Title

How can physical interfaces support group collaboration?
A study of MouseHaus Table, a physical interface in an urban context

1. Thesis Statement

This thesis uses MouseHaus Table as an example to demonstrate that tangible interaction offers advantages in collaborative design. I applied usability research methods to investigate group collaboration and analyze the communication among participants as an indicator for the quality of collaboration.

2. Abstract

MouseHaus Table is a physical interface for urban pedestrian movement simulation in a group setting. The interface includes a video camera, colored paper, scissors, and a table with a projected display. With a registration process, users can employ everyday objects such as color paper cutouts to represent building type, size, and location as input for the pedestrian movement simulation program. MouseHaus Table employs 1 of 2 interfaces – multiple standard mice (SM) and colored paper and scissor (PS). Groups of 3 will complete two tasks using the SM and the PS interface. Verbal and gesture group interaction during the task will be recorded. Participants' evaluations will be determined using a post-task questionnaire. The hypothesis that the PS interface will evoke better group interaction than the SM interfaces will be examined.

3. Introduction

Land-use planning and urban design decisions today must involve community participation. However, insufficient information and understanding among different collaborating stakeholders (such as development sponsors, their opponents, public officers, and community members) often result in problems and conflicts. Providing urban information visualization for public participation may improve the quality of the design process and enable the community to express design criteria and alternatives that designers might not anticipate. Interactive simulation can offer powerful tools to facilitate this discussion. Along these lines, MouseHaus Table provides a multi-user environment to engage discussion in the urban design context. MouseHaus Table provides a simple pedestrian movement simulation program to the complexity of urban design process. Its physical interface enables participants without previous computer experience to interact with the simulation.

The concept of physical interface follows a tradition of participatory design practice that became popular in the 1960s and 1970s. In this tradition, the design process was carried out with physical materials- designers, acting as consultants to a community group, would construct scale models from cardboard, foam-core, and wood and utilize physical materials to facilitate methods such as cognitive mapping (by drawing maps on paper or using paper cutouts to represent individual identification in a collaborative role play exercise) in the design process [10]. Community group stakeholders would be encouraged to manipulate these materials and to use them to comment on the relative merits of design and to propose new alternatives.

Recently, the concept of tangible user interfaces has become an active area of human computer interaction (HCI) research. In a tangible user interface, a computer system detects a user's manipulation of physical objects and provides responsive feedback. The MouseHaus Table physical interface, using everyday objects in the design process, is a proof of concept prototype of a tangible user interface for collaborative design. However, unlike many other tangible interaction projects, MouseHaus Table enables users to employ ordinary materials as the interface. Users register various building types by showing objects to the system under the camera and then use the objects to construct the layout for simulation. MouseHaus Table bridges physical object manipulation, group activity, and computer simulation of pedestrian behavior.

The main concept of the MouseHaus Table physical interface is to leverage from users' everyday knowledge. In order to understand how group collaboration can benefit from physical interfaces, I apply usability research methods to the evaluation of MouseHaus Table. I conducted three user interviews, a participatory observation of the preparation for the King Street Station Design Charrette visioning tool, and a behavior observation in the charrette. I further design a two-treatment experiment to test the difference between multiple mice and paper & scissors interface.

A preliminary usability test of one wireless mouse verse paper interface shows that greater group interaction resulted when using the MouseHaus table with paper and scissors as input devices than using MouseHaus Table with a mouse input.

4. System Architecture

In order to engage the discussion in the urban context, I developed a working prototype for a multi-user collaborative environment, MouseHaus Table and implemented the concept using everyday objects as interface. MouseHause Table has three components: (1) hardware setup - a table with an embedded projection screen and a video camera 3 feet above the table to capture the image of the desktop, (2) the MouseHaus pedestrian simulation program, and (3) a physical interface – two image processing programs, a Physical Objects Register and an Object Detector, to register objects by color and recognize object types and locations on the table. Each of these three components is described in the following paragraphs.

4.1 Hardware Setup

The hardware setup for MouseHaus Table consists of a custom-made table with a rear projection screen, a video camera and projector. I implemented the system with common and inexpensive computer peripherals that can easily be made available at any community meeting. We wanted to make MouseHaus Table easy to setup and portable.

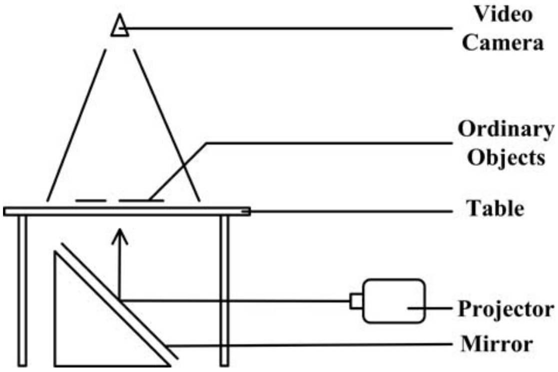

Figure 1 Hardware Setup

The table surface is made of wood with a translucent plastic surface in the center. This tabletop is where users place pieces of colored paper to indicate or propose the location of urban elements such as buildings and parks. A mirror mounted under the table reflects the image from the projector to the translucent plastic display screen. Figure 1 shows the hardware setup and Figure 2 shows the interaction of MouseHaus Table. The screen of the MouseHaus simulation that was originally displayed on a computer monitor is displayed on the MouseHaus Table. The captured image from the camera above the table is sent to the image processing program (described below) to identify physical object placements and create objects in the MouseHaus simulation program. Collaborating stakeholders thus can place physical objects on the table as input and view the corresponding simulation results overlaid on the same table.

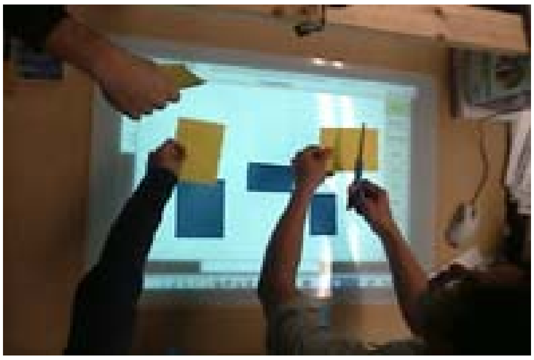

Figure 2 Interactions in the MouseHaus Table

4.2 The MouseHaus Pedestrian Behavior Simulation

MouseHaus is a simple pedestrian simulation program implemented in Java by Therakomen [17]. The MouseHaus pedestrian simulation program was inspired by a traditional Thai-Chinese toy, "Mouse Palace". Mouse Palace consists of a set of wooden house-like blocks for children to construct an environment to observe the behavior of mice. MouseHaus is hence a simulation program to enable designers to project the impact of a physical environment on pedestrian behavior.

In the MouseHaus simulation, pedestrian movement follows the concept of artificial life. Each "Mouse" agent has both an internal and external state. For example, when the simulation starts, one type of agent in this model selects a random destination as the initial internal state. At each time step, the agent accumulates external stimuli as it travel through the urban layout users have constructed and decides on a course of action - to move forward, turn, pass or stop. The combination of all the individual motion paths produces a pedestrian pattern. MouseHaus simplified the complexity of human behavior in the agent simulation. Hence the name of the agent in the simulation is "Mouse" rather than "pedestrian".

The color of each pixel passed by a pedestrian agent will turn from green to yellow, to orange- the more the pedestrian agent passes through a certain point, the more saturated the color becomes. Figure 3 shows an example of the pedestrian movement pattern. In the picture, the saturated color is where the pedestrian agent tends to gather and the white rectangle indicates where the orange color emerges.

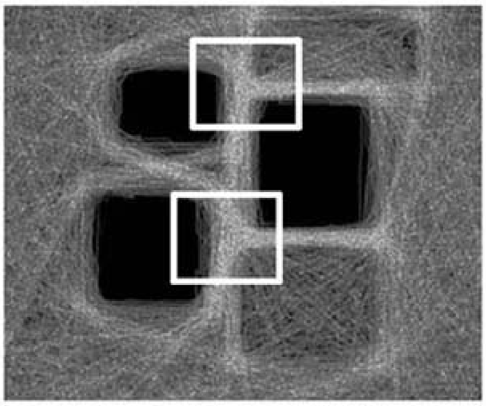

Figure 3 A sample pedestrian movement pattern

4.3 MouseHaus Table

MouseHaus Table is a physical interface for the MouseHaus pedestrian simulation. The physical interface is driven by an image processing program employing Java Media Framework to capture and analyze an image. We wrote a Java application to capture individual frames from the real time camera stream and process the image. The image processing program has two parts: a physical objects register and an object detector.

4.3.1 Physical Objects Register

MouseHaus Table uses color to distinguish different objects from one another. Users must put the objects that they want to use as urban elements under the video camera and the Physical Objects Register program will complete the registration process. Different colored objects are then associated with different elements types in the MouseHaus simulation.

With the registration process, people can choose the most appropriate objects for their presentation in accordance with their everyday knowledge such as having green paper represent a park in an urban space.

4.3.2 Object Detector

When users place previously registered objects on the table, the object detector program scans the screen image from the top left to lower right, row by row. Each time the object detector finds a non-empty pixel, it calls a flood function to determine the boundary box of adjacent pixels of same color. Figure 4 shows the searching path of a black object and a grey object. The boundary box searching process finds the diagonal top left pixel and bottom right pixels and draws the rectangle.

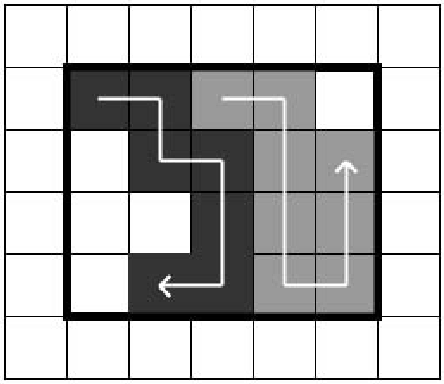

Figure 4 Searching paths in the Object Detector program

Based on the physical objects register and the object detector, the arrangement of the colored paper on the MouseHaus Table is then represented as a street layout for the simulation program. The mapping between urban block and tangible user interface is accomplished through the color image recognition.

5. Preparation Work

5.1 Preliminary Usability Test

5.1.1 Result of Preliminary Test

To observer how MouseHaus Table enables users to collaboratively discuss the impact of street layout on pedestrian flow with everyday objects as interface, I conducted a preliminary usability testing. The focus of the test was to find out how the application affects user collaborative behavior. Thus, I created three tasks: hands-on task for MouseHaus Table, a paper interface task, and a traditional mouse interface task. All tasks were carried out on the table. I also administered post-test questionnaires and conducted user interviews that addressed the participants feeling on these two interfaces.

The first task was designed to familiarize participants with the system. Participants were given a print-out pattern and asked to construct the layout pattern on the table. The second and third task started with the street layout of the first task. With the existing blocks in the first task, the second task was to decrease the overall pedestrian density using a paper and scissors interface (PS) and the third task was to increase the overall density using a standard mouse interface (SM). As I mentioned in System

Architecture, an even green color in the pedestrian pattern indicates a low density level while yellow or orange indicates a higher density level. Participants repeat the second and third task three times in order to get several design alternatives and then select a preferred layout at the end of each task. In the third time of using mouse interface, one participant asked to construct one more layout. Due to the preliminary setup, I allowed them to try the system with mouse one more time. However, in order to balance the trial numbers I discard the fourth mouse trial. Thus, I have results named Paper and Scissors Trial No. 1-3 (PS1-PS3) and Standard Mouse Trial No.1-3 (SM1-SM3).

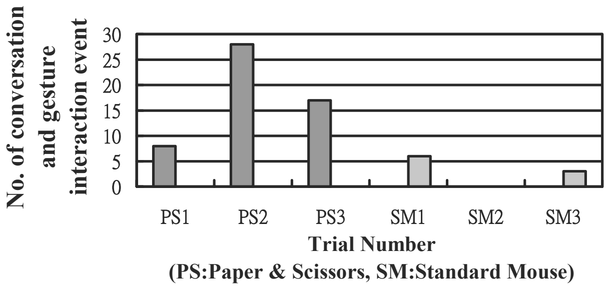

Figure 5: Number of conversation and gesture interaction events among participants

I recruited three participants for the preliminary test: two architecture graduate students and one undergraduate with an architecture minor. Results showed that people had more conversation and gesture interaction with the paper interface than in the mouse interface (Figure 5). Moreover, in SM2, one person seemed to dominate the change of layout while the other two participants acted as bystanders. Table1 shows that the number of layout changes is higher in the paper interface. For example, participant A did not engage any layout arrangement in SM2, and SM3, but he changed the layout 11 times in PS3. I did not report any statistical significance due to the small sample.

Table1 Number of layout change

ID	Paper & Scissors			Standard Mouse		
	PS1	PS2	PS3	SM1	SM2	SM3
A	9	9	7	6	0	0
B	14	14	17	9	0	7
C	7	7	17	0	7	5

The post-test questionnaire revealed that the paper and table input makes it slightly easier to contribute to the layout and facilitates more group interaction. When using the mouse, participants felt that one person should be in charge of the layout configuration.

5.1.2 Discussion of the preliminary test

Although the quantitative data from figure 5 and table 1 suggested that people had more conversation and gesture interaction in the paper trial, these numbers are not sufficient to represent the span of interactions that occur between people. I plan to make changes to the questionnaire based on Burgoon's interactivity principle research [1] and more details are included in Related Work.

I also found from user interviews that participant appreciated the paper and table interaction with the computer simulation. Two of the participants mentioned that the paper interface created a "dialogue" between humans and computer. They emphasized the value of hand movement in the design process. They described how traditional user interface such as a pop-up window and the use of the mouse device affected the interaction. They enjoyed the table and paper interaction and used the terms such as "you can not concentrate" and "you have to change your mind" to described how mouse and screen interaction distracted their thinking process.

6. Related Work

6.1 Tangible User Interface

A tabletop workspace has long been an appealing topic for HCI researchers. DigitalDesk, Tangible Geospace, metaDESK, Sensetable, etc. are a few examples that apply either a computer-vision-based approach or a sensor-embedded presentation [11, 13, 18, 21].

DigitalDesk is a system that merges the physical and electronic desktop together. It has a projector and a camera with computer and image processing program. it allows users to interact with computer program via their finger or pen. When users put documents on the desk, the camera captures certain region selected by users in the document. After the data in this region is recognized by the computer, users can use the data in calculator application.

Projects such as Envisionment and Discovery Collaboratory (EDC), Urp, Illuminating Clay, further applied the tabletop digital media into an urban design or landscape planning context [5, 14, 20]. In the EDC project, Eden et al. use an electronic whiteboard and an antenna-embedded tabletop as workspaces for design collaboration. The electronic whiteboard has a single-user limitation similar to a standard mouse. In the antenna-embedded board, tokens provided for information gathering must be specially prepared. These token activate the display of a walking-distance circle for resident to evaluate where a bus stop should be placed. Urp provides shadow casting, wind simulation and other feedback as system functions and uses physical objects to activate these functions. Illuminating Clay provides moist porcelain clay for users to shape terrain while a laser scanner mounted on the ceiling captures the geometry of the model and processes data to project feedback images back on the clay model.

The physical interaction of MouseHaus Table is similar to DigitalDesk. A video camera is used to capture physical input from users and overlaying computer generated feedback onto the table with a projector. However, unlike other tangible user interface projects, MouseHaus Table works with ordinary objects that don't require advance preparation.

EDC depends on pre-configured coils in the token. To recognize the physical objects in Urp, a pattern of actual colored dots must be affixed to each object. In the Illuminating Clay, users can form landscape models and see images cast back onto the model, but the porcelain clay and laser scanner are both specific and costly requirements. Unlike other tangible user interface projects having to depend on pre-configured gadgets, MouseHaus Table enables users to register everyday objects and assign them specific meanings for later application use. There is no need for users to have any professional skill to work with the dynamic digital simulation.

6.2 Computer Supported Collaborative Work

The notion of computers might be useful to support group work was appreciated by early technology visionaries. In 1945, Bush hypothesized an ordinary desktop system, Memex, as a new form of encyclopedias [3]. With "a mesh of associative trails", Memex linked knowledge and benefited societal group collaboration. In 1968, Engelbart demonstrated the concepts of collaborative annotation at the Fall Joint Computer Conference in San Francisco [7]. Engelbart also proposed a series of tools to support group collaboration such as teleconferencing at separated display terminals, a file sharing mechanism, electronic mail, etc. Engelbart saw computer as providing an important medium for communication.

After Bush and Engelbart, many collaborative researches pursued computer support collaborative work, but major investments are focused on supporting people that are working apart from each other. For example, Grudin published papers discussing groupware development [8, 9], but examples he selected are emphasized on information processing and communication activities in an organization wide shared environment. In the most recent Proceedings of the 2002 ACM conference on Computer supported cooperative work (CSCW), almost all papers are focused on peer-to-peer, instant messaging, co-location and shared space concepts.

However, supporting people that work together require different knowledge from distributed environment. In the early 1990s, some researchers studied group decision support system and integrated systems into electronic meeting rooms. This kind of system often included networked workstations, a large display controlled by the computer, and audio/video equipments. Colab, Project Nick, and Liveboard are all examples aimed to augment the meeting process [4, 6, 15]. Although these projects summarized findings in their development and proposed design guidelines, their system input are more similar to distributed environment than interaction around the table. Moreover, these projects seldom have evaluation.

Furthering the electronic meeting rooms, Stewart et al. proposed Single Display Groupware as a model for co-present collaboration [16]. This model supports computer programs to enable users to interactive with one shared computer simultaneously via multiply input devices. Based on the concept, Stewart et al. developed a collaborative drawing application and conducted a usability testing by assigning one mouse or two mice to two participants. In the post evaluation, Stewart et al. found that participants thought that it was easiest and more fun to complete the drawing task in the two device condition.

6.3 Communication

Stewart et al. cited McGrath and Hollingshead's empirical studies to list three variables that can be measured as how technology impacts group interaction [16]. These three variables include task performance, user reaction, and member relation. In order to evaluate the group interaction of MouseHaus Table, these three variables are applicable.

In the research of computer mediated communication, Burgoon et al. compared five communication interface conditions: unmediated face-to-face, mediated face-to-face (proximal text), distributed (text), distributed audio-conferencing, and distributed video-conferencing [1]. The way Burgoon et al defined the dependent variables is based on interactivity measures, social judgment measures, and task outcome measures. Interactivity measures include perceived involvement, mutuality, interaction ease, and assessments of the expectedness and desirability of the partner's interaction behavior. Social judgment measures are task attraction, four dimensions of credibility, dominance, and utility. Task outcome measures are decision quality and influence.

McGrath and Hollingshead's and Burgoon et al's research both addressed task performance. However, MouseHaus Table is at prototype stage and the embedded simulation is not applicable in real prediction. Measuring the task performance is not critical. The evaluation for group interaction in MouseHaus Table focuses only on user reaction and user relation. The measures in Borgoon's study are integrated into the post-test questionnaire.

7. Methodology

7.1 Usability Testing

Usability research is widely practiced in the industry to assess the use of a product. Usability research methods include usability testing, contextual inquiry, low-fidelity prototyping and heuristic evaluation. The most common method is usability testing. Although a formal usability testing is best employed when a product is near the end of development cycle, usability testing is still applicable for a less finished product.

Usability testing is often done in the laboratory. Participants are required to use the product to complete a set of given tasks. Participants are often asked to use a 'thinking aloud' protocol to vocally describe their opinions as they do the tasks. The usability researcher observes how participants use the product and takes notes to record what occurs.. The researcher records the sequence of actions, the time it takes to complete a task and the number of errors made by the user. Often, test sessions are recorded on videotape in order to review the session at a later time. Participants also fill out pre- and post-test questionnaires to confirm their behaviors that were observed during the test. For example, a questionnaire might ask participants about their frustration, confusion, and difficulty as well as enjoyment. Sometimes, questionnaires also measure amount of learning involved in the process. All of the data are used to assess the problems and recommend improvements to the product being tested.

I conducted a preliminary usability testing as the preparation study. The test focuses on how people interact with physical interface in group collaboration. The task is the same with the experiment design described in the following paragraphs. The main observation is reported in Preparation Study. Usability testing techniques are also integrated into later experimental procedure.

7.2 Experimental Design

7.2.1 Task

The tasks for the experiment are the same with Preparation Work, but the condition for the standard mouse trial was changed. In the preliminary testing, I compared paper & scissor with one standard mouse. However, it is difficult to make sure the effect is form the input channel (single-user interface vs. multi-user interface) or the different interface (paper & scissor vs. standard mouse). Thus, in the following experiment, I will use multiple mice in the standard mouse trial. In the paper and scissor trail, I will also provide same number pairs of scissors as the number of mice.

7.2.2 Participants

Participants will be students in the Department of Architecture or Urban Design and Planning at the University of Washington. The preliminary experiment will recruit 4 groups of three people.

Participants inevitably differ from one another and their response can be simply a fact of life that participants differ greatly. I will apply within-subject designs that assigning the same participant in each condition. Thus the difference among participants can be removed from error. The order of the second task and third task is counterbalanced. Table 2 shows the assignment strategy.

Table 2 Task Assignment

	Task 1	Task 2	Task 3
Group 1	PS	PS	SM
Group 2	PS	SM	PS
Group 3	PS	PS	SM
Group 4	PS	SM	PS

7.2.3 Data Analysis

In the preliminary testing, I recorded the group interaction and counted for the verbal and gesture interaction events happened in the group. However, in contrast to most communication researches [1], the analysis was too simplified and might lack of significance. Instead of further adopting a formal communication analytic method, I select # items from Burgoon and Hale's questionnaire of relational communication research as measures to evaluate user reaction and user relation [2]. The hypothesis- whether physical interface increase interactivity will be tested by comparing the paper & scissors interface and the standard mouse interface.

8. Schedule

April 20/2003	Testing for Rear projection/Front projection
April 30/2003	Introduction
May 15/2003	Related Work
	1. Tangible User Interface
	2. CSCW
	3. Communication
May 31/2003	System Architecture
	4. MouseHaus Pedestrian Behavior Simulation
	5. MouseHause Table
	2a. Physical Object Register
	2b. Object Detector
May 31/2003	Experiment
June 30/2003	Related Works
	Methodology
	1. Usability Testing
	2. Experimental Design
June 30/2003	Data Analysis
	Result
July 10/2003	Conclusion
	Abstract

Reference and Annotative Bibliography

1. Burgoon, J. K., Bonito, J. A., Ramirez, A. Jr., Dunbar, N. E., Kam, K., & Fischer J. (2002). Testing the Interactivity Principle: Effects of Mediation, Propinquity, and Verbal and Nonverbal Modalities in Interpersonal Interaction. Journal of Communication 52, pp. 657-677.
2. Burgoon, J. K., & Hale, J. L. (1987) Validation and measurement of the fundamental themes of relational communication. *Communication Monographs,* 54, pp. 19-41
3. Bush, V. (1945) As We May Think. *Atlantic Magazine*, 176(1), pp. 101-108
4. Cook, P., Ellis, C., Graf, M., Rein, G., & Smith, T. (1987) Project Nick: meetings augmentation and analysis. ACM Transactions on Information Systems (TOIS), Vo5, Issue 2, pp. 132-146.
5. Eden, H., Hornecker E., and Fischer, G. (2002). Multilevel Design and Role Play: Experiences in Assessing Support for Neighborhood Participation in Design. In *Proceedings of Designing Interactive Systems (DIS '02)*. ACM

This Envisionment and Discovery Collaboratory (EDC) project uses an electronic whiteboard and an antenna-embedded tabletop as workspaces for design collaboration. The interaction of electronic whiteboard follows a single-user limitation similar to a standard mouse. In the antenna-embedded board, the tokens provided an interface to display corresponding images such as walking-distance circle form a computer program. Both interfaces were applied in a community discussion. Limitations and advantages are also addressed in this paper.

6. Elrod, S., Bruce, R., Gold, R., Goldberg, D., Halasz, F., Janssen, W., Lee, D., McCall, K., Pedersen, P., Pier, K., Tang, T., Welch B. (1992) Liveboard: a large interactive display supporting group meetings, presentations, and remote collaboration. In *Proceedings of the conference on Human factors in computing systems (CHI '92)*, ACM, pp.599-607.

This paper describes a large size wall display system. It is basically wireless digitizers (pen) and a projected screen. The pens are supported by a pen detection model which allows pens be used at some distance from the board surface. This system provides two applications: Whiteboard and SildeShow. Whiteboard is a simple paint program and SlideShow is a presentation tool providing functions such as changing slides and scrolling.

7. Engelbart, D. C., English William K. (1968). A Research Center for Augmenting Human Intellect. In *AFIPS Conference Proceedings*, Vol. 33, Fall Joint Computer Conference, pp. 395-410.
8. Grudin, J. (1988). Why CSCW applications fail: problems in the design and evaluation of organization of organizational interfaces. In *Proceedings of the 1988 ACM conference on Computer-supported cooperative work (CSCW '88)*, ACM, pp.85-93.

9. Grudin, J. (1994). Groupware and social dynamics: eight challenges for developers. *Communications of the ACM*, Vol. 37 Issue 1.

10. Hamdi, N. and Goethert R. (1997). *Action Planning for Cities: a Guide to Community Practice*, West Sussex, England: John Wiley & Son Ltd.

This book first provides a review for the traditional development theories and practices. It then introduce Action Planning in theory and tools for practice. It also addresses training and education issues such as how to design a program in the community. In the last section, it offers cases of participatory planning in use.

11. Ishii, H., & Ullmer, B., (1997). Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. In *Proceedings of the conference on Human factors in computing systems (CHI '97)*, ACM, pp.234-241.

This paper layouts the concept of making digital information accessible through the physical environment. It defines tangible user interfaces as a way to augment the real physical worlds by coupling digital information to everyday physical objects and environment. It emphasizes legibility of interface and provides metaDESK, Tangible Geospace, ambientROOM, and transBOARD as tangible interaction prototypes.

12. Jones, S. E. & LeBaron, C. D. (2002) Research on the Relationship Between Verbal and Nonverbal Communication: Emerging Integrations. *Journal of Communication*, 52, pp. 499-521.

This Paper argues for studying verbal and nonverbal message as inseparable phenomena. It summarizes a brief history of verbal-nonverbal research since the 1960s. These assumptions and strategies include channel summation, channel reliance, structural model of communication, microanalytic methods, etc. This paper also see hope for a middle ground of verbal-nonverbal communication regarding quantitative and qualitative research. It presents current verbal-nonverbal analysis by referring to the studies in the 2002 special issue of Journal of Communication.

13. Patten, J., Ishii, H., Hines, J., & Pangaro, G. (2001). Sensetable: a wireless object tracking platform for tangible user interfaces. In *Proceedings of the conference on Human factors in computing systems (CHI '01)*, ACM, pp.253-260.

This project utilizes the electromagnetic sensing technology to track pucks on the tabletop and project corresponding images on the pucks and the table. The pucks also equip adjustable dials as the modifiers. The system can be supported by computer programs such as system dynamics simulation. This paper states that the system can provide better tracking ability to computer vision based systems. In addition, this paper asserts that manipulation of physical objects, real-time feedback about the change in simulation, and affording collaboration as the advantage for tangible user interfaces.

14. Piper B., Ratti C., & Ishii, H. (2002). Hands-On Interfaces: Illuminating clay. In *Proceedings of the conference on Human factors in computing systems (CHI '02)*, ACM, pp.121-129.

This paper describes a system which has a terrain model made of a special material as the interface. Users can change the shape of terrain by hand very easily. After users reforming the terrain, a laser scanner scans the model and takes the geometry as input for embedded simulation program. Simulation feedbacks such as water flow are projected back to the model surface. It is a very convincing tabletop application for tangible user interfaces.

15. Stefik, M., Foster, G., Bobrow, D. G., Kahn K., Lanning S., & Suchman, L. (1987) Beyond the chalkboard: computer support for collaboration and problem solving in meetings. *Communications of the ACM*, v.30 n.1, pp.32-47.

16. Stewart, J., Bederson, B. B., & Druin, A. (1999). Single Display Groupware: A Model for Co-present Collaboration. In *Proceedings of the conference on Human factors in computing systems (CHI '99)*, ACM, pp.286-293.

This Paper describes Single Display Groupware (SDG) as a program allowing co-present users to interact with a shared computer via multiple input devices, but only have one display output. Based on the architecture, the authors built a collaborative drawing application for kids and conduct a 60-participant usability study by assigning one mouse or two mice to a pair of 3rd, 4th, and 5th grade students. From the post evaluation debriefing, the author found children thought that two device condition was easiest and more fun.

17. Therakomen, P. (2001). *MouseHaus.class: The experiment for Exploring Dynamic Behaviors in Urban Places*, Maser Thesis. Department of Architecture, University of Washington, United States.

Therakomen's thesis is the architecture of MouseHaus and the foundation of MouseHaus Table. In the MouseHaus simulation, pedestrian movement follows the concept of artificial life. Each "Mouse" agent has both an internal and external state. For example, when the simulation starts, one type of agent in this model selects a random destination as the initial internal state. At each time step, the agent accumulates external stimuli as it travel through the urban layout users have constructed and decides on a course of action - to move forward, turn, pass or stop. The combination of all the individual motion paths produces a pedestrian pattern.

18. Ullmer, B., & Ishii, H. (1997). The metaDesk: Models and Prototype for Tangible User Interfaces. In *Proceedings of the 10th annual ACM symposium on User interface software and technology (UIST '97)*, ACM, pp.223-232.

This paper describes a user interface platform. The design approach is borrowed from graphic user interfaces. It creates a set of physical objects manipulation to represent the graphic user interface metaphor. This mapping includes lens-window, phicon-icon, tray-menu, phandle-handle, and instrument-control. It explores physical affordances supported by users' natural expectations and build a system architecture to assist its points. The paper also discusses some interaction issues, but does not give a more general explanation.

19. Ullmer, B., Ishii, H., & Glas, D. (1998). mediaBlocks: Physical Containers, Transports, and Controls for Online Media. In *Computer Graphics Proceedings (SIGGRAPH 1998)*, ACM, pp.379-386.

    This paper presents a tangible user interface to control online media. The control system has a set of electronically tagged wooden blocks and each block is link to different function such as storing digital media, copy and paste, indexing files, etc.

20. Underkoffler, J., & Ishii, H. (1999). Urp: A Luminous Tangible Workbench for Urban Planning and Design. In *Proceedings of the conference on Human factors in computing systems (CHI '99)*, ACM, pp.386-393.

21. Wellner P. (1991) The DigitalDesk calculator: tangible manipulation on a desk top display. In *Proceedings of the 4th annual ACM symposium on User interface software and technology (UIST '91)*, ACM, pp.27-33.

    This paper describes a system that merges the physical and electronic desktop together. With projector and camera with computer and image processing program, it allows users to interact with computer program via their finger or pen. When users put documents on the desk, the camera captures certain region selected by users in the document. After the data in this region is recognized by the computer, users can use the data in calculator application.

Appendices

Appendix A. Consent form
Appendix B. Participant Profile
Appendix C. Pre-Briefing Script
Appendix D. Scenario
Appendix E. Task List
Appendix F. Post-Test Questionnaire 1 & 2
Appendix G. Post-Test Interview Sheet