► *Report*

Urban Simulation and the Luminous Planning Table

Bridging the Gap between the Digital and the Tangible

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Abstract

Multi-layered manipulative platforms that integrate digital and physical representations will have a significant impact on urban design and planning processes in the future. The usefulness of these platforms will be in their ability to combine and update digital and tangible data in seamless ways to enhance the design process of the professional and the communication process with the public. The Luminous Planning Table is one of the first prototypes that use a tangible computerized interface. The use of this system is unique in the design and presentation process in which, at the moment, the activity of viewing physical models and the viewing of animation and computerized simulations are separate. This ability to engage and provide an integrated medium for information delivery and understanding is promising in its pedagogical, professional, and public engagement outcomes.

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One of the great challenges that physical planners and urban designers face is communicating their spatial concepts and ideas to the broader public. Obermeyer (1991) contended that while planners are trained to think in spatial terms, they often fail to highlight the spatial implications of proposed policies to public administrators and policy makers. This inattention, she concluded, can be in great part explained because spatial consequences have not been made salient in presentation materials. While modes of imaging technologies—from two-dimensional maps, charts, and diagrams to computer models—allow professionals to explain their designs and planned interventions more clearly than ever before, few platforms exist that allow immediate, real-time, and seamless changes in response to public or professional inputs. If our aim is to let the public become more involved in the planning and design of physical spaces, better methods and tools of urban simulation have to be developed. Ideally, these tools would communicate changes that are proposed so that nondesign professionals could easily understand the impact of the proposed changes. These systems could be used not only as tools for design professionals but also as an interactive application to enrich communication and learning within the design process. The integration of such envisioning tools into the decision-making process will allow for better professional judgments while incorporating various stakeholders' expectations.

Often, several different modes of representation must be used within a project to convey different kinds of information and aspects of the design. It is this separation between various representative forms that increases the cognitive load on both the urban designer and the audience, who must draw relationships between dislocated pieces of information. Mitchell and McCullough (1995) articulated the many different forms of representation within a design process and demonstrated how these forms are separated from each other in time, space, and scale (see Figure 1). Planning and urban design professionals are in need of a platform that allows the simultaneous understanding of a wide variety of representations, spanning drawn, physical, and digital forms. The Luminous Planning Table (LPT) is one such promising interface. Developed at the Massachusetts Institute of Technology (MIT) Media Lab and the School of Architecture and Planning, the LPT originated from the development of the input/output (I/

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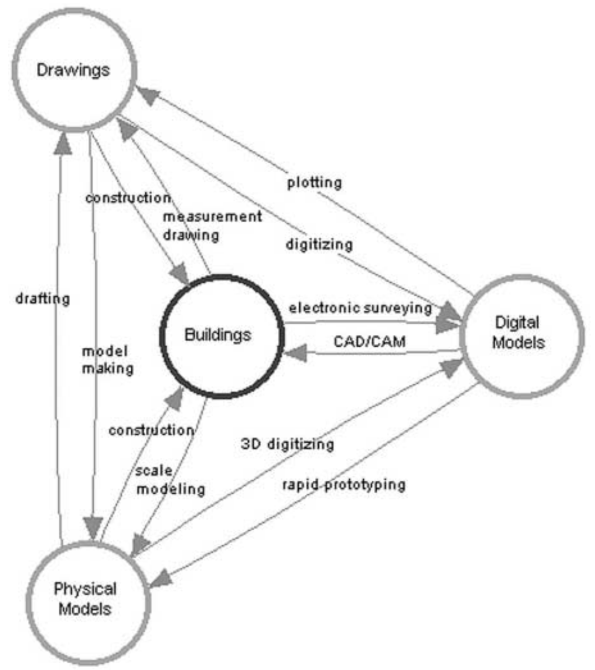

Figure 1. *Each form of representation remains separated from the other in time, space, and scale.*
Source: Image courtesy of William J. Mitchell.

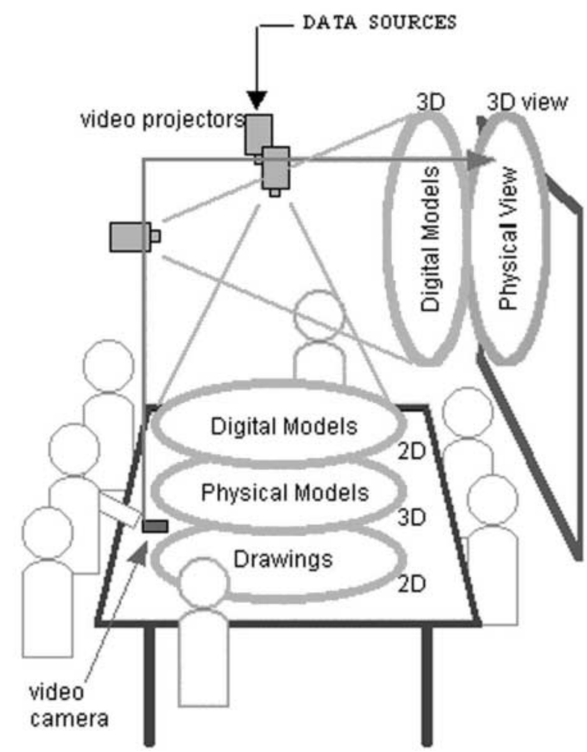

Figure 2. *Luminous Planning Table integrates digital and physical mediums.*

O) bulb workbench (Underkoffler 1997; Underkoffler and Ishii 1998). This prototype is composed of projectors hanging from above, with cameras pointing down at the surface enabling it to see the changing positions of different physical objects. The attached computer computes a variety of features that are associated with these objects and projects them back on the table's surface, moving and changing the features as the objects are shifted or manipulated (see Figure 2). For example, models of proposed buildings placed on the table generate projected data such as shadows, ground wind patterns, reflective glare, and view corridors. These projections are immediately changed and updated as one moves the buildings around on the table (see Figure 3). Because of its dynamic nature, the system can also show the movement of shadows across a site as a day progresses in winter, summer, or any time of the year, show prevailing winds as they change by seasons or the increase of traffic at rush hour on surrounding streets. In addition, two or more tables at different locations may be electronically interconnected, enabling individuals to participate in the design or analysis of a three dimensional project simultaneously over a distance as a group. The result is a powerful simulation tool that provides access to a full efficacy of computational resources in a manner that is comfortable and intuitive (see Figure 4).

The integration of digital and tangible interfaces provided by the LPT is unique in its presentation of urban simulation, where the activity of viewing physical models and the viewing of animation and computerized simulations are separate. This new form of information delivery is a product of technological improvements as well as the advancement of computation and simulation in the planning and design process.

▶ Development of Urban Simulation and Planning

In the early 1960s, citizen groups began to rise against large-scale urban renewal projects that came about with little public understanding of their associated physical impacts. As a result, some planners and urban designers became interested in developing new types of imagery and visual simulation to better present and understand the proposed changes. The exploration of new representational techniques as planning tools received an official boost in the United States with the passage of the National Environmental Policy Act of 1970. The act required that all large planning and engineering projects be analyzed for their impact on the existing natural and man-made environment, including visual effects (Bosselmann

1998). Professionals were driven to respond with new simulation tools such as those built at the Environmental Simulation Laboratory (ESL) at the University of California at Berkeley. At ESL, cameras and scale models were used to examine proposed changes of San Francisco's downtown zoning ordinances and simulate their urban design consequences, such as new building bulk and height, the city's skyline, and the penetration of sunlight into street corridors (Bosselmann 1992).

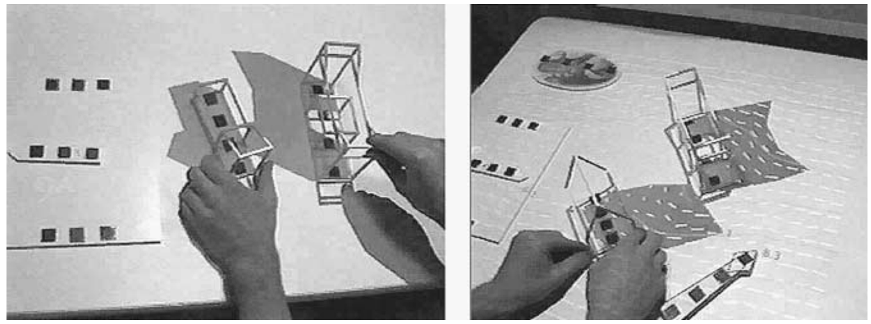

Figure 3. *Luminous table prototype showing building shadows and wind patterns.*

Until the late 1980s, computer-based urban simulation was prohibitively expensive. While computers were used to help calculate different camera positions and angles for film making, they were not used to create the simulation itself (Bosselmann 1998). The development of computer-generated urban modeling was linked to and dependent on the concurrent development of computer hardware and computer-aided design software.

► Urban Simulation and Computation

In the 1960s, development of interactive computer graphics was primarily used in large automotive and aerospace companies and government agencies, which developed their own software with room-sized mainframes. In the 1970s, the U.S. Navy began development of three-dimensional programs based on simple geometric forms: boxes, cones, cylinders, and so forth. With the development of the personal computer (PC) platform in the early 1980s, CAD software started to gain widespread acceptance. AutoDesk, which released its AutoCAD PC platform in 1983, gained recognition as the industry standard. With the introduction of Intel's 386, the use of CAD spread to many more companies and end-users. It particularly gained momentum in 1988 with its first exploratory release of a three-dimensional modeling system. By the early 1990s, the technology for generating entire landscapes by computer was readily available to design and planning professionals. Yet such simulations required time-consuming calculations to generate realistic lighting, reflections, and rendering details (Greenberg 1991). The advancement of the PC platform, military flight

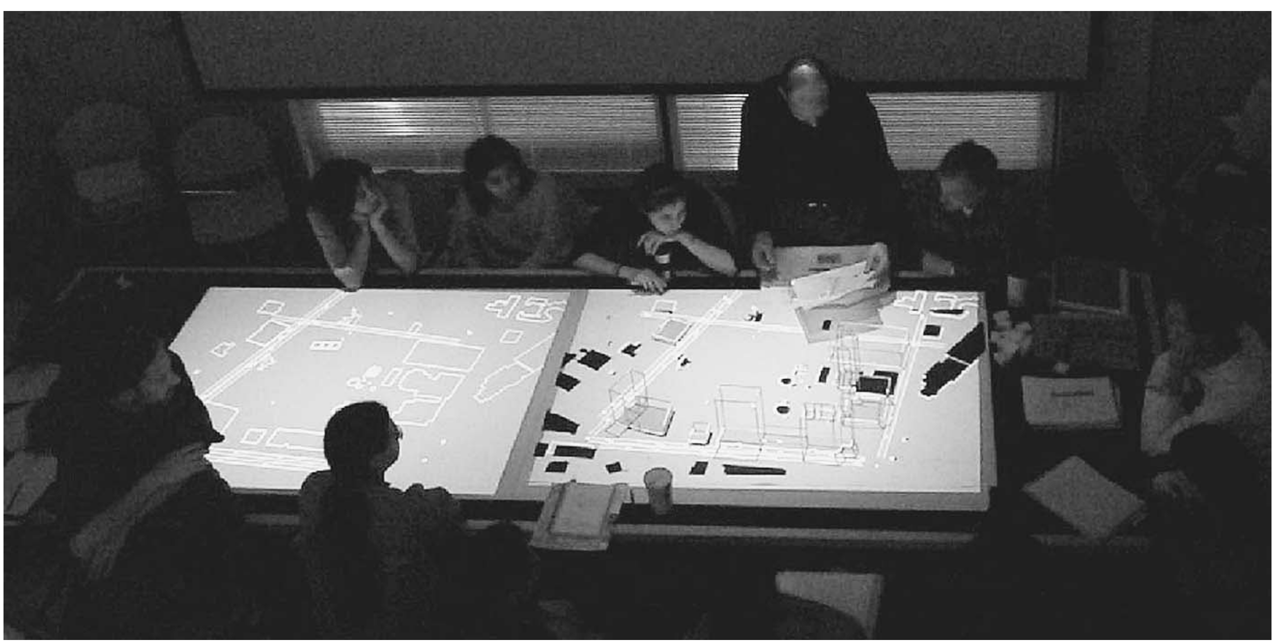

Figure 4. *The Luminous Planning Table used in a classroom setting.*

simulation, virtual reality, and the utilization of the World Wide Web as a delivery system opened new possibilities in the late 1990s. Widely available programs allowed the creation of realistic shapes and surfaces and have resulted in the creation of various large-scale urban simulations, most notably the City Simulator of the University of California, Los Angeles. This system combines three-dimensional models with aerial photographs and street-level video to create an urban model that can then be used for interactive fly, drive, and walk-through demonstrations.[1]

While urban simulation programs have made steady progress in the past decade, they are still confined to two-dimensional flat interfaces. As such, they leave much to be desired. In 1981, the Xerox Star workstation set the stage for the first generation of Graphic User Interface establishing the “desktop metaphor,” which simulated an interaction between a working page on a bit-mapped screen, a pointing device (mouse), windows, and icons. It also set several important Human Computer Interface (HCI) principles: the “seeing and pointing” and “what you see is what you get” (Ishii and Ullmer 1997). The Apple Macintosh and later Microsoft Windows rendered this style of computer user interface obsolete. Still, in the early 1990s, a few researchers continued to call for new computing visions. In an article titled “The Computer for the 21st Century,” Mark Weiser (1991) stated his vision of “ubiquitous computing,” arguing for a different paradigm of HCI that renders computers “transparent” and tailors their interface to each unique task.

▶ New Paradigms in Digital User Interfaces

Augmented Reality (AR)

One of the areas of research that investigates the integration of the real world and computational media is Computer-Augmented Environments or AR (Wellner 1993; Mackay and Pagani 1994). The most common AR approach is the visual overlay of digital information onto real-world imagery with see-through, head-mounted (or hand-held) display devices or video projections. Several researchers have tried to create AR-based urban planning support systems. The Envisionment and Discovery Collaboratory of the University of Colorado at Boulder focuses on the creation of shared understanding through collaborative design using an augmented table and wall-size screen. By using a horizontal electronic whiteboard, participants work around a table incrementally creating a shared model of the problem. They interact with computer simulations through the movement of physical objects, which are recognized by means of the touch-sensitive projection surface. This placement of the objects becomes the medium through which the stakeholders can collaboratively evaluate and prescribe changes in their efforts to frame and resolve a problem. On a second vertical electronic whiteboard, the information of the problem at hand is relayed for all to see (Arias et al. 2000).

BUILT-IT, of the Swiss Federal Institute of Technology and the Technical University at Eindhoven, demonstrated the use of small Lego-like bricks to control the position and orientation of virtual buildings on a large computer screen. Groups of persons seated around a table interact with objects in a virtual scene. A plan view of the scene is projected onto the table where object manipulation takes place. A perspective view is simultaneously projected on the wall. The planar interaction with bricks, however, only provides position and rotation information (Fjeld et al. 2000).

Tangible User Interfaces

At MIT’s Media Laboratory, researchers have extended the notion of ubiquitous and invisible computing by affiliating digital information to everyday physical graspable objects and environments. The Tangible User Interface’s (TUI’s) distinct approach is in its focus on graspable physical objects for input rather than by enhancing visual devices.[2] Thus, luminous digital information is integrated with tangible physical objects or, as described by William Mitchell, “biomass and infomass are intersected, in some effective combination . . . where physical actions invoke computational processes, and where computational process manifest themselves physically” (Mitchell 1999, 31-32). Mitchell further suggested that breaking the boundaries of the screen as a display area to include peripheral information is crucial in simulating the “role and character of place” (p. 37).

In the realm of urban simulation, the spanning of representational tools across the physical and digital boundary into one coherent physical space (such as on a table or wall) can enrich the design process and facilitate discourse among planners, clients, and the public. Applications of TUIs offer the first step in integrating various mediums into one space and time in a realistic and practical manner.

▶ The Luminous Planning Table

One of the most promising simulations of place projects developed by the Media Laboratory in the late 1990s was the development of the I/O bulb concept and the Urp—A Luminous-Tangible Workbench for Urban Planning and

Design. The I/O bulb was conceived as a light bulb that could be both a projecting and a collecting device, where each action (either input or output) influences the other. The prototype was constructed using commercially available digital projectors and tiny video cameras positioned above a table. Optically tagged objects were placed on the table's surface, enabling the cameras to view them (Underkoffler and Ishii 1999). One of the results of the I/O bulb prototype experimentation was the use of the system for urban planning purposes. The following scenario describes a context for which such system could be used: Two urban planners, charged with the design of a new plaza, unroll onto a large table a map showing the portion of the city that will contain their project. They place an architectural model of one of the site's buildings onto the map. Immediately, a long shadow appears, registered precisely to the base of the model, and tracks along with it as it is moved. They bring a second building model to the table and position it on the opposite side of a large fountain from the first; it too casts an accurate shadow. "Try early morning," requests one of the planners. Her colleague places a simple clock on the map; a glowing 3 P.M. appears on the clock's face. The colleague rotates the hour hand around to 7 o'clock, and as 3 P.M. changes to a luminous 7 A.M., the shadows cast by the two models swing around from east to west. It is now apparent that in the morning, the second building is entirely shadowed by the first and will receive no direct sunlight. The urban planners decide to try moving the first building south by eighty yards and, upon doing so, can immediately see that this solution restores the second building's view of the sun. The just-moved building is now only twenty yards to the north of an east-west highway that borders the plaza on the south; one of the planners places a long roadlike strip of plastic on top of the map's representation of the highway, and tiny projected cars begin progressing at various speeds along its four lanes. The other planner brings a wand into contact with the nearby building, and the model's facade, now transformed to glass, throws a bright reflection onto the ground in addition to (but in the opposite direction from) its existing shadow. "We're blinding the oncoming rush-hour traffic for about ninety yards here at 7 A.M.," he observes. "Can we get away with a little rotation?" They rotate the building by less than five degrees and find that the effect on the sun's reflection is dramatic: it has gone from covering a long stretch of highway to running just parallel to it. The urban planners position a third building near and at an angle to the first. They deposit a wind-generating tool on the table, orienting it toward the northeast (the prevalent wind direction for the part of the city in question). Immediately, a graphical representation of the wind, flowing from southwest to northeast, is overlaid on the site; the simulation that creates the visual flow takes into account the building structures present, around which airflow is now clearly being diverted. In fact, it seems that the wind velocity between the two adjacent buildings is quite high. The planners verify this with a probelike tool, at whose tip the instantaneous speed is shown. Indeed, between the buildings the wind speed hovers at roughly twenty miles per hour. They slightly rotate the third building and can immediately see more of the wind being diverted to its other side; the flow between the two structures subsides.

▶ LPT—Applications in Urban Planning

Classroom Setting

In the spring of 2000, the LPT was installed for use in MIT's Site and Urban Systems Planning class.[3] The goals of the installation were to evaluate the LPT and to further develop its functionality based on feedback from end-users through its implementation with an actual site slated for development. The project was located at Kendall Square in Cambridge, Massachusetts, and the site-planning schemes developed for implementation were responding to an existing proposed development for the area.[4]

Working in teams of three and four, the students developed and tested various configurations using the LPT to simulate the impacts resulting from their design decisions. Through direct, hands-on manipulations carried out over numerous sessions, each group finalized its preferred plan. The final plans were then presented to an audience of professionals, developers, and guests in an interactive display using the table as the main presentation format. Other media, such as plans and hand renderings, supplemented the computer graphical output of the LPT as base information superimposed on the horizontal LPT surface and illustrative information on surrounding pin-up boards.

In the design development phase, the LPT provided a benefit over conventional digital CAD platforms by allowing students to physically model their work with immediate results. In addition, in contrast to the standard computer interface where a single user has dominance over the creative space of the screen, the ergonomics of the table allowed the entire design team to work simultaneously on a single scheme. The use of the LPT enabled the students to achieve a consensus on the design solution while accommodating the opinions of all the individuals themselves (see Figure 5).

While the students were working with the LPT, they were encouraged to openly express their experience with the table, making suggestions for improvement and pointing out

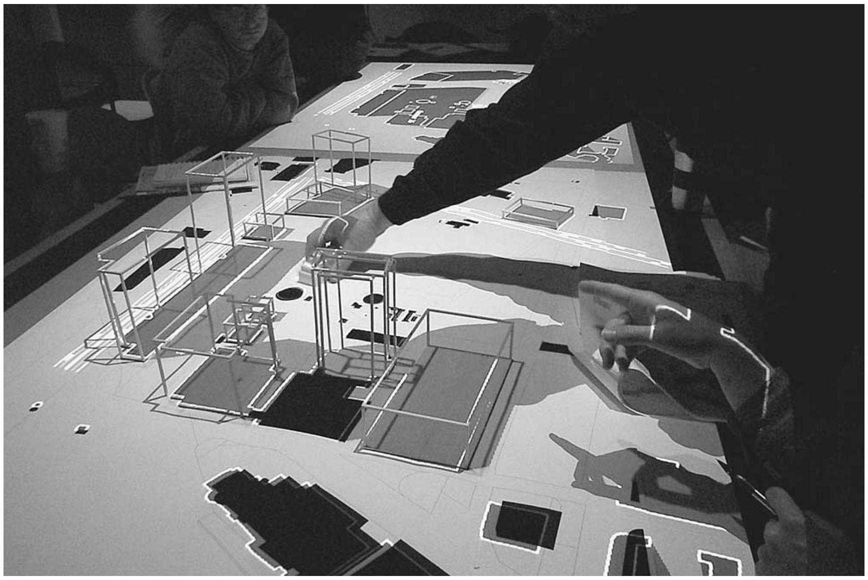

Figure 5. *Students manipulating buildings on the table's surface.*
Note: The combination of real-time digital information and physical manipulation helped considerably in reaching a group consensus as to the agreed design solution.

limitations of the table as a design tool. A questionnaire was also used to seek out reactions to the usability of the LPT that may not have been expressed in the public setting of the class. The table's most powerful function, as most noted by the users, was its ability to merge time-based digital representation with the more conventional modes of drawing and modeling. One student wrote that the LPT "highlighted aspects of the site which are normally cumbersome to analyze and was excellent for bringing the site 'to life' and showing it as a dynamic place which changes temporally through the course of day and year." Another remarked, "The table greatly facilitates decisions about building height, location and alignment with respect to sun/shade conditions and wind and helped us recognize possibilities we had previously overlooked" (see Figure 6).

Market Setting

As a result of the class project, Lyme Properties, the developer of the Kendall Square site, voiced its interest in using the table to simulate its proposal to the city of Cambridge. During the summer of 2000, a team of researchers constructed a simulation for the site and further developed the traffic and representation capabilities. Since traffic impacts resulting from new developments are a major concern for many municipalities, the LPT was equipped with the ability to graphically show and manipulate both the number of cars per hour on any given street as well as the traffic cycles at the intersections. Once constructed, the simulation provided the opportunity to view and compare various scenarios of traffic patterns and congestion dynamically. Titled "A Day in the Life of Kendall Square," the presentation simulated the various impacts generated by the proposed development on the site, such as sun, shade, wind, and traffic, from dawn until night in a seamless transition. This was the first step toward developing the LPT for presentation to the Cambridge Planning Commission, which will further test the system's ability to convey complex variables to professionals involved in planning decisions as well as to the general public (see Figures 7 and 8).

Figure 6. *The Luminous Planning Table highlighted aspects of the site that are normally cumbersome to analyze and was excellent for bringing the site to life and showing it as a dynamic place which changes temporally through the course of the day and year.*

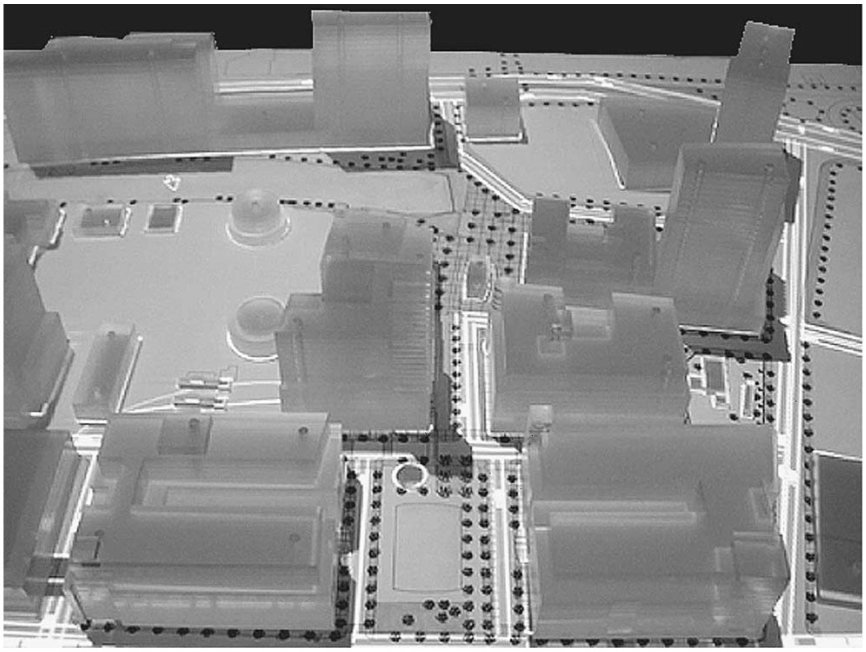

Figure 7. *A day in the life of Kendall Square.*
Note: The presentation allowed the simulation of the various impacts generated by the site (sun, shade, wind, traffic) from dawn until night in a seamless transition.

One concern in using the LPT for design development and presentation is its overemphasis of physical issues due to its inherently graphical nature. As one student noted, "Over reliance on the table could be problematic, that is, we also need to think about social, political, and economic factors we cannot show on the table. Also are the models/calculations correct? It can be misleading if they are not. Also the Table can distract from other effective presentation media drawings, etc." In other words, the emphasis on visual representation and the extensive use of reflex-based interactions—originally envisioned to be the key benefits of the LPT interface—discourage certain activities in design where deliberate and planned work is needed. The issue becomes which activities require the use of a more dynamic representation in the design process and which ones do not. Another concern is the amount of technological infrastructure required to install the LPT tool in its current form, which limits its portability, and use in design practices.

The concept underlying Luminous-tangible interactions, however, remains engaging. The proposition of giving additional meaning and animate life to ordinary inert objects is a

► Prospects and Limitations

The LPT is in the early stages of development as a fully functional platform and is in need of both technical and social design improvements. While preliminary experience shows great potential for the LPT, many limitations still exist. Future research will focus on improving the synchronization between the physical and digital models as well as exploring means of manipulation on the table's surface. A use of a magic wand will, for example, guide the audience and highlight specific areas while simulating various site noises. A video camera, in calibrated positions, will be used to superimpose a rendered CAD image on the vertical screen with the physical models on the table. The simulation of other dynamic processes such as drainage, microclimate, auditory mapping, and topography will be integrated as well as compliance of regulations such as setbacks and density.

Figure 8. *Public presentation using both conventional and tangible/luminous tools.*

cognitively powerful idea. Along with offering a missing link between the palpable and the digital, the promise of the LPT may be in shaping a plural planning process. Typically, during public planning reviews, suggestions and input cannot be immediately simulated and explored and often require repeated meetings and presentations. The LPT, on the other hand, offers a seamless I/O planning and design process. Ideas, changes, and suggestions and their resulting impacts can be seen and explored in real time, allowing the public to be better informed and involved. As with its implementation in a classroom setting, the LPT has the potential to influence not only the way technological devices are used but also has a pedagogical outcome: a new classroom format; effective communication along with physical manipulation between remote locations; and new forms of collaboration between the instructor and student, the professional and layperson, the expert and novice, and academia and the municipality.

Authors' Note: *We would like to thank Dan Chak and Zahra Kanji for their commitment to the project success. We are also grateful to the Wade Fund of the Massachusetts Institute of Technology and Lyme Properties for their financial support. Since this paper was submitted for publication the LPT interface has been improved to include landform and topographical manipulation and analysis. Please see the Illuminating Clay web site at: http://tangible.media.mit.edu/projects/IlluminatingClay/IlluminatingClay.htm*

▶ Notes

1. As part of the Virtual Los Angeles and the Virtual World Data Server projects, the University of California, Los Angeles, Department of Architecture and Urban Design is building a real-time simulation model of the entire Los Angeles basin. This model will cover an area well in excess of 10,000 square miles and will elegantly scale from satellite views of the Los Angeles basin to street-level views accurate enough to allow the signs in the windows of the shops and the graffiti on the walls to be legible. See http://www.ust.ucla.edu/ustweb/projects/downtown.html. Other projects are as follows: Urban Data Solutions constructed detailed digital models of major American cities for use by the telecom, commercial real estate, media and entertainment, security/defense, and architectural/engineering industries (http://www.u-data.com). Three-dimensional urban models remain expensive, both in time and labor, to construct. Yet advances in technology may simplify the construction of such models. New computational algorithms being developed at the Massachusetts Institute of Technology are advancing the possibility that digital urban models will be computable via the capturing of digital photographs of the environment (http://graphics.lcs.mit.edu/city/city.html).

2. See, for example, the work of the Tangibel Media Group at http://www.media.mit.edu/groups/tangible/.

3. The tool is composed of a fourteen-inch long and four by six feet wide table, with two video projectors hung from a ceiling, to overlay digital representations of onto the table surface. Two video cameras capture the images of the activities on the table. Behind the table, large vertical projection screen provides complementary 3-D view of the plan captured by a small camera. The computation is done with two Silicon Graphics Incorporated machines.

4. The ten-acre property is one of the last large development parcels in Cambridge, MA. Its former use as a coal gasification plant has left a challenging legacy of neighboring buildings that turn their backs to the site as well as adjoining vacant or underused lots. With the growth of Cambridge as an international bio-tech center, Lyme Properties (the site developers) intends to attracts a mix of start-up labs and larger established companies by providing cultural amenities, office/lab spaces, and dwelling units through a comprehensive mixed-use development.

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