [the tool] helped me imagine alternative travel scenarios</td>
<td>- helped me imagine alternative travel scenarios</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Social Learning</th>
<th>Learning</th>
<th>Double-Loop Learning</th>
<th>Attitude Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>- I had helpful conversations with others while using the tool</td>
<td>- I learned a great deal in the workshop</td>
<td>- I was able to get answers to the questions I asked</td>
<td></td>
</tr>
<tr>
<td>- I helped others learn</td>
<td>- I learned through listening</td>
<td>- Workshop participants discussed issues in an open way</td>
<td></td>
</tr>
<tr>
<td>- Learned through observing others using the tools</td>
<td>- -</td>
<td>- Participants were open to differences in opinion</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Usability</th>
<th>Relevance</th>
<th>Social Learning</th>
<th>Learning</th>
<th>Double-Loop Learning</th>
<th>Attitude Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold Standard score obtained by naming four elements of BRT</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Figure 2.2A: Activity flow chart**

Activity I/O & Flow Chart

1. **SHARE INDIVIDUAL DATA**
   - Identify participants' interests, prior domain & local knowledge

2. **SEE BRT AT HUMAN SCALE**
   - Learn about station types, payment methods, and right-of-way options

3. **SEE REGIONAL IMPACT / SYNTHESIZE**
   - Evaluate transit systems based on accessibility measure

4. **HANDS-ON EXPLORATION**
   - Explore service & design variations of bus systems across corridors

5. **EVALUATE NEIGHBORHOOD IMPACT**
   - Visualize traffic and land use impact

6. **REPORT LEARNING OUTCOME**
   - Evaluate participants' perceived experience, learning and feedback

- **Mode**
  - Shift
  - Mode
  - Gold Standard score obtained by naming four elements of BRT

- **Attitude Change**
  - I can play an active role in the planning of the community where I live
  - Public participation in planning advances the interests of my community
  - Times per week would you travel by 1) car, 2) train, 3) bus
2.2.2 Workshop Flow & Facilitation

The overall sequence of the workshop consisted of the registration/orientation phase, exploration phase, and debrief phrase to match the proposed flow of activities illustrated in Figure 2.2A. Upon arrival, each participant filled in the entry survey, geo-bookmarked their POIs and listened to an introductory presentation. Participants were then separated into groups of 4-6 people to explore each tool for about 20 minutes with the help of a facilitator at each station. After this exploration, they regrouped for an open-ended, 30-minutes discussion, at the end of which they completed exit survey.

The facilitation of the workshops was conducted mainly by members of a partner organization Nuestra Communidad, a community development corporation with a relatively long history in the Roxbury neighborhood. Prior to the workshop, the project team held training sessions with the facilitators to familiarize them with the tools and receive their feedback for tool refinement (Figure 2.2B). In addition, the team provided a facilitation manual covering the topics of workshop goals, agenda, and various items that sought to standardize the overall operating procedure of the workshop to ensure consistent experience across the participants in the six different workshops.

Figure 2.2B: Facilitator Training Session
2.2.3 Recruitment, Date & Venue

The research was organized as a series of six workshops between October 11-14th, 2015 between late-morning and early-evening at the Roxbury Innovation Center located in the Bolling Building in Dudley Square, Boston. The workshop venue (Figure 2.2C) had adequate daylight and space to allow workshop participants to comfortably gather around each model for discussion and exploration.

Subject recruitment was done by Nuestra Comunidad using various communication channels, and by members of the academic team using a digital and printed flyer (Figure 2.2D). The flyer offered potential participants the ability to sign up through a web link as well as contact the organizing team through telephone and/or email. In addition, the flyer indicated that language support as a service would be available on October 10th for one of the workshop dates, to reduce the likelihood that language would become a determinant of non-participation.
2.2.5 Follow-up Focus Group

After the main workshop series, the project team organized an additional follow-up focus group, inviting participants from all six of the October workshops, on March 28th, 2016 at the same location in the evening to share selected results from the survey analysis as a way to contextualize the findings and gain additional insights. Eighteen participants attended the focus group and were organized into three subgroups during the event. Two students and one faculty member from MIT each spent 15 minute with each subgroup to discuss findings from the October workshop.
CHAPTER THREE

SUMMARY
This research began with three aims: 1) to test the overall performance of a multi-scale interactive planning platform, which combined a GUI-based data visualization tool with a LEGO-based tangible user interface; 2) to understand the relative efficacy and (dis)advantages of each scale simulation; 3) to uncover or validate some generalizable design principles to inform the future iteration of multi-scale participatory policy design systems. The first portion of this chapter reports on the overall system’s performance using measurable indicators of learning and changes in attitude and behavioral intention, and how they differ across users of different capabilities and experiences (e.g. data literacy). The second part is a cross-scale evaluation, comparing the overall usability and relevance of each scale model and testing their linkages to the workshops’ intended outcome of attitude change and double-loop learning. The third part synthesizes findings into generalizable design considerations for future iterations of similar tools.

The overall finding, based on 45 valid survey responses (Appendix F) suggests that the system was able to convey at least the basic knowledge related to the transportation topic chosen as the focus for the pilot, Bus Rapid Transit (BRT). The learning outcome of basic knowledge and the effect of attitude change were more prominent among the participants who were “less experienced”—younger, had attended fewer planning meetings and had no prior knowledge of BRT. As for behavioral intention, the majority of participants expressed a positive intent to change behavior (use the bus more and car less). Finally, we identified at least one apparent critical design criterion for the future iteration of the platform: that for the breadth of “big data” to gain meaning and credibility in the minds of “non-expert” participants, at least one aspect of the data needs to be made relatable to the personal experience of its intended audience.

3.1 OVERALL PERFORMANCE

3.1.1 Learning Outcome: higher Gold Standard score among the “inexperienced”
Recall from chapter two’s evaluation design, we proposed two approaches to measure learning. One infers from the participants’ responses to the question of “I learned a great deal”; the other
compares the BRT elements they listed down at the pre- and post-workshop surveys. To represent the learning outcome using an indicator relevant to the pilot topic of BRT, we assigned a numerical score to each listed BRT element using the scorecard rubric developed by the Institute for Transportation and Development Policy (ITDP, 2014) for the purpose of certifying classifications to BRT projects. For instance, if a respondent listed “Off board fare collection, designated bus lane, median busway, signal priority” in the post-workshop questionnaire, the individual’s post-workshop BRT knowledge would be calculated as 8 (pre-board payment) + 8 (dedicated lane) + 8 (median alignment) + 7 (intersection treatment) = 31. This method led to a total pre-workshop score and post-workshop score for each participant. We subtract the prior from the latter to obtain the difference to represent learning outcome.

Figure 3.1A shows an overall improvement by an average of 4 BRT Gold Standard points, with the maximum score an increase of 26 points and minimum a decrease of 11 points. The largest score increases were concentrated among the age group 21-34 and below, among those who reported attending one or zero planning meeting over the past year, and among those who reported having no prior familiarity with BRT systems. As for the influence of data and map literacies, we observed no identifiable relationship with the learning outcome.
Figure 3.1A: Learning Outcome by Gold Standard Score

- Learning Outcome by Gold Standard Score
- Learning Outcome by Age Group
- Learning Outcome by Frequency of Planning Meeting Attendance
- Learning Outcome by Familiarity with BRT
- Learning Outcome by Data Literacy
- Learning Outcome by Map Literacy

Legend:
- Score increase (BRT Gold Standard Score)
- All Participants
- 1:25
- 5:14
- 15:34
- 35:64
- 65+
- Reported Yearly Frequency of Planning Meeting Attendance
- Reported Familiarity with BRT
- Reported Level of Data Literacy
- Observed Map Literacy
3.1.2 Attitude Change & Behavioral Intention

To measure whether the workshops affected the participants’ attitude (beliefs in agency and potential impact) and intention to change commuting behavior (travel behavior), we compared three questions that were asked in both pre- and post-workshop surveys. The statement, rated on a scale of 1-5, “I can play an active role in the planning of the community where I live” was used as a proxy indicator for the participants’ belief in agency, and “public participation in planning advances the interests of my community” as one for belief in impact. Agency and impact were proposed as indicators to help observe the tools’ relationship to potential changes in the participant’s sense of ownership and responsibility over the conditions of their communities because we recognize the importance of such a belief—irrespective of the sophistication of the tools—as a pre-condition to an effective and involved public participation, and as an opposite condition to political disengagement.

For the participants’ intentions to shift travel mode, we compared the pre-workshop question of “in the last week, how many times did you travel by: car; subway/train; bus” to the post-workshop question: “if corridors like we discussed today are implemented, do you imagine yourself changing the way you travel? If so, how many times per week would you travel by: car; subway/train; bus”.

For beliefs in impact and agency, Figure 3.1B shows that nearly half of the responses were neutral, and the other half split across positive changes and negative changes. For mode shift, as measured by the participants’ inferred intention to decrease car usage and in increase bus usage, we see an average shift of 2.5 times a week, indicating a potential change in one’s transit behavior (Figure 3.1C).
Mode shift: no apparent influence of age, experience and data literacy

It is worth noting that beneath the overall positive shift in potential modal choice, there is a visible concentration of shift against bus usage among the 55-64 year olds (n=6) and those identified with the lowest level of map literacy (n=2) (Figure 3.1C).

Figure 3.1C: Inferred Mode Shift across participants, by age group, map literacy and profession
**Impact: Subtle correlation with data/map literacy**

Among the three-quarters of participants who self-reported as having “average” or “good” data literacy (n=29), we see no change or positive increase in their beliefs in agency, compared to the three-quarters among those having “poor” data literacy (n=9) that showed zero-to-negative change. Those identified with the lowest level of map literacy (n=2) also exhibited more negative change than those identified with higher level of map literacy.

*Figure 3.1D: Change in Belief in Impact by age groups, data literacy, map literacy, familiarity with BRT, profession and planning meeting attendance.*
Agency: subtle positive change among the "lesser-experience"

For the belief in agency (Figure 3.1E), we observe no visible relationship with age, or data and map literacy. Some subtle patterns emerge, however, between the positive/negative changes in the belief and prior familiarity with BRT, frequency of planning meeting attendance and profession. For instance, three-quarters of participants expressed no change or indicated a decrease among those who are classified as subject matter experts\(^1\) (n=13) (Figure 3.1E) and those who self-reported as being familiar with the subject of BRT (n=32) and having attended 4 or more planning meetings over past year (n=18).

\(^1\) Classification based on self-reported occupations in the pre-workshop survey and on team members' knowledge of participant backgrounds. See Appendix G.
3.1.3 Discussion of Overall Performance

The detailed evaluation of learning outcomes, inferred by mode shift intention and changes in beliefs in agency and impact revealed a stronger “change” effect among the participants who may be classified as the “lesser-experienced” (e.g. younger age, fewer planning meetings attended, unfamiliar with BRT and non-professional), but also those who were identified to have higher data and map literacies. Notably, this group scored higher in the evaluation of learning basic BRT features, and slightly more positive—and fewer negative—changes in their beliefs in agency (“I can play an active role in the planning of the community where I live”) and impact (“public
participation in planning advances the interest of my community” after attending the workshop. This finding invites future developers of the platform’s tools to further explore ways to improve the possibilities for enhancing learning and the attitude- and behavioral-changing components so that the tools might ultimately fulfill their intended function as a participatory planning system and be effective across a wide spectrum of participants.

3.2 CROSS-SCALE EVALUATION

3.2.1 Usability versus Relevance

In the post-workshop survey, we asked the participants to compare the street, neighborhood and regional models using three identical sets of seven questions, answered on a 1-5 Likert scale. While each question indicates a specific concept, they also fold into a larger latent variable, or construct, of usability or relevance.

**USABILITY**
- "[the tool] was easy to understand.” [communicability]
- "was encouraging for me to use it.” [motivation]
- "was engaging when I used it.” [stickiness]

**RELEVANCE**
- “reflected my unique issues & concerns.” [relatability]
- “raised important issues for my team to discuss.” [common resonance]
- “used data & simulations that seemed credible.” [credibility]
- “helped me imagine alternative travel scenarios.” [stimulation]

Overall, the indicators representing the latent variables usability and relevance of each scale display good internal consistency, as shown by composite reliability$^2$ (COR) scores that ranged from 0.734 to 0.864 (Table 3.2A), well above the typical 0.7 acceptable threshold (Bagozzi and Yi, 1988).$^{21}$ The Average Variance Extract (AVE) scores of all except one construct (Street scale relevance) meet the acceptable threshold of 0.5, demonstrating convergent validity (Bagozzi and Yi, 1988). Figure 3.2A’s boxplot illustrates the distribution of combined scores organized into

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$^2$ Composite Reliability (COR) measures internal consistency, or the “validity” of a construct as formed by the given set of indicators (e.g. survey questions). COR been suggested as a less conservative measure for internal consistency compared to Cronbach’s Alpha (Bagozzi and Yi, 1988; Hair et al., 2012).
the construct of *usability* and *relevance* across the three model scales. The graphs show that, overall, workshop participants found the neighborhood model to have the lowest level of *usability*, with a mean of 3.7, and the regional model to have the highest level of *relevance*, with a mean of 4.5.

**Table 3.2A:**

<table>
<thead>
<tr>
<th>Latent Variable</th>
<th>Indicators</th>
<th>Loading</th>
<th>Indicator Reliability</th>
<th>Composite Reliability (COR)</th>
<th>Average Variance Extract (AVE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability (Street)</td>
<td>easy to understand - ST'</td>
<td>0.401</td>
<td>0.161</td>
<td></td>
<td>0.801</td>
</tr>
<tr>
<td></td>
<td>encouraging to use - ST'</td>
<td>0.915</td>
<td>0.837</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>engaging to use - ST'</td>
<td>0.891</td>
<td>0.794</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relevance (Street)</td>
<td>my unique issues &amp; concerns - ST'</td>
<td>0.311</td>
<td>0.097</td>
<td></td>
<td>0.734</td>
</tr>
<tr>
<td></td>
<td>important issues - ST'</td>
<td>0.666</td>
<td>0.444</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>credible data &amp; simulation - ST'</td>
<td>0.642</td>
<td>0.412</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>help imagined alternative - ST'</td>
<td>0.881</td>
<td>0.776</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usability (Neighborhood)</td>
<td>easy to understand - NB</td>
<td>0.685</td>
<td>0.469</td>
<td></td>
<td>0.842</td>
</tr>
<tr>
<td></td>
<td>encouraging to use - NB</td>
<td>0.885</td>
<td>0.783</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>engaging to use - NB</td>
<td>0.82</td>
<td>0.672</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relevance (Neighborhood)</td>
<td>my unique issues &amp; concerns - NB</td>
<td>0.607</td>
<td>0.368</td>
<td></td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>important issues - NB</td>
<td>0.593</td>
<td>0.352</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>credible data &amp; simulation - NB</td>
<td>0.821</td>
<td>0.674</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>help imagined alternative - NB</td>
<td>0.835</td>
<td>0.697</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usability (Regional)</td>
<td>easy to understand - RG</td>
<td>0.685</td>
<td>0.469</td>
<td></td>
<td>0.831</td>
</tr>
<tr>
<td></td>
<td>encouraging to use - RG</td>
<td>0.814</td>
<td>0.663</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>engaging to use - RG</td>
<td>0.858</td>
<td>0.736</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relevance (Regional)</td>
<td>my unique issues &amp; concerns - RG</td>
<td>0.645</td>
<td>0.416</td>
<td></td>
<td>0.864</td>
</tr>
<tr>
<td></td>
<td>important issues - RG</td>
<td>0.85</td>
<td>0.723</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>credible data &amp; simulation - RG</td>
<td>0.734</td>
<td>0.539</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>help imagined alternative - RG</td>
<td>0.888</td>
<td>0.789</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
To understand how usability and relevance might vary by participant backgrounds, we separate the scores for each model by age, prior familiarity with BRT, data literacy, map literacy, frequency of planning meeting attendance, and profession. Figure 3.2B shows that the regional model had the most polarized ratings for relevance and usability, and the biggest rating gap between age groups. For usability, Figure 3.2B shows that three-quarters of participants in the age groups of 21-34 (n=18) and 35-54 (n=14) rated the regional model 4 or above, out of five. Meanwhile, not one person in the age groups of 20-, 55-64 and 65+ gave it a rating of more than 4. Aside from the regional model, no visible pattern of the effect of age on usability and relevance ratings is found.

Another subtle pattern is seen in Figure 3.2C, where one sees the relatively lower rating of the neighborhood model by the participants who self-identified to have average or good data literacy, and those who were observed to exhibit relative comfort reading and using maps.
3.2.2 Discussion of Usability versus Relevance

A brief comparison across three scales indicates a low usability of the neighborhood scale model, and high relevance of the regional model. The low usability rating of the neighborhood scale originates mainly from the participants who were considered more data- and map-literate. This finding suggests that the neighborhood model's low usability rating is likely not a reflection of the inherent disadvantage of the neighborhood representation, per se. Anecdotal feedback on the neighborhood model revealed a lack of clear focus and learning objective. Suggestions in the exit survey further showed that the neighborhood model indeed did not take full advantage of the digital technology to meet the participant expectations. Several participants commented on the lack of scenario comparison; one suggested a broader scope of letting users "put stations along any road. Calculate, optimize, show costs and effects."³

One known shortcoming of the neighborhood model—and to some extent of the street scale also—is the lack of easily observable differences in the traffic simulation. "It was not clear what the exact differences between the different bus station types in the simulations were," wrote one trial user. In other words, while both LEGO-based models had an accompanying dashboard displayed on an adjacent screen, participants could not easily discern obvious impacts through the traffic visualization as they replaced one LEGO station piece with another. This is also related to a comment that there was "not enough play" in the two LEGO-based models, where the presence of both LEGO bricks and traffic simulations likely helped the participants form the expectation of an interactive experience. But the participants ended up having only

³Post-workshop survey
limited ways to interact with LEGO elements and could see no discernable changes in the traffic simulation through the interaction. At the regional scale, however, the participants would perhaps not have the a priori expectation of a high level of interactivity.

As for the regional model’s higher relevance rating, we see a visible contribution from those in the age of 21-54. This might be a reflection of that particular age group’s higher travel demand and, therefore, a reflection of their aspirations for any travel modes that might potentially improve their daily commute experience. In the following section, we examine the potential influence of relevance and usability ratings on the intended outcome of the workshop: attitude change and double-loop learning.

3.2.3 Usability and Relevance in Relationship to Intended Outcome

To develop a deeper understanding of the mechanisms behind changes observed through the workshop engagement, we tested the relationship of usability and relevance to the intended engagement outcome of learning, social learning, double-loop learning, and attitude change. Learning is the basic measure of “single-loop learning” that represents the participants overall experience of having “learned a great deal” without questioning the workshop’s underlying value, goals and strategy. Social learning measures whether the workshop offered condition where the participants learned through the presence of others took place. Double-loop learning, compared to single-loop learning, represents a deeper form of learning that involves the questioning of the underlying values and goals. Attitude Change measures the extent to which the participants showed indications of changing their beliefs as a result of the workshop. Table 2.2A shows the survey questions used as indicators to form the constructs of intended outcomes mentioned above.

Structural Equation Analysis

The data set is analyzed through the method of Partial Least Squares Structural Equation Modeling (PLS-SEM), using SmartPLS (v. 3.2.3) (Ringle, Wende, and Becker, 2015). In order to examine the influence of usability and relevance from each scale simulation on the intended outcome of learning, social learning, attitude change and double-loop learning, the questions related to these two constructs were posed three times, once for each model, in the post-workshop survey. The structural model presented in the upcoming analysis is constructed roughly based on the hypotheses two, three and four presented in chapter two:

Hypothesis 2: Adequate usability of the tool invites and sustains user interaction with the tool, which in turn provides opportunities for the present users to observe, discuss
and learn through the interaction. Therefore, we hypothesize that *usability* has a positive effect on *social learning*, which in turn has an indirect positive effect on *learning* and *double-loop learning*.

Hypothesis 3: *Relevance* is a proxy measure of how well the design of the information in each tool supports the participants’ level of mental engagement with the issue the tool seeks to represent. Therefore, *relevance* is hypothesized to have a positive effect on the deeper form of learning (*double-loop learning*) and on transformation (*attitude change*).

Hypothesis 4: Different scales of representation will differ in their effectiveness on the users, therefore we expect some varying levels of effect of each scale’s *relevance* and *usability* on learning and transformation.

**Measurement Model**

Prior to forming the structural model, the latent variables representing *usability, relevance, social learning, learning, double-loop learning* and *attitude change* were examined and adjusted by the loading factor and indicator reliability scores of their contributing questions (Table 3.2B). Indicators with an indicator reliability score lower than the acceptable minimum of 0.4 (Hulland, 1999) for exploratory research were taken out, which resulted in item loadings ranged from 0.642 to 0.923, and Average Variance Extract scores ranged from 0.564 to 0.821, above the 0.5 recommended threshold for a latent variable’s convergent validity (Bagozzi, Yi, 1988).

**Table 3.2B: Adjusted Reflective Outer Models based on Aggregated Latent Variables Across 3 Models**

*Crossed out indicators were removed due to their low indicator reliability for increasing the internal consistency of latent variables.*
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability</td>
<td>(Neighborhood) easy to understand - NB</td>
<td>0.685</td>
<td>0.469</td>
<td></td>
<td>0.842</td>
</tr>
<tr>
<td></td>
<td>encouraging to use - NB</td>
<td>0.885</td>
<td>0.783</td>
<td></td>
<td>0.642</td>
</tr>
<tr>
<td></td>
<td>engaging to use - NB</td>
<td>0.82</td>
<td>0.672</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>my unique issues &amp; concerns - NB</td>
<td>0.607</td>
<td>0.368</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>important issues - NB</td>
<td>0.503</td>
<td>0.362</td>
<td></td>
<td>0.793</td>
</tr>
<tr>
<td></td>
<td>credible data &amp; simulation - NB</td>
<td>0.821</td>
<td>0.674</td>
<td>0.840</td>
<td>0.523</td>
</tr>
<tr>
<td></td>
<td>help imagined alternative - NB</td>
<td>0.835</td>
<td>0.697</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Regional) easy to understand - RG</td>
<td>0.685</td>
<td>0.469</td>
<td></td>
<td>0.623</td>
</tr>
<tr>
<td></td>
<td>encouraging to use - RG</td>
<td>0.814</td>
<td>0.663</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>engaging to use - RG</td>
<td>0.858</td>
<td>0.736</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>my unique issues &amp; concerns - RG</td>
<td>0.645</td>
<td>0.416</td>
<td></td>
<td>0.864</td>
</tr>
<tr>
<td></td>
<td>important issues - RG</td>
<td>0.85</td>
<td>0.723</td>
<td></td>
<td>0.616</td>
</tr>
<tr>
<td></td>
<td>credible data &amp; simulation - RG</td>
<td>0.734</td>
<td>0.539</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>help imagined alternative - RG</td>
<td>0.888</td>
<td>0.789</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social Learning</td>
<td>helpful conversations with others</td>
<td>0.762</td>
<td>0.581</td>
<td></td>
<td>0.719</td>
</tr>
<tr>
<td></td>
<td>helped others learn</td>
<td>0.584</td>
<td>0.338</td>
<td>0.884</td>
<td>0.699</td>
</tr>
<tr>
<td></td>
<td>learned through listening</td>
<td>0.923</td>
<td>0.852</td>
<td>0.889</td>
<td>0.699</td>
</tr>
<tr>
<td></td>
<td>learned through observing</td>
<td>0.816</td>
<td>0.666</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double-Loop Learning</td>
<td>get questions answered</td>
<td>0.777</td>
<td>0.604</td>
<td></td>
<td>0.599</td>
</tr>
<tr>
<td></td>
<td>open discussion</td>
<td>0.711</td>
<td>0.506</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>open to different opinions</td>
<td>0.753</td>
<td>0.567</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>support participant recommendations</td>
<td>0.848</td>
<td>0.719</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning (Perceived)</td>
<td>learned a great deal</td>
<td>1</td>
<td>1.000</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

47
Structural Model

To establish correlations among the constructs, we applied the bootstrapping procedure to the model. In the structural model (Figure 3.2D), the combined usability ratings of the three scales explained only 27% of the variances of social learning, with the regional-scale having the most significant contribution ($\beta=0.357$; $T$-Statistic=2.102). However social learning explains 32% of the variances in learning, which in turn, when combined with relevance across three models, explains 67% of the variance in double-loop learning. Relevance across three models also explains 42% of the variance of attitude change, with the regional-scale having the most significant contribution ($\beta=0.326$; $T$-Statistic=2.424), and the street-scale having semi-probable contribution ($\beta=0.279$; $T$-Statistic=1.616). The strength of relationship between these constructs are indicated, in strength, by the path coefficient and the $T$-statistic (in parenthesis) marked on the arrow lines. Based on the two-tailed t-test with a significance level of 5% used to evaluate the path coefficient, any path with a $T$-statistic larger than 1.96 is considered significant. Based on Figure 3.2C, we can infer the contribution to social learning comes from the usability of the regional model. We see moderate contribution of the regional model’s relevance to attitude change. The strongest linkages are found between social learning and double-loop learning by way of learning.

$$
\begin{array}{|c|c|c|}
\hline
\text{Attitude Change} & 0.847 & 0.717 \\
\hline
\text{belief in individual participation} & 0.777 & 0.604 \\
\text{belief in planning meeting} & 0.304 & 0.092 \\
\text{mode-shift intention} & 0.837 & 0.719 \\
\hline
\end{array}
$$

Footnote: The Bootstrap method, available in SmartPLS, is used here by taking 5,000 subsamples from the original sample with replacement to produce standard errors, which generates $T$-values for significance testing of the structural path. The result approximates the normality of data.
3.2.4 Discussion of Structural Equation Analysis

Through PLS regression and bootstrapping analyses, we begin to see indications of how usability and relevance of each scale model relate to intended outcomes of double-loop learning and attitude change. Few insights can be inferred from the structural model, expect for the minor contribution of the regional model's usability to social learning, social learning's contribution to double-loop learning, and the regional model's relevance to attitude change. Assuming these effects were real, they beg the question of how one might concretely improve the operationalization of these features in the future iterations of the tools. In other words, what do social learning, relevance and usability really mean to the participants, in their own minds? In the following section, we compare usability and relevance by their individual contributing questions, and supplement this information with user feedback gathered from the follow-up workshop to help us further analyze their design implications for a participatory urban planning and policymaking system.

3.2.5 Communicability, Relatability & Credibility

In this section, individual questions used to form the constructs of usability and relevance were evaluated one-by-one across scales. A broad observation of the charts revealed three notable
findings. First, the participants found the street model most “easy to understand” (Communicability), with over 50% of responses being the maximum score of 5 (Figure 3.2E). Meanwhile, they found the regional model to be most reflective of their “unique issues & concerns” (Relatability), with over 70% of responses being greater than 4 points (Figure 3.2F). Similarly, for the regional model, 90% of respondent’s scores for “data & simulations that seemed credible” (Credibility) were 4 or 5 points, versus 65% for the street model (Figure 3.2G).

To validate the statistical significance of the participants’ favoring of a specific model for the above three questions, we applied Fisher’s Exact Test to the data in the form of a contingency table. For the question of “easy to understand”, the test returns a p-value of 0.005(Figure 3.2H), meaning we can reject the null hypothesis and signifying that the three models do not have the same patterns in their ratings of “easy to understand”. As for the tools’ reflecting “unique issues & concerns,” we obtain a p-value of 0.001; we can again reject the null hypothesis—people viewed the models to reflect their unique issues and concerns differently. In
terms of using “data & simulations that seemed credible”, the test returns a *p-value* of 0.09; one cannot be certain that that deviation of regional scale’s *credibility* is sufficiently far apart from the overall pattern of *credibility* rating across the three scales. As a result, we can conclude that the street scale is significantly more “communicable” than the neighborhood and regional scales, and that the regional scale is significantly more “relatable”, but only moderately more “credible” than the other two scales. Broadly speaking, these findings are consistent with what one would
expect of the participants’ reaction toward the street model’s unique tangibility and “human-scale” quality and the regional model’s features that allow for different users to personalize the data visualization according to their individual experiences. Section 3.2.6 further discusses the implication of these findings.

Figure 3.2H: Fisher’s Exact Test output for measures of “communicability”, “relatability” and “credibility”

Question: “The tool was easy to understand”

<table>
<thead>
<tr>
<th>Data: Contingency Table</th>
<th>Expected: Contingency Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Street</td>
<td>Neighborhood</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
</tr>
<tr>
<td>38</td>
<td>37</td>
</tr>
</tbody>
</table>

Odds Ratio: 4.7E-09
P-Value: 0.005

Question: “The tool reflected my unique issues and concerns”

<table>
<thead>
<tr>
<th>Data: Contingency Table</th>
<th>Expected: Contingency Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Street</td>
<td>Neighborhood</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>37</td>
<td>37</td>
</tr>
</tbody>
</table>

Odds Ratio: 4.2E-10
P-Value: 0.001

Question: “The tool used data and simulation that seem credible”

<table>
<thead>
<tr>
<th>Data: Contingency Table</th>
<th>Expected: Contingency Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Street</td>
<td>Neighborhood</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>38</td>
<td>36</td>
</tr>
</tbody>
</table>

Odds Ratio: 9.3E-08
P-Value: 0.090


3.2.6 Focus Group Follow-up Discussion

The findings regarding the street scale model’s ease of understanding and the regional scale model’s reflection of personal concerns and use of credible data and simulations have several plausible explanations. The street model was intentionally designed to represent the BRT at its most literal and human-scale (or LEGO figurine-scale) form. Key features of the BRT such as prepayment gates, elevated platform, shelter and dedicated lane were clearly articulated in the LEGO model. As users switched station types from a traditional bus stop to a BRT station, they were able to see parking spots being immediately replaced by a dedicated bus lane. Compared to the neighborhood and regional models where BRT features were not clearly articulated, the street model was expected to have the appearance of being most understandable, especially to the participants who had no prior knowledge of BRT. In the follow-up focus group, one participant reflected on the high communicability rating of the street model by saying you “can see changes as you go,” referring to the changes in the visualization of streetscape as one replaced one LEGO bus station with another.

As for the regional simulation being most “relatable,” or reflective of people’s “unique issues & concerns,” one might attribute this difference to the fact that the regional scale model approach had three unique features that enabled the participants to personalize the input and output. The participants could: 1) place icons on the map to indicate their homes and frequented destination as a form of bookmark; 2) choose to edit the service of a route of their interest, and; 3) visualize the accessibility based on a point of their interest. In contrast, simulations of the street and neighborhood scale did not have features that specifically reflect the participants’ geographies or locations of interest, per se.

When asked to comment on the relatability of the simulations, several focus group participants focused on using the street scale model’s relatively limited, static scope as an explanation. “It won’t work on my street,” commented one participant. “Every street block has different problems,” said another. One also pointed to the limited visualization of impacts of the street scale versus that of the regional scale. On the contrary, the regional scale model was seen as “more integrated with more functionalities.” Another participant rightly pointed out that through the regional scale model, “one could see transit deserts,” spots unreachable through public transport, as depicted in the isochrones maps.

Finally, for the measure of credibility of the regional scale, focus group participants explained this finding largely through the level of relatability between the information they saw across the three simulations and their personal commuting experience. At the regional scale, for
example, a few participants commented how one could use personal commuting experience to frequented destinations as a reference for evaluating the accuracy of the travel time map. Whereas in the neighborhood- and street- scale simulations, travel time appeared "hypothetical."

In addition to the issue of relatability, one participant noted that the LEGO-based neighborhood scale simply had "wrong labels of streets and intersections," which prompted people to question its reliability.

### 3.3 FUTURE DESIGN CONSIDERATIONS

#### 3.3.1 Breadth vs Depth: Be Aware of Potential User Reaction to Each

Through comparing the three scales of simulation both quantitatively and qualitatively, we observed a certain difference in the way people responded to the breadth and the depth of information. In both street and neighborhood scales, the dashboards displaying impacts such as travel time to destination, waiting time, number of parking spots, miles of dedicated lanes, pollution, average traffic speed, and lane cost were positioned as a side-by-side product of the scenarios chosen by the participants. As participants replaced one LEGO station with another, they were asked to refer to the dashboard that automatically and immediately reflects the latest impact. Beneath this apparent efficiency, however, one participant reflected that he felt there were "too many numbers to figure out which ones to trust," while another asked the question of "what made up the numbers?" Whereas both street and neighborhood simulations emphasized the dashboard data fairly early during the user interaction, the regional simulation placed a greater emphasis on letting the users explore different travel time maps based on unrestricted placement of the map icon (Figure 3.3A). Overall, the users were given more time to focus on exploring the travel time map before they were asked to look at the dashboard that displayed a greater number of associated statistics such as operating cost, number of stations, etc. During this initial phase using the regional simulation, the users experienced the depth to which they could visualize and re-visualize the travel time map, based on a fictional scenario or personal scenario they could relate to and therefore judge the validity of the data representation.
3.3.2 Data Relatability: Engage Users by Making Data Interaction Personal & Human-Scale

Novels and stories are effective at inculcating us with new knowledge and understanding of certain life phenomena by triggering the individual’s imagination. The information as presented across the three simulation models—such as operational cost, travel time from Dudley Square to Downtown Boston, or pollutions—represent abstractions that may not often be thought about by the general public. In other words, these statistics were not presented in a “human-scale” form to trigger imagination, and therefore may have been hard for people to relate to and develop trust and interest in. To this end, one focus group participant suggested that the LEGO street simulation, instead of displaying just the average waiting time at a station on the Dudley Square-Downtown corridor, should also have allowed the users to somehow see the average waiting time at their respective neighborhoods and stations under new transit scenarios.

The regional simulation, though LEGO-less and 2-dimentional, provided everyone a chance to test the validity of the statistics based on personal commuting experience. The below excerpt of the transcript from one workshop reflects this process:

**Participant:** hen cuz by train if I hit it right in the mornings I can get owntown pretty fast, it is like an 8 min walk from my house own to the station

**Facilitator:** hat s a great point his tool actually assumes you that you ha e ba luck, that you ust misse the bus an misse the train

**Participant:** h kay he mornings are pretty goo he Blue line is also anomalous, it runs, as oppose to orange an re lines followe by an 8 secon pause as he obser es the simulation screen

**Facilitator:** ou sai it woul take 55 min for you to get here to ay right

**Participant:** eah about that
participant: eah, that's what it usually takes

In the above scenario, we observe the workshop participant examining the travel time from his home to downtown as represented by the simulation. He questions the assumption and receives a clarification from the facilitator. The facilitator also uses the additional test case of the participant’s commute from home to the event venue as a comparison to the simulated travel time map. The participant confirms the validity of the data. This process is consistent with what several focus group participants suggested; that they found the regional model more credible because “people can match their personal experience to it.”

3.4 LIMITATIONS

Disproportionate features between LEGO- and browser-based Tools
While the regional simulation had the built-in feature for comparing travel maps generated based on different route compositions, the LEGO-based neighborhood and street simulation showed scenario impacts as discrete visual feedback, on both the dashboard and the LEGO model. Such a disproportionate implementation of functionality likely distracted the participants from being able to objectively compare the three models based on the scale of representation.

Lack of iteration and user feedback for the making of LEGO-based models
The browser-based regional simulation saw its first group feedback session during the “pre-pilot” event in June 2016, where the majority of functionalities had already been implemented for trial use (Figure 3.4A). The two LEGO-based models, however, did not become interactive until less than one week prior to the workshop date. This production delay prevented the implementation of features beyond basic scenario generation and usability adjustments. In other words, the workshop participants evaluated three tools that were of vastly different maturities, which introduced further noise to the participants’ evaluation of the models. One potential
improvement would be the migration of the dashboard from the TV display onto the LEGO model itself to consolidate the display of information from two displays to one display. Such an effort may help reduce the cognitive load of the users.

Figure 3.4A: Pre-pilot event for regional scale simulation model three months prior to workshop

Lack of Alternative Treatments
The research originally intended to limit certain participants to using only one or two scale models instead of all three, which would allow the research to more precisely understand the influence of different scale models on the intended outcome. But the difficulty in recruiting a large sample size of participants prevented the research from setting up alternative treatments that could lead to significant comparable findings.

Lack of Representative Participation
In an ideal scenario, the workshops would include diverse participants that reflect the broad spectrum of community groups that are affected by the chosen topic. But without sufficient representative participation, we are unable to generalize the findings.
The overall positive response and learning from deploying the prototype of a multi-scale, interactive participatory planning platform suggests a likely materialization of a new form of urban policymaking. In the opening discussion of the potential opportunities for ICT in participatory planning, three questions were raised:

1. Communication: How might ICT help improve the quality of conversations and motivate greater diversity of participation in the urban planning and policymaking process?
2. Generation: How might ICT stimulate collective exploration, discovery or even reframing of ideas and problems?
3. Integration: How might ICT, given its replicable nature, become both accessible and relevant to designers, planners and policymakers operating within different institutional cultures, workflows and resource constraints?

Thanks to the rising availability of data, affordable computing hardware and open-source software, it has become increasingly viable to build tools that convey complex urban information and dynamics and gather feedback on represented issues. This trend widens the prospect of participation, moving the decision-making process from the centralized, expert-centric, single-agency driven approach to a more co-creative one. The trend also points to a new constellation of knowledge and decision management in urban policymaking, one that can be understood along the dimensions of socio-political costs vs. monetary cost, and of statistical representation versus live representation (Figure 4.1A).

### 4.1 Socio-Political Cost vs. Up-Front Rollout Cost

The traditional processes of urban policymaking that prioritize “expert” decisions without broader decision support resources can suffer from less awareness of the potential impact of decisions on the affected persons, groups or populations. As not all policy decisions lead to a positive or acceptable outcome, public agencies often pay a substantial political cost while the affected community endures the socioeconomic consequence. These negative externalities may be reduced as the decision process becomes more informed of the otherwise overlooked considerations from other stakeholders, as well as more inclusive of “layman”, street-level knowledge. In addition, the political risk can typically be reduced as the ownership of decision-making is distributed among a wider set of stakeholders. The extent to which the urban policymaking process becomes participatory depends on the stake of the decision. The
participatory and co-creative approach is suitable where stakeholder buy-in and/or behavioral interventions are important. Mass transit redevelopment in Boston, with a history of contentious proposals and accusations of inequitably poor service, provides a case in point where investment in the innovation of a participatory process makes good political sense. While the upfront development cost of the participatory process is high, a software-based tool such as CoAXs has the potential to become a scalable service, and therefore be amortized in the form of licensing or R&D grants as more public agencies across geographies adopt the tool.

**Figure 4.1A: Proposed cosmology of urban information & decision management tools**

*Definable / Representable Problems*

- Predictive Analytics / Automation
- Street Score
- INCLUSIVENESS
- FLUID & OPEN-SOURCE reproducible cheaply & across geographies
- Crowdsourced Intelligence
- Place Pulse
- Visual Zero
- Kansas City 311 Feedback
- Change By Us

*Time-Resource Constrained Decisions*

- Expert-Centric: top-down, single-agency driven
- Closed Door Politics
- Consensus Generation

*SCALABILITY*

- Expert-Centric
- INCLUSIVENESS
- Experiential tailored but tactile, face-to-face & emotionally appealing
- Complex / Abstract Problems

*Stakeholder Buy-In / Behavioral Intervention*

- Socio-Political Cost
- Rollout Cost

4.2 Statistical Representation vs. Live Representation

The centrality of decision-making actors aside, the management of knowledge and decisions in urban planning and policymaking now also considers the question of reproducibility. While CoAXs, as a browser-based app, can easily be rolled out across cities, enabling large-scale participation and communication, its main features of transit service modification and accessibility mapping are built based on problems that are definable and representable by bits and numbers. It directs the participants to address the issue of transit design through the more
utilitarian and functional aspect of the bus service (e.g. service frequency). Related web-based platforms such as Boston’s Vision Zero, New York City’s Change by Us, Kansas City’s 311 Feedback, or MIT Media Lab’s Place Pulse and Street Score are all scalable platforms that focus on aggregating urban intelligence through pre-defined choices. These tools have the advantage of gathering data at large scale for decision support or for real-time service response. As in the case of using social media, according to New York City’s former deputy mayor of Stephen Goldsmith, the method can help “build social capital via online civic engagement and instill a sense of confidence and trust in the government and justice system.” Not all problems and relationships, however, are as definable or addressable via the web.

For problems that are complex or abstract, human presence and face-to-face problem-solving or negotiation still hold much value. Face-to-face interaction facilitates the building of trust and empathy among people, especially as the decision-making intends to accommodate diverse voices. The relationship between human presence and empathy is well documented in the economic experiment of the “ultimatum game” (Güth, 1982), where individuals are more prone to make choices that are fair to the counterpart when they are put in the same room, and choices that are more predatory when put in separate rooms. For planning and policy decisions that might lead to disproportionate effects on different socio-economic groups, live representations from each group become all the more important. The difference between “in-room representation” and “out-of-room representation” can also be inferred from researches on charitable giving that compare the donation rate toward identifiable subjects versus that toward statistical subjects. In them, individuals are found to be favorably biased toward donating more to victims that are represented in human, narrative forms than to victims that are shown in statistics, even if the statistical victims represent a larger scale problem.

While the LEGO simulation models fell short of the functionality of actual co-creation and personalization, they show great promise in breaking down the initial barrier of the fear of lacking qualification to participate in policy-related discussions. The physical features of the LEGO models and interactive data visualization also serve as an effective talking piece for breaking the ice between the otherwise unrelated participants, especially if the participant base

becomes more diversified across socio-economic and professional backgrounds, or simply across
different governmental agencies and departments.

The ultimate confirmation of the value of providing an experiential setting to facilitate
face-to-face engagement is the occurrence of social learning at the trial workshop for the prototype
platform. Irrespective of the usability and relevance, social learning contributed to learning and double-
loop learning. Usability and relevance are persuasive design features that can be more easily replicated
on web-based tools. Social learning, however, requires substantial human presence. For these
reasons, we begin to see the value of the physical and experiential dimensions of the
participatory planning and policymaking process.

CONCLUSION

As learned through studying the trial users of the prototype of a multi-scale participatory urban
policymaking platform, the representation of data must be relatable at the personal level for the
information to garner credibility and interest across diverse participants. We also learned that
technology, and the design of its user interface, can complement and facilitate an experiential,
face-to-face experience and social learning, which may be crucial when the issues at stake are
complex and require decision-making participants to learn and synthesize new information.
Research in behavioral economics reinforces the value of the experiential setting, the idea that
the representations of the stakeholders must be humanized for them to receive the due empathy
and respect.

This study supports the value of the experiential and co-creative approach. As such, it
suggests a new means for the public agencies and communities to manage decision-making when
faced with complex and abstract scenarios. It points to the positive prospect of adopting
technology for the purpose of nudging policy decision-making away from closed door politics
toward consensus generation. It supports the creation of a new class of tools that complement the
tools built for decision support, namely software-based tools developed for crowdsourcing
intelligence, predictive analytics and automation. It is my hope that this sketch of the new constellation
of tools suitable for managing urban intelligence and decisions will support change makers in the
field of public service and community organization in making effective choices of instruments
under different scenarios and requirements, and therefore shape urban policies, services and
experiences that are efficient, satisfying, equitable and resilient.
Better Transit?

Welcome! Please help our MIT team evaluate new technologies by answering the following questions:

Age

Occupation

Please list any community organizations you are affiliated with:

Over the past year, how many public planning meetings have you attended?

(circle one option) 0 1-2 3-5 6+ 6+

At how many did you make a formal presentation?

At how many did you speak and share your opinion?

At how many did you learn new things about planned projects?

In the last week, how many times did you travel by:

Car? Subway/Train? Bus?

Are you familiar with the concept of bus rapid transit (BRT)?

Yes No

If yes, try to list four important elements of BRT:

How familiar are you with digital graphical representation of information and data?

Not familiar 1 2 3 4 5 Very familiar

To what extent do you agree with the statements:

I can play an active role in the planning of the community where I live

Disagree 1 2 3 4 5 Agree

Public participation in planning advances the interests of my community

Disagree 1 2 3 4 5 Agree
Better Transit?

[Image: Survey questions and responses]

B). Post-workshop survey
Appendix C: Mode Shift Intention

Mode Shift Across All Participants

Mode Shift by Data Literacy

Mode Shift by Prior Familiarity with BRT

Mode Shift by Map Literacy

Mode Shift by Frequency of Planning Meeting Attendance

Mode Shift by Workshop Session

Mode Shift by Age

Mode Shift by Workshop Number

Mode Shift by Profession
Appendix D: Usability & Relevance Comparison Across Scales

Usability Across Scales

Relevance Across Scales

Usability by Age across Scales

Relevance by Age across Scales

Usability by Prior BRT Familiarity across Scales

Relevance by Prior BRT Familiarity across Scales

Usability by Data Literacy across Scales

Relevance by Data Literacy across Scales
Usability by Map Literacy across Scales

Relevance by Map Literacy across Scales

Usability by Across Scales by Frequency of Planning Meeting Attendance

Relevance Across Scales by Frequency of Planning Meeting Attendance

Usability by Profession across Scales

Relevance by Profession across Scales
Appendix E: Assignment of “Experts” and “Non-Experts” based on reported occupation and team members' knowledge

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### Appendix F: Descriptive Statistics for the Sample

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**Number of Valid Responses: 45**


23 Institute for Transportation & Development Policy. (2014). The BRT Standard [Brochure]. Author


