Informing Architecture and Urban Modeling with Real-world Data on 3D Tangible Interfaces and Augmented Displays

ABSTRACT
The proliferation of online and digital data in our world yields unprecedented opportunities for connecting physical and digital parametric models with live data input and feedback. Tangible interfaces and augmented displays provide theatrical settings for designers to visualize real-world data and experience real-time feedback while manipulating physical and digital models on the table. This paper proposes a new approach to design workflow, where physical model and virtual model can be interconnected and informed in real-time by multiple analytical datasets and live data streams. Using 3D scanning, blob detection, and multi-touch techniques, multidimensional tangible interfaces and augmented displays presented in this paper demonstrate a powerful new approach for designing and interacting with physical models, materials, and environmental data.
1 Introduction

Cities and communities around the world are generating a vast amount of data at a rapid rate on online, mobile, and social platforms. Realtime weather and wind data, activities, movements at different places, roads, buildings and street blocks can be harvested from these public feeds and further analyzed to inform our design processes. There is an opportunity to explore a new kind of design collaboration informed by real world data from Google Maps, Twitter, Facebook, and other data sources from the cities and public websites. However, the proliferation of live data streams is rarely taken into account in early stages of design, where 80% of major design decisions are made. In order to make these decisions, parametric models and simulations are established at an early stage to enable generations of design options that can be compared against each other.

This paper proposes a novel method for collaborative design that enables tangible and gestural interactions with physical and digital models, at the same time using realtime data input and feedback projected on the table or the wall. This proposal has been tested in five projects, which generate either tangible table or augmented display prototypes for various architecture and urban design cases.

We prototyped a series of tangible table and ambient displays that synthesize real-world data about the city, the environment, forms and materials from the Web and sensors for a hands-on collaborative modeling experience. With realtime data analysis, the modelers and users of the tangible tables or ambient environments receive immediate feedback while interacting with the physical models.

2 Tangible User Interfaces and Augmented Displays in Architecture and Urban Design

In the late 1970s, John Frazer designed the grid and the Universal Constructor (Frazer 1995), building blocks that had internal circuitry and were able to be connected as a 3D structure which would respond to the users. Robert Aish prototyped the Interrogable Building Systems as a 3D input device for CAAD systems (Aish 1979).

Tangible user interfaces emerged as tabletops in the 1990s. The Bricks project (Fitzmaurice et al. 1995) was an input device with graspable user interfaces on top of a large horizontal display surface. The ActiveDesk and the metaDesk (Ishii and Ulmer 1997) were interactive surfaces to manipulate digital data between the physical and architectural objects. Along with metaDesk, ambientROOM (Ishii and Ulmer 1997) was made with ambient displays and media using daily objects and surfaces, with the aim to employ both the foreground and background of users’ attention and senses to convey information to users. URP, a tag-based luminous tangible table for urban planning (Underkoffler and Ishii 1999), was designed for designers and urban planners to gather around a simulated view of the entire urban planning stage and manipulate the positions and orientations of the building blocks on the table. However, these tabletops and ambient displays were using static objects and trackers, or building blocks that have a fixed geometry and cannot be flexibly modeled in realtime.

The only precedent of tangible interfaces which scanned a flexible 3D model and produced near realtime feedback on the physical model was the Illuminating Clay (Piper et al. 2002), which simulated sun shading, traffic, wind on a 3D landscape made of clay-like plasticine. Multiple drawbacks of the Illuminating Clay, as reported in (Piper et al. 2002), include the latency in geometry updates, low accuracy and speed, and the high cost of setting up the system (£45,000). The visual feedback projected on the table comes from a simulated environment, not from real-world data sources.

3 Setup and Methodology

Two types of tangible table setups were used for the prototypes. One was using a 3D scanning technique with a Kinect sensor (Kinect 2011); another was based on the blob detection technique used for multi-touch detection. Unlike the Illuminating Clay, our prototypes employed low-cost technology and materials to achieve a powerful and playful user experience.
In the first setup, a Kinect sensor was positioned directly above table surface, so its viewing axis was pointing at the middle of the working area (Figure 1). In this way, the center of the coordinate system was aligned with the center of the physical environment. Next to the Kinect, a short-throw projector was suspended on a rig, which was hanging above the tables. The scanning area was juxtaposed with the video-projection area, thus after correct calibration, both virtual and physical model were aligned.

The second setup utilized DSI technique (Diffused Surface Illumination). A piece of EndLightenT acrylic was inserted in the middle of the table, then infrared light emitters were injected from the edges using IR LED strips. A special tracing paper was used as a diffuser and positioned on the top. On the back, a modified PS3 EyeToy camera was positioned below the table looking up to the acrylic. Whenever fingers or objects were positioned on the surface, the camera could see blobs of light from the internal illumination.

The algorithms used for data analysis on the table vary. One of the main techniques used for data analysis and simulation of urban spaces on the table was visibility analysis. Visibility analysis has been used in architecture for calculating measures of centrality and accessibility of space. Space syntax research has found a strong relationship between spatial properties of visibility, movement potential and how cities evolve and self-organize over time. The analysis can be pre-computed in a raster for all locations of the plan. On the other hand, the analysis can be also connected with the artificial pedestrians (agents), in order to obtain and simulate more complex data and relationships. Visibility analysis was employed in three projects, wind analysis and energy simulation were used on one project, and terrain and comfort level analysis was used on another project. Since Kinect was used to scan objects or people, depth map analysis was also used to identify various users on objects.

Using Web 2.0 technology to capture online data from public APIs, Processing (Processing 2011) was used as the engine to run various data analysis. We integrated 3D point cloud scanning, realtime data analysis, contour and color projections, parametric modeling, and digital fabrication, to enable designers and users to interact live with the physical 3D models.

4 Projects

4.1 HANDS ON OFELIA BEACH

The Hands on Ofelia Beach (Figure 2) project explored the concept of interacting with a digital model through the use of tangible objects for rapid experimentation with forms and shape. By creating an interface to the digital models integrated with an environmental
Figure 2, Hands on Ofelia Beach

The installation combined depth-sensing cameras with visual projection of realtime wind and weather data to generate a simulation of environmental conditions on a surface with tangible three-dimensional building blocks. The map of Ofelia Beach (the Royal Danish Theatre’s outdoor stage and lounge area on Kvaesthusmolen in central Copenhagen) was projected on the surface with the simulation overlaid. Architects and designers could use the building blocks (made of foam, paper, or cardboard) to explore the effect of any given building design on the site in regard to local sun and wind conditions. Through careful manipulations performed on the set of blocks, users could find urban volumetric configurations that could potentially slow down or cancel the wind in the area and match the desired solar radiation exposure.

A Kinect sensor was used to scan the 3D geometry of the foam models. Volumes cut from foam scanned by the Kinect sensor were translated into a point cloud in Processing. Convex hull algorithm was used for detecting objects on the table. This allowed the height, angle and orientation of the physical volumes on the site to be accurately manipulated. Realtime weather data were streamed from weather stations in Copenhagen. This data was used to determine the effect of the building design in regards to comfort zones and the potential energy savings for cooling, heating and lighting.

The wind flow was calculated using the Navier-Stokes algorithm (Stam 2003). For this purpose the point cloud was sliced at an optional height. From the sampled points, using convex hulls algorithm, boundaries of each object was determined. The algorithm used live wind data (direction and speed) to compute the simulation, which was projected onto the table and the physical models. When the physical model was changed, the new condition was computed and the simulation was updated almost instantaneously.

Finally, the physical model captured using Kinect, was continually being streamed to the digital model in Generative Components (Generative Components 2011) giving the opportunity to record the different design stages and continue the design in a digital environment. The connection made by UbiMash enabled the point cloud to be exported and converted into 3D geometry (UbiMash 2011). Using Generative Components (GC), a live connection between the model and Ecotect was maintained to get the solar radiation and daylight analysis of the physical models on the site (Figure 2, bottom right).

Further work is required to calibrate the Kinect sensor with the projector. Further studies will involve coding for multiple 3D projections from more than one side, and optimization of the simulation codes to minimize latency during the interaction.
4.2 UPLANSIM

uPlanSim (Interactive table as a tool for planning and simulation) was a multi-touch tabletop interface with agents running in the simulated city of Copenhagen (Figure 3). The project was aimed to bring together visibility analysis of urban environments and tangible real time virtual environments as an integrated design tool.

Agent based visibility analysis can inform a designer as to how their spaces may be used and what the ‘natural’ flows of movement may be. Ideally, the design process would be coupled tightly with the analysis, enabling short design cycles and instant performance feedback. However, visibility analysis has never been available as an integral part of a CAD software package, but rather being a standalone application, e.g. UCL Depthmap (Turner 2001). One reason for this was the specific data structure needed for the analysis (i.e. a visibility graph), another was the computational expensiveness of the analysis that requires sophisticated algorithms to be feasibly implemented without any performance issues.

uPlanSim was prototyped to explore ways to overcome these impediments. It integrated aspects of the visibility analysis in real time into a design context. The virtual agents calculated a partial visual field as they moved around, incrementing a visibility value of all the pixels they have seen. The overlay of these visual fields gave, over time, an indication of how visible each location or building facade was from the typical journeys of the agents. Another measure that was derived in real time was the overlapping agent paths, showing the amount of movement in each space.

The table had multiple modes of operations, which were based on visibility analysis. Agents were mimicking pedestrian activity on the map, finding their routes using spatial information (field of vision), navigating through network of streets. The first mode displayed occupational information as brightness, where higher densities of pedestrians added intensity to the pixels. At the same time, every building facade they saw was also becoming brighter (red). When viewed in 3D, these bright red pixels appeared as rectangular volumes, signaling visual importance (and visual accessibility) of each facade.

The second mode added interaction to play. Using special crosses located on the corners of building blocks, users could change shapes of part of the urban fabric. Changes were applied by dragging the finger when on top of the cross. Utilization of this bi-directional approach allows the designer to test multiple urban scenarios during one design session.

The third mode was generative. Agents flagged most visible parts of the buildings as described earlier, and started moving parts of solid city fabric from hidden areas to more visible ones. This generative process resembled termite behaviors, as the simulated city was reshaped to create a coherent visually accessible entity.

Different modes could be triggered by pressing special buttons located on the multi-touch screen. By default, the urban scene was seen from above, as a 2D plan, but after sweeping multiple fingers through the screen, it entered the 3D mode and the model could be rotated freely in space. Dropping new attractor points for pedestrian simulation was done by a touch of a finger. Panning and zooming of the model was enabled by the multi-touch interface.

The analysis could be enriched by adding layers of real time information, such as traffic, weather data, or information on existing land use and social activities. This is feasible through hooking up the current prototype with online data sources such as Google maps, Twitter, or to GIS software.

4.3 SOCIAL CONSTRUCTS

SocialConstruct (agents of mass construction) was an agent simulation system that used real-world data from Google Maps and Twitter to inform agents’ movements across the city based on attractors (hot spots) and visibility analysis (Figure 4). The agent was building a public structure over the city space, which reflected the most traversed path, over a period of time.

There is no doubt that technical systems are influenced by social systems and that the direction of influence is bidirectional. Our society and cities around the world consist of socio-technical systems. The technology and artefacts in a city represent the technical systems, and the humans representing the social system, both affecting each other.
The idea behind the design of this tangible table workspace was to provide designers with a satisfying representation of the real world, with the ability to interact with the model and see how it responds.

Raw data from online need to be refined, processed, and analyzed before it becomes useful information. In this project, visualization and interaction played a crucial role to help the user interpreting data. We visualized agents’ movements in Copenhagen city, and with Google Maps we brought the data into a spatial context. This realtime visualization and feedback on a tangible table was based on agent behavior according to visibility. Humans find comfort in open spaces and, by default; people navigate through wide spaces. We used Twitter to provide real world hotspots in realtime as attractors for agents. Kinect was used to scan and track users’ fingers and gestures. Multi-touch navigation of the model was enabled through physical interactions on the tabletop.

The most traversed spaces created a color-coded map, constantly updating as agents passed through. At areas of high intensity movement, nodes were generated and adjusted vertically based on the updated level of intensity. These nodes were the beginning of a branching structure that grew towards the ground to create a canopy above the movement and occupied spaces. These structures became a visualization of human interaction with the city informed directly by realtime Twitter feeds.

4.4 iUBI

In our design projects, there is a need to interact with the natural and urban environment in realtime to get direct contextual information and feedback from the site. Thus, we developed a system based on microclimatic and topographical data that allowed us to define the most efficient residential areas according to comfort levels of a specific landscape terrain in terms of solar energy gains, winds and relative humidity. iUrban Bioclimatic Informer (iUBI) was conceived as a design tool for this purpose (Figure 5).

iUBI applied sustainable parametric urbanism and augmented reality to optimize the activities of new urban areas. iUBI used Kinect to scan a 3D freeform model on the table. The point clouds of the scanned model were sent to Processing and Generative Components (GC) for analysis and normalization. By changing the topography of the physical model, we obtained a different color mapping related to the optimum user activity, which was projected back on the tangible model, and finally visualized on site using a smart phone.

The data flow facilitated a loop between the physical and the digital model, informing the decision making process of the designer. This data flow took place in four different stages: 1) From physical to digital by 3D scanning with Kinect, Processing 1.2.1 and UbiMash; 2) From
raw data to information design with Generative Components (GC); 3) From the informed digital responsive model back to the tangible model; 4) From the informed GC model to the Layar 4.0.2 database in Internet for visualization in the augmented reality.

For on-site visualizations, we automated the system to export the resulting GC file from every update to an OBJ file. Then, this file was exported automatically into L3D format and uploaded to our online server using a Java code. This database fed the input system of the augmented reality software for smart phones, Layar, which enabled the on-site visualization of the digital model by geolocating it using the GPS coordinates of the real site. Using a smart phone such as an iPhone, this software allowed realtime visualization of the digital representation of the physical freeform model. This made iUBI a powerful “on site tool”.

iUBI was conceived to be used for various architectural scales, from an urban master plan, to a freeform roof of a building. The flexibility and use of parametric design software make iUBI an excellent design tool for architects.

Future directions of the research include optimization of the UbiMash and GC connection to increase the speed of the responsive system (by now 15 seconds per update). There is a need for improving the geolocalization and positioning of the digital model in the augmented reality. The moldable materials used for the tangible freeform models require further experimentation. Accuracy of the interaction with the physical model will also be improved by obtaining precise numerical values of ambient temperature, slope, orientation and specific points touched on the tangible surface.

4.5 AUGMENTED ENVIRONMENT

The Augmented Environment project (Figure 6) was an experiment for imagining an urban environment, which was informed by human factors from both the virtual and the physical realities. It combined the projected image of the cityscape, which existed as a virtual reality accessible from anywhere and anytime (thus without spatial and temporal constraints), and the kinetic canopy as the local physical reality (in a particular space and time). These realities, representing a virtual image and a responsive structure, were combined and transformed to generate reactions to contingencies of human movement, another critical factor of the city. At this stage, the realities were no longer mere static representations. They formed a constantly changing organism, a “city” as a complex hybrid of images, structures, and movements.

The kinetic physical canopy was installed over a walkway in a workshop/studio space in Copenhagen, with Kinect scanning the space and moving images of Copenhagen Central Station projected on the wall. Each factor was thus informed by the others, and reiterated itself. The scenery of Copenhagen Main Train Station, transcribed by Google Street View, updated simultaneously with the changing geometries of the canopy. The canopy changed its geometry according to human movements in space. Whenever someone walked over the space, it would be recognized by Kinect, and the program code would send the user position to the physical installation, and hence triggered movements on the canopy, and updated the Street View at the same time. The local space was defined by changing images and forms of the city and the canopy. Such dynamics, perceived as visual and haptic stimuli, were the core outcomes of this project.

The project raises some questions that have haunted the designers and architects for some time. How do we assimilate the flux of complex contingencies and unintended moments of the city within the physicality of built environment? In other words, can life and the built environment merge? How do we overcome the familiarization of our built environment? Can globalization and abstraction facilitated by the internet contribute in integrating varying forms from local and remote sites?

5 Conclusion

Architects have, for the first time, an affordable opportunity to bridge the virtual and actual, the material and immaterial. Tangible tables and augmented displays can be used to generate direct live feedback to the designers during physical and digital modeling on-site and in studio.

Projects described in this paper are attempts to push the potential of available technology to create tangible design interfaces in the context of urban design. We are convinced that currently only a small percent of this potential is being used in everyday design practice, although
components for building such environments are freely available (open source software and easily accessible hardware). Working prototypes of these new design tools have to be explored further in the next iterations to provoke creative discussions on this subject.

Furthermore, a number of future works have been noted in each project. The importance of realtime feedback must not be underestimated. As shown by the ‘Hands on Ofelia’s Beach’ installation, full weather information can be utilized during the simulation, thus depicting the model of the city almost “as is” in reality in any given moment. Other factors, such as pedestrian encounters can be included in socialconstructs’, making it very close to real world states. Tapping into actual data streams becomes a very important factor for understanding the city’s mechanisms and behavioral patterns, which must be taken into account when investigating properties of the city as a system.

Also, collaborative qualities of those prototyped work environments are essential for the effectiveness of such tools. The entire idea of the table is that it should allow viewing and manipulation of spatial models/markers by many users. Some effort was made to make it easy for non-expert users, for example by enabling simple buttons on the multi-touch screen, or adding quick gestures for 3D model rotation and zooming.

Further investigations planned will include multiple gesture recognition for better navigation and user inputs. The use of multiple Kinect sensors and multiple projectors is envisioned as this can lead to a full 3D virtual connection with larger objects or space and enable seamless interaction between the actual building site, modeling workshop and studio.

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References


