

LUDI: A CONCURRENT PHYSICAL AND DIGITAL MODELING ENVIRONMENT

LU HAN¹ and DANIEL CARDOSO LLACH²

^{1,2}*Carnegie Mellon University*

¹*luhan9061@gmail.com* ²*dcardoso@cmu.edu*

Abstract. This paper explores the potential of a concurrent physical and digital modeling environment. We describe a prototype for a novel design modeling interface where users can take advantage of the affordances of both physical and digital modeling environments, and work back and forth between the two. Using Processing, along with the Kinect depth sensor, the system uses depth data read from a physical modeling space to produce an enhanced digital representation in real time. Users can design by moving and stacking wooden blocks in a physical space, which is represented (and enhanced) digitally as a “voxel space,” which can in turn be edited digitally. The result is a proof-of-concept concurrent physical and digital modeling environment combining design affordances specific to each media: the physical space offers tactile and embodied forms of design inter-action, and the digital space offers parametric editing capabilities, along with the capacity to view the modeling space from different perspectives, and perform basic analyses on designs. Following a brief review of experimental computational and tangible interaction design interfaces, the paper discusses the system’s implementation, its limitations, and future steps.

Keywords. Computational Design; Processing; Concurrent Modeling Environment; Tangible Interaction.

1. Introduction

We propose that physical objects may serve as interfaces to their own digital representations in a modeling environment that combines the capacities of both physical and digital media. Useful features of digital modeling tools include drawing accuracy, the encapsulation of data within different components, the capacity to create realistic renderings through texture mapping, performance and contextual simulation, navigation from different views on the same screen, saving and preserving data, parametric flexibility, among others (Fukuda, Tomohiro, et al. 9). A key strength of physical models in design is that users can touch them directly. The shape and material qualities of graspable objects arouse our natural intuition, and our desire to touch and play (Papert, “Constructionism”). Further, physical models allow for multiple interactions at the same time, and can help to quickly and more accurately communicate scaling and spatial concepts (Sun, Lei, et al 28).

T. Fukuda, W. Huang, P. Janssen, K. Crolla, S. Alhadidi (eds.), *Learning, Adapting and Prototyping, Proceedings of the 23rd International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2018*, Volume 1, 515-523. © 2018 and published by the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) in Hong Kong.

While the benefits of both physical and digital modeling can help to complement the other's shortcomings, the workflow between them is often segmented (Fukuda, Tomohiro, et al. 9). Prior work addressing this area include configuring a robotic system as an interactive design partner operating on a "chaotic" micro-world of cubes (Nicholas Negroponte's SEEK); coupling physical objects or 'interactors' with digital interfaces to present useful information (Underkoffler, Ishii, "Urp."); to design (Viny, Dabholkar, and Cardoso Llach); or to bring the fluidity and precision of digital representations to shape-changing physical artifacts (Follmer, Leithinger, Olwal, Hogge, Ishii, "inform"). Similarly, researchers have explored synchronized modeling processes where digital representations can be quickly materialized through a system of modular rods (Fukuda, Tomohiro, et al. 9).

In contrast with these approaches, our research asks how a low-fidelity modeling environment may enable concurrent design across physical and digital media. Two practical goals guided this exploration concerning our system:

- Users shall be able to design by open-endedly configuring and reconfiguring physical objects;
- The system shall offer a constantly-updating digital representation of the physical modeling environment enabling users to refine, change, or evaluate aspects of the design.

For example, the proposed system would enable a user to physically reconfigure a set of physical components and then parametrically edit it, or perform basic analysis on it, in the digital environment. By enriching digital editability with tangible interaction, our approach echoes constructionist ideas about embodied cognition (Papert, "Constructionism"), including playful kits for design and education such as Froebel's gifts (Provenzo Jr. 87).

2. Methods

We chose a simple design vocabulary of 2-inch x 2-inch wooden cubes, which offer countless possibilities for rearrangements. The cubes are arranged in a flat 20-inch x 20-inch x 20-inch gridded workspace equipped with a Microsoft Kinect sensor, which tracks their position. Using the Processing programming language, we wrote software that reads the Kinect's depth sensor data and reconstructs the physical workspace as a digital voxel-space (Figure 1). Similar to a pixel, which has X and Y coordinates, a voxel has X, Y and Z coordinates. By mapping data points to virtual voxel points, the workspace can be visualized and manipulated computationally in real time.

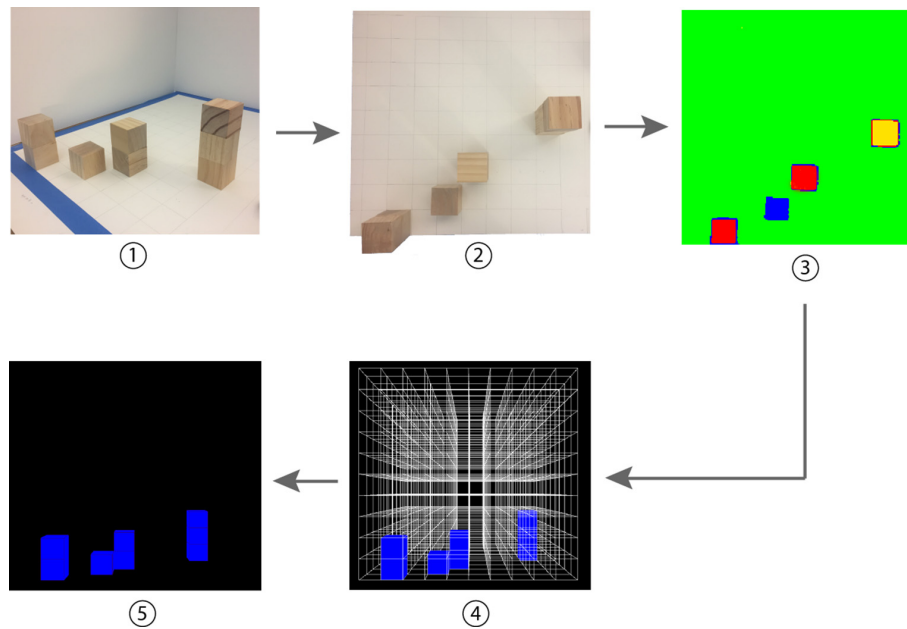


Figure 1. Depth to Voxel - Mapping Process, showing 1) Cubes in physical space; 2) Top view of cubes from Kinect's perspective; 3) Kinect's depth data as represented by color; 4) Boxes are drawn inferred from depth data in voxel space; and 5) Digital representations of cubes in physical space.

The Kinect sensor is fixed three feet above the workspace (see Figure 2). Its viewport is cropped to an evenly gridded modeling space that fits exactly a matrix of 10 x 10 x 10 2-inch cubes. The software parses the Kinect depth data and - based on the height of the tallest surveyed point - infers the presence of cubes at each point in the 3-D matrix. Based on this evaluation, the drawing space turns each voxel on or off, offering a real-time representation of the workspace.

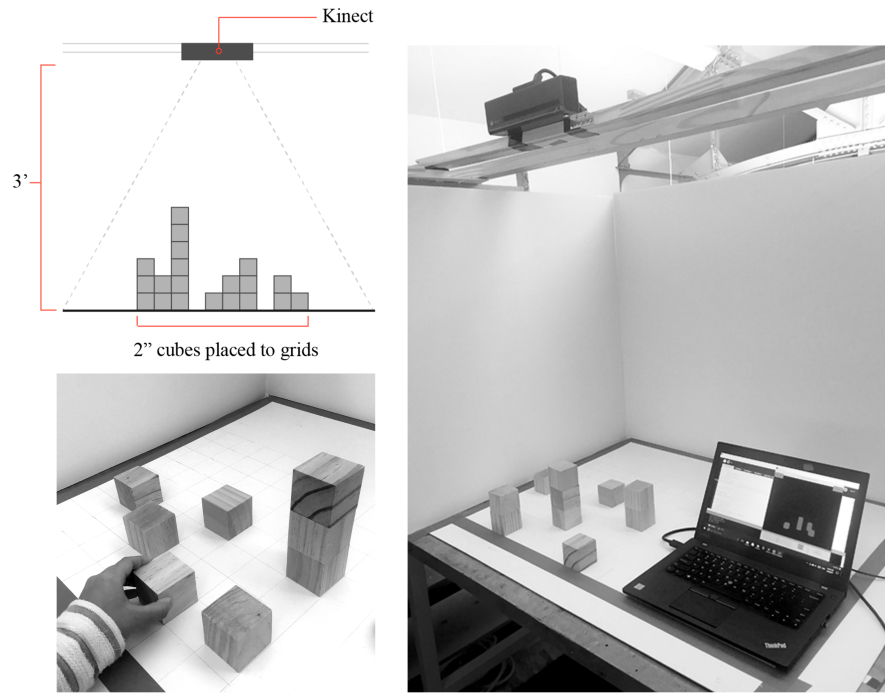


Figure 2. Ludi's physical workspace.

3. Graphical User Interface and Viewports

A graphical user interface (Figure 3) offers users various features including model viewports, basic shape editing, a “save” feature, and visual analysis. The system's GUI was created with the G4P library in Processing. Users can rotate the scene around the X, Y, and Z axis in the main viewport. Further, users have the option to see the plan view and left, right, front and back elevations in other viewports (Figure 4). The brightness of the color in the plan and elevations indicate how close or far away it is from the view of the “camera” - the brighter the color, the closer the object from that viewpoint. These different viewports are updated in real time as the user interacts with the physical cubes.

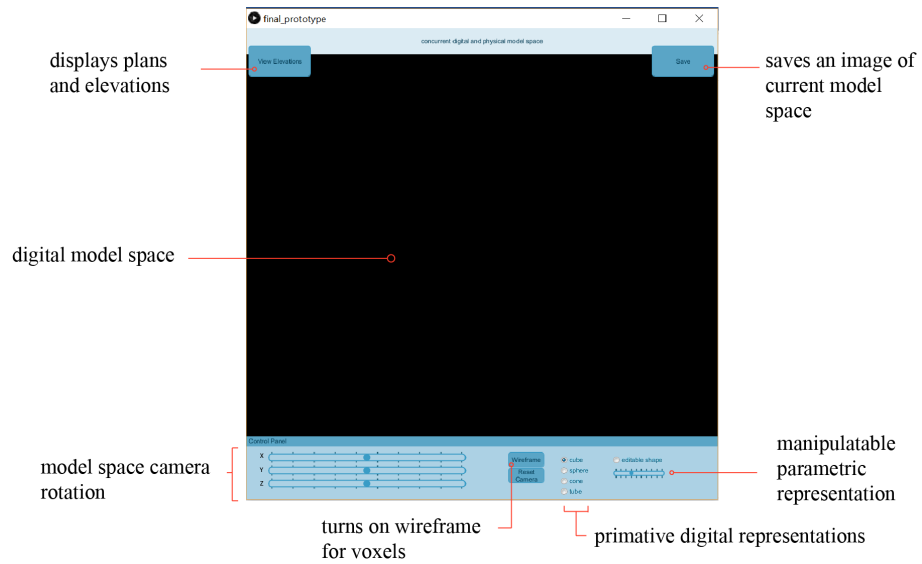


Figure 3. Ludi's graphical user interface.

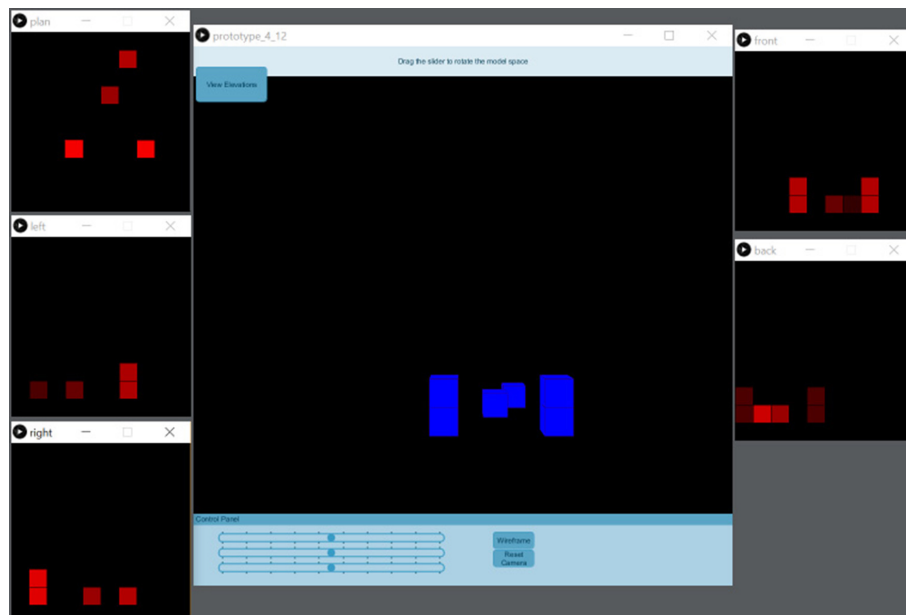


Figure 4. Multiple viewports displaying plan and elevations.

4. Editing Geometry

Building on the idea that users can work back and forth between the two media -playing around with the configuration of the cubes in physical space, while editing shapes in the digital space- we created two simple shape changing and editing features. We first offer four basic primitives (cubes, spheres, cones, tubes) selectable on the interface so that users can quickly and easily change geometric representations in the model viewport. Second, we present a simple shape-editing prototype, where users can slide a bar to explore basic parametric manipulations (Figure 5). In such ways, the cubes may be seen as physical embodiments, proxies, or interactors for digital representations -encouraging a special type of form-making experimentation.

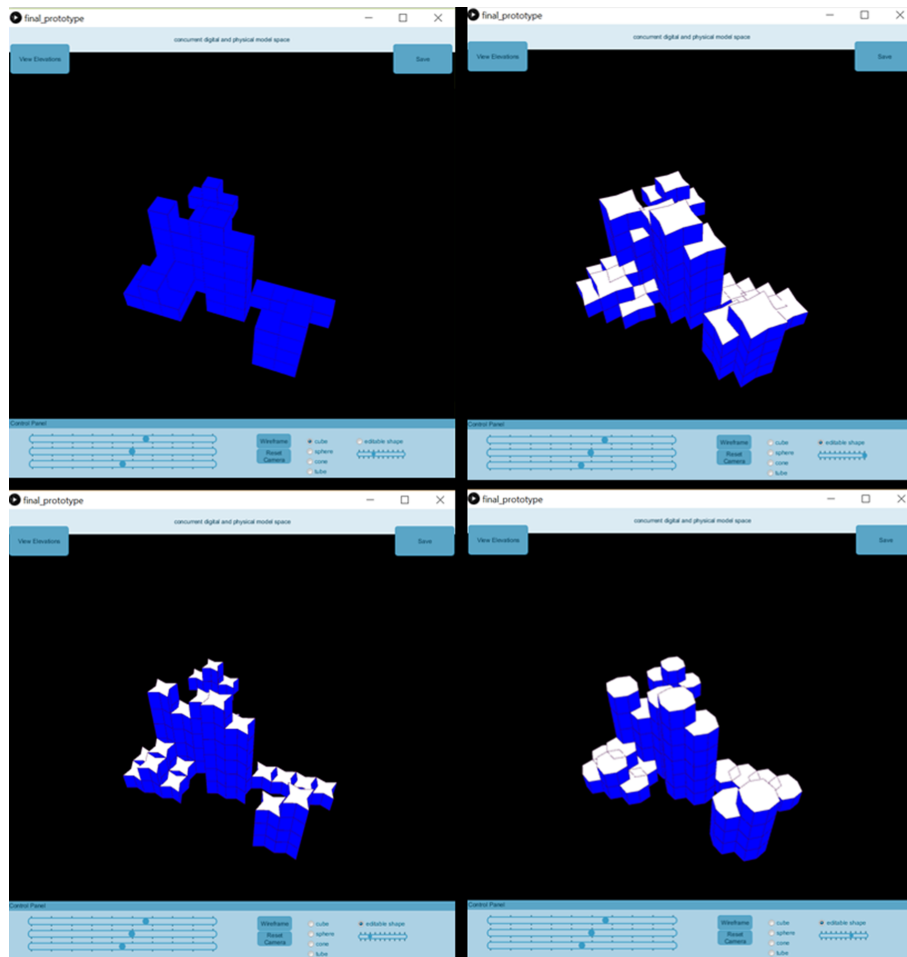


Figure 5. Options to select and manipulate primitive representations.

5. Saving Configurations

A basic “save” feature allows users to keep ‘snapshots’ of configurations before rearranging physical objects and editing geometric forms. The saved configuration pops up in a new window for convenient quick comparisons.

6. Visual Analysis

We implemented a simple visual analysis function that colors the geometric elements according to the order in which they were placed in the physical space. The potential of this feature is to help distinguish the history of the model, to differentiate the temporary movements and noise data from the permanent, and the intentional. We can also take this concept further to map brightness of the colors to reflect the time for which each unit of geometry was placed. In this way, we show how the digital space can reflect not only movements and positions, but also additional data about the physical construction of the model.

7. Results

The prototype was on display in an art gallery in Pittsburgh, where it was available to a range of gallery crawlers comprising faculty, students, and curious passersby - giving us an opportunity to informally observe people’s interaction with the system (Figure 6). We witnessed around 30 casual user interactions, and observed that when people approached the system, everyone’s inclination was first to touch the cubes, ignoring the screen and mouse. Unsurprisingly, children were less cautious than adults. They seemed to enjoy playing with the physical cubes, and seeing the mirroring digital representations. Adults spent comparatively more time trying to understand how the system worked, and tried to test its limits by moving things around to find the “boundaries” and making various configurations, seemingly trying to understand the logic of the system, and its limitations.

An important limitation of the system is that the digital representation is less flexible than the physical modeling space. While users can move the wooden blocks to any position in the physical workspace, the digital voxel-space is an orthogonal three-dimensional grid whose cells are either on or off. First-time users mostly did not want to follow this rigid grid and wanted to break the rules. Many experimented with stacking, rotating, and creating overhangs with the cubes, pushing the system’s limits. The digital representation is simply not as flexible as the physical one.

A second limitation is that the system cannot distinguish between the users’ hands and the cubes. Users’ hands thus created ‘noise’ which was fascinating to some, but distracting to others. We observed one user who flinched when first trying to touch the cubes after seeing the noise data appearing in digital model (he thought he had broken the system). Although we included measures to remedy this (by using color and time analysis to distinguish users’ hands from the cubes), the system was only able to reconstruct the workspace digitally once users’ hands were away from the physical modeling space.

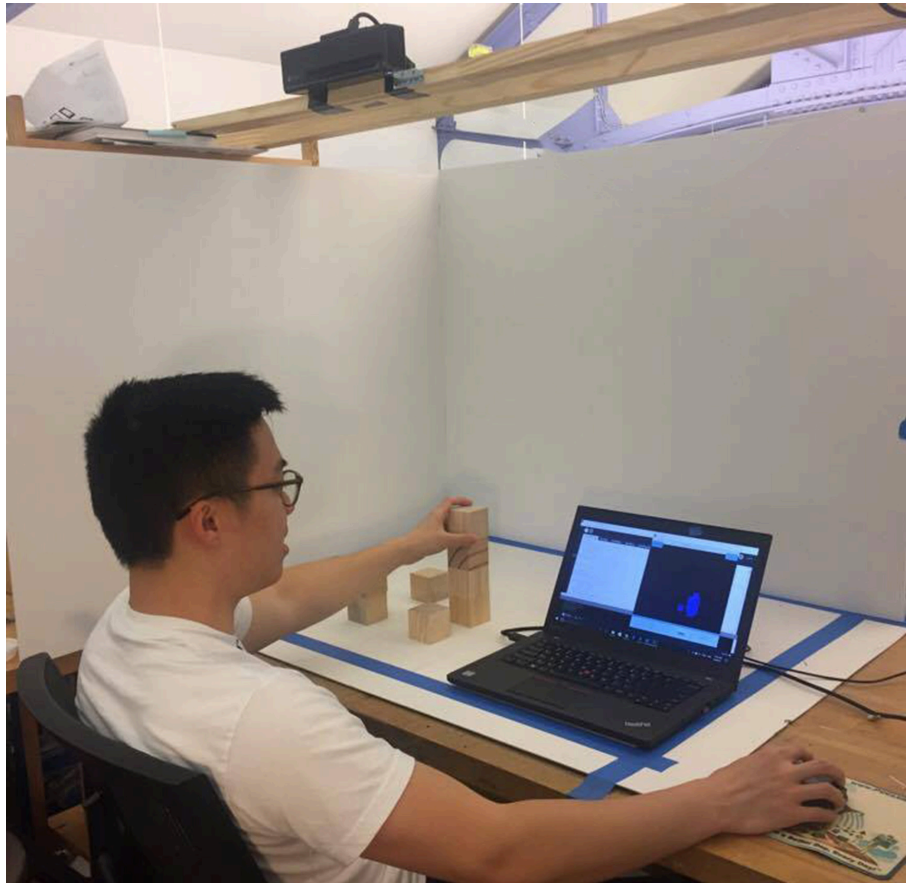


Figure 6. A user interacting with the system.

8. Next Steps

More formal testing is needed to test Ludi's capacity to enable design work across both digital and physical media. Although users were informed about its editing features, most were more interested in playing and stacking the cubes while simply seeing the digital representation on the screen, only a few engaged with its user interface.

Several further improvements can be made. For example, equipping the cubes with fiducial markers and physical sensors may improve the accuracy of the cubes' positional data, and help track additional movements such as cube rotation and flipping, as well as reducing noise data from users' movements. This would also open another potential avenue of development. By identifying each cube as an individual entity, one-to-one mappings between physical and digital elements become possible. For example, what if clicking on a cube in digital space cause the corresponding physical cube to light up or vibrate? Finally, the ideas and concepts

in this project can be applied to malleable physical objects in future studies. We can take user manipulation to go beyond merely spatial movement to also include the recognition of object deformation.

9. Conclusion

This paper presented a proof-of-concept prototype for a low-fidelity modeling environment allowing users to interact with both tangible objects and digital representations. It can be seen both as a physical interface to a digital modeling environment, or as a digital augmentation of a physical modeling space. These mutual augmentations include the capacity for exploring multiple views and perspectives, a “save” feature to quickly capture and preserve various configurations, simple parametric editing capabilities, as well as a simple time-based analysis of the design process using color. Based on a limited number of informal user interactions observed, the system suggests that there is much to gain by mutually-complementary physical and digital modeling environments. Some limitations and opportunities for future development were discussed. We hope that the ideas and methods presented inspire others to study concurrent physical and digital spaces and their potential in design and human-machine configurations.

References

- “Nicholas Negroponte’s SEEK” : 2011. Available from <<https://www.cyberneticzoo.com/robots-in-art/1969-70-see-nicholas-negroponte-american/>> (accessed 27th April, 2017).
- Follmer, S., Leithinger, D., Olwal, A., Hogge, A. and Ishii, H.: 2013, inFORM: Dynamic Physical Affordances and Constraints Through Shape and Object Actuation, *UIST*.
- Fukuda, T.: 2016, A Dynamic Physical Model Based on a 3D Digital Model for Architectural Rapid Prototyping, *Automation in Construction*, **72**, 9-17.
- Provenzo Jr., E.: 2009, Friedrich Froebel’s Gifts, *American Journal of Play*, **2**, 85-99.
- Papert, S.: 1986, *Constructionism: A New Opportunity for Elementary Science Education*, Massachusetts Institute of Technology, Media Laboratory, Epistemology and Learning Group.
- Sun, L.: 2014, Differences in Spatial Understanding between Physical and Virtual Models, *Frontiers of Architectural Research*, **3**, 28-35.
- Underkoffler, J. and Hiroshi, I.: 1999, Urp, *CHI '99*.
- Viny, A., Dabholkar, A. and Cardoso Llach, D.: 2017, Two Design Experiments in Playful Architectural Adaptability, *Nexus Network Journal*.