Title

Let's Get Physical: Thinking with Things in Architectural Design

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Abstract

To study the cognitive role that tangible objects play in design thinking, we gave 17 architects and novice students a set of blocks and asked them to design their dream house. Although the blocks seem simple they are filled with perceptual surprises. We regard manipulating blocks as a form of physical thinking because through interaction designers increase the dimensionality of their design space. This happens because a) perceptual ambiguity leads to multiple semantics - multiple ways of identifying what shapes are out there, and b) kinesthetic and other forms of non-visual interaction enables designers to feel inertia, mass, force and gravity and thereby encounter blocks and their relations in additional ways. The effects of tangibility and enactive forms of perception is that the design space expands, often leading architects to more divergent thinking. Physical interaction broadens the basis of creativity.

Keywords: multimodal interaction; extended cognition; architectural design; blocks world; design thinking; creativity

Introduction

Much research has been done on how designers think by sketching on paper or tablet (Suwa and Tversky, 1997; Bilda and Demirkan, 2003); considerably less has been done on how they think with physical objects (Kim and Maher 2008; Maher et al, 2014), either when making a model of a nearly completed structure or in the early conceptual phases of design. Our goal in this qualitative study is to understand how architects make use of physical blocks to arrive at an early conception of a building design. Seventeen subjects were positioned in front of a 4' x 4' wooden model of a generic building site (Figure 1). Their task was to design their dream house from 3D printed blocks scattered on the site. We report here on how the blocks were used to facilitate creative design thinking. We found trends that suggest more experienced designers exhibit physical behaviors that distinguish them from novices. In addition, we argue that these interactive strategies enable forms of thought that would be hard if not impossible to reach otherwise.

Background

Architects make many types of physical models including massing models, concept models, detail models, section models and many more. They use materials like paper, wood, plastic, and rockite (a casting material) to construct complex assemblies by performing operations like folding, joining, pouring, cutting, and layering using tools as different as knives, laser cutters, hammers, jigs, clamps, and 3D printers. In our study we abstract from the making process and reduce architectural model making to picking and placing physical blocks. This limits the range of possible forms but highlights the nature of tangible interaction as designers move blocks against each other, drag them over the site, build assemblies and so on.

When architects make physical models – especially when exploring design possibilities – we believe they are literally thinking with those objects. They are not just manipulating objects and inducing internal representations, as if only by working with those inner elements can we think. Our view, like Andy Clark's (2013), is that cognition extends beyond the brain to include physical manipulations and transformations. Sometimes brains drive thinking forward and sometimes the events happening around us drive thinking forward. If our coupling is tight enough the simplest explanation of why thought unfolds as it does will inevitably include our manipulation of epistemically

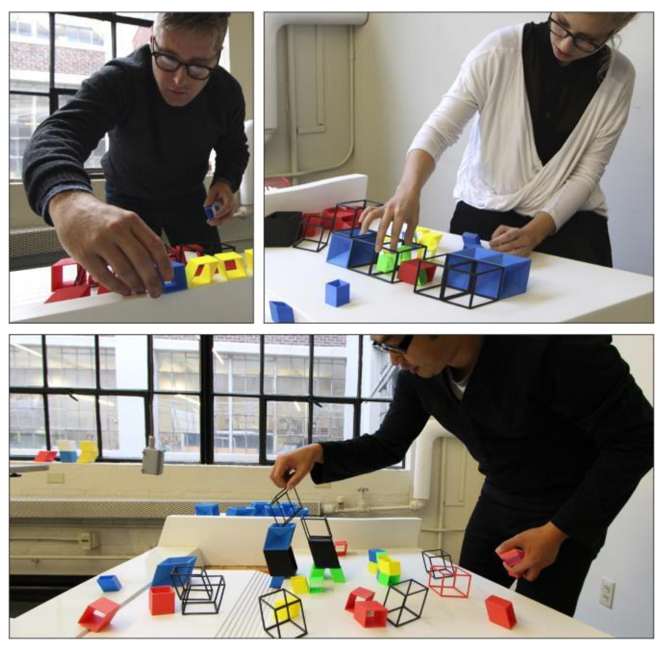

Figure 1: Architectural model-making as block assembly

charged objects. Such manipulations have been called epistemic to differentiate them from actions that are performed on things that satisfy pragmatic goals such as eating, running from danger, driving to work, etc. (Kirsh Maglio, 1994). Our work here is a baby step toward understanding how a few blocks can be used to think creatively about architectural design solutions.

Design Task Experiment Setup

In Figure 2 we show the site on which the subjects were to build their structure and the blocks provided. Subjects were given up to 15 minutes to complete the task of designing their dream house with the blocks. They were informed that they could use as many or as few of the blocks provided, and as much or as little of the site as needed. Nothing specific was said about what would constitute a completed structure, or how the product would be judged, however, we informed each subject at the beginning that they were to describe their design verbally at the end of the task.

Why Parallelepiped Blocks

Instead of using simple cube shaped blocks, we gave the subjects parallelepipeds. These shapes are close enough to cubes to look familiar and be useful in a construction task, but different enough to offer surprises and allow for a variety of spatial relationships, an important aspect of architectural design. This is achieved through the asymmetrical nature of the parallelepiped. When a parallelepiped is rotated 90 degrees, or when a subject repositions him or herself, the shapes that are in view are all different. This contrasts with a cube, where because of its 48 symmetries, each 90° rotation, whether in the X, Y, Z or diagonal axes, yields the same shapes and appearance (Figure 3).

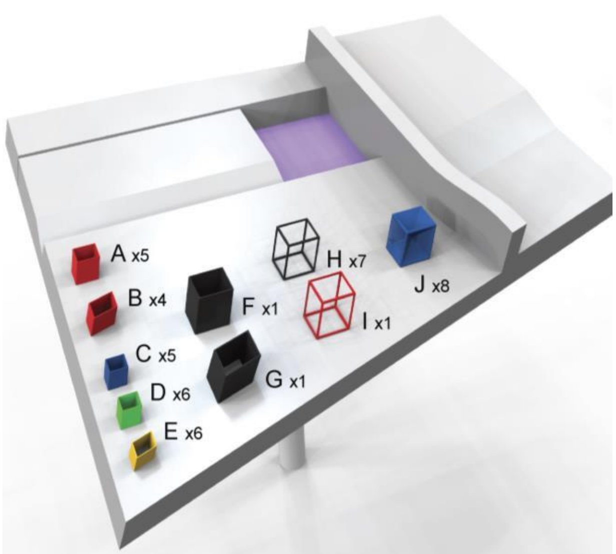

Figure 2: The design task site and block type counts

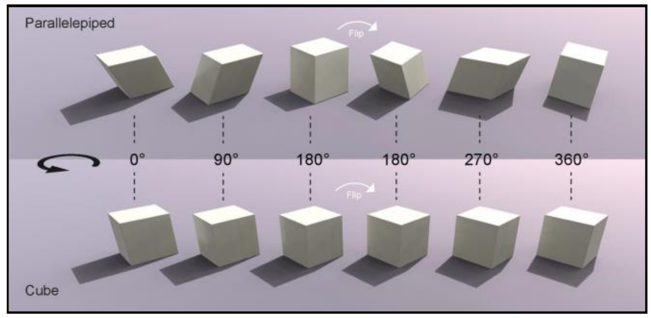

Figure 3: Shading changes unpredictably along with face shapes on the parallelepiped under rotations while it remains constant on the cube under the same rotations.

Practice Phase with the Blocks

Before the dream house design task subjects were given an opportunity to familiarize themselves with the blocks through a series of manipulation tasks (See Figure 4). It was noteworthy that even expert subjects did not find these tasks easy, often taking several minutes and over 25% not completing the task correctly.

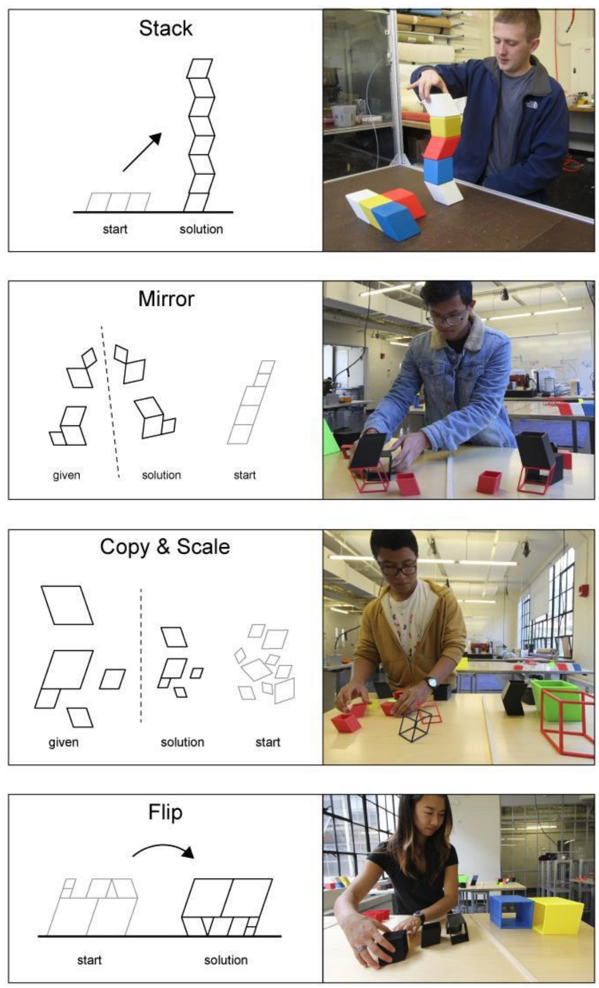

Figure 4: Practice tasks for familiarizing the subjects with the blocks.

Method

We used video-based protocol analysis and concurrent voice out loud methods to codify the subjects' interactions over time and relate them to general thoughts expressed by the subjects as they completed the task. Such methods are used in design research to identify different types of expertise; to establish criteria for measuring creativity; and to provide empirical support for developing new design tools (Gero and McNeill, 1998). Each video was watched and manually coded following the completion of all of the experiments.

Participants 6 experts, 6 novice students, and 5 non-architecture students were selected for participation. The expert group included 4 men and 2 women with a mean age of 36. All experts were professionally trained practicing architects with 4-8 years of teaching experience at the college and graduate level.

The novices were either sophomores or juniors all enrolled in the same architectural design department. The novice group included 5 women and 1 man with a mean age of 20.

The non-architectural design students were all undergraduates enrolled at the same university as the novice students, however they were from different departments. This group included 2 women and 3 men with a mean age of 20.

Coding Scheme As this is a novel analysis of the physical interactions exhibited by architectural designers in early stage design, a vital first step is to establish a coding scheme that captures behaviors at a broad enough level to be applicable to related research and future studies, and yet specific enough to identify behaviors and strategies unique to architectural design. Our scheme in Table 1 creates a framework that establishes ten interaction types that occur between different parts of the body (hands, head, and full body), the blocks, and the site. The illustrations in Figure 5 convey three different interactions visually.

The ten interaction types are grouped within three categories: inspectional, exploratory, and transitional. Inspectional interactions do not directly support the assembly of a configuration of blocks. For example, as seen in Figure 5A, Ins.B, is an interaction type in which the subject picks up a block off the surface of the site and manipulates it in space. In this case, the subject is focused only on the block's properties such as its shape, shading, or weight. This can be distinguished from an exploratory interaction such as Ex.B.H (Figure 5B) in which the subject is building a configuration of blocks on the site while also reorienting his head. In this situation, relationships between multiple blocks and the site are being explored. Both of these categories can be distinguished from transitional interactions. For example, with Tran.B the subject is holding a block but is neither constructing a configuration nor inspecting it through manipulation (Figure 5C). Rather he may be looking for what to do next with the block in hand. Variations within the interaction types may exist however we have not broken down the coding scheme further.

Table 1: Coding scheme for physical interactions in the dream house design task.

Inspectional Interactions	Exploratory Interactions	Transitional Interactions
Ins.B Manipulates block(s) in space	**Exp.B.site** Organizes blocks in relation to site	**Trans.B** Holding block(s) between moves
Ins.H Reorients head in relation to site	**Exp.BB.site** Manipulates blocks in relation to each other on site	**Trans.H** Reorients head while holding block(s)
Ins.FB Repositions full body in relation to site	**Exp.BH** Manipulates blocks on site while reorients head	**Trans.F.Bo** Repositions full body while holding block(s)
	Exp.B.FB Manipulates blocks on site while repositions full body	

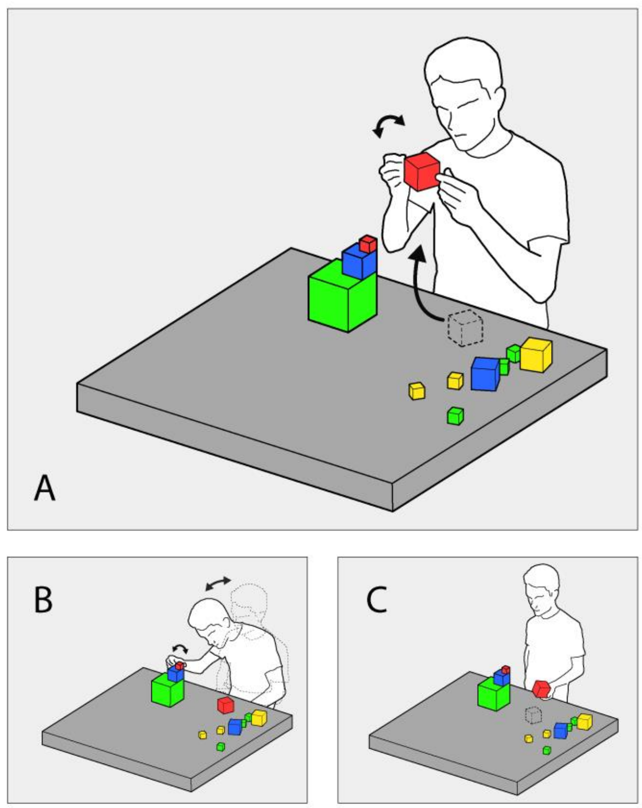

Figure 5: Illustrations of interaction types from the coding scheme. (A) **Ins.B** subject manipulates block in space; (B) **Ex.B.H** subject manipulates blocks on site while reorienting head; and (C) **Tran.B** subject holds blocks between moves.

Initial Results

We cannot make statistical claims from our small sample size; however, we can present some qualitative findings that suggest differences in how experts and novices approached the dream house design task. Figure 6 includes renderings of the final design solutions produced by three experts, three novices, and three non-architecture students.

For example, one novice designer described her process as one of finding blocks to represent typical house-hold features: "I'm using this [block] as the entrance…and I'm going to use these [blocks] as the grass and flowers…and these [wireframe blocks] will be windows" (See 1-N in Figure 6).

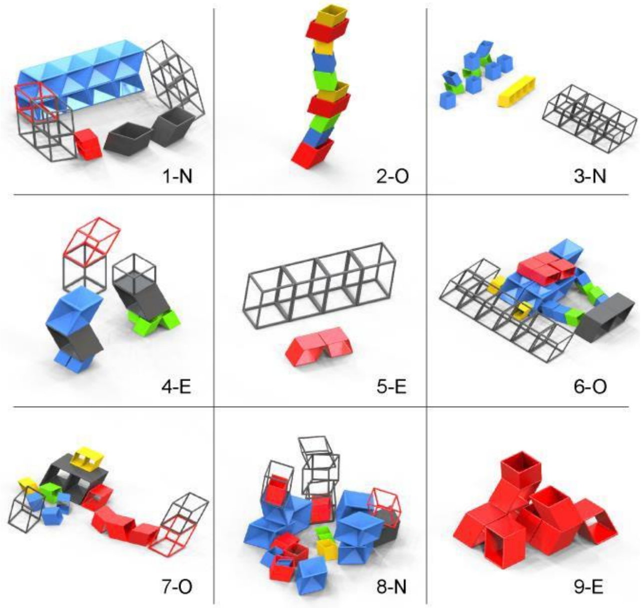

Figure 6: Subset of final solutions for dream house design task. E=expert; N=novice; O=non-designer

Experienced architects had a slightly different approach. Experts commented on the effect of moving shapes around to explore relationships between multiple blocks and the site. For example, one expert remarked, "I didn't intermingle the blocks because I like the way the red ones fit together. It's more controlled for me. I still really like the ability to make a single figure that has a lot of interior/exterior spaces. I can't go through it and say what's my bedroom, what's my living room…but as a plain figure I like it and can imagine it occupied in many ways" (See 9-E in Figure 6).

The key difference is the generative approach taken by the expert and the representational approach taken by the novice architecture student. Manipulation for the expert is more like visual-kinesthetic experimentation rather than executing a preconceived idea. This difference may also be highlighted in the interaction protocols of the novice and expert discussed above. Table 2 shows results of their time spent on different interaction types as a percentage of total time spent interacting during the dream house task. What is interesting to note is the difference between time spent on interactions that either directly support the assembly of a configuration or involve inspection of a single block vs. time spent on interactions that may provide multiple viewpoints such as Ins.H and Ex.BH.

Table 2: Interaction times for a novice and an expert. Not all interaction types are shown so total will not equal 100%.

	Ins.B	Ins.H	Ex.BB.site	Ex.BH
Novice 1-N (% of total time)	16	0	62	8
Expert 9-E (% of total time)	2	17	47	26

Discussion: Multiple Semantics

Advanced architects use terms such as negative space, symmetry, groupings, inside-outside relations, figure-ground, and more to characterize how they visually see connections between shapes. Because of this large variety of ways of seeing, they inevitably resort to sketches and physical models to help them envisage and constrain what a structure will look like from different vantage points, and how inhabitants engaged in different types of activities will move in and around a space, seeing it this way and that.

This process of envisioning through interacting with models is central to architectural thinking. Many of the tools that architects use exist primarily to help them see and understand the spatial, perceptual and functional properties of shapes. These stimulate ideas and reveal possibilities.

When a visualization supports interaction – i.e. where it is possible to change viewing angle, or zoom up close, or put more blocks on site – more things can be seen and so there are more opportunities for discovery (Pike et al, 2009). Our study supports this claim as we found that our expert subjects moved themselves and blocks frequently to see possibilities and to pick up design ideas.

One provocative explanation of the power of physical exploration is that it facilitates perceptual plurality. According to Stiny (2006) every shape is relentlessly ambiguous. A cube sitting motionlessly on a surface that is seen as a cube one moment the next may be seen as something with 3 visible square faces; looking more closely the faces may be seen as trapezoidal, or even as shapes containing triangles. We are free to change what we see almost at will. See Figure 7. Motive, interest, attention and nuance leads to seeings of all sorts. The psychological basis for such differences in phenomenal experience presumably lies in saccadic change, altered expectations, and on-going thoughts. Regardless of cause, though, the implication is that what is there to be seen is not driven by a single semantics. There are as many versions of what is there as there are ways of seeing. According to

Goodman, "There are many ways the world is, each true description captures one of them" (1960).

One way to understand this diversity of appearances is to think of blocks world as supporting indefinitely many semantics. A semantics maps syntactical elements onto an interpretation. In one semantics, the focus may be the 2D shapes visible from volumes. In another, vertices may be an entity that carries meaning. In architectural massing models the structure in its broadest strokes is the focus. Blocks already are representations at the massing level but when put together they can merge to form a new mass. So there is a massing semantics. In yet other semantics, the elements that are attended to and assigned interpretation may be the lines and planes between structures – a negative space semantics. The power of multiple semantics is that the same collection of stuff on a table may be perceived and interpreted multiply, thereby throwing up hints that are hard to anticipate. It also suggests that accounts of creativity that rely only on heuristic or even stochastic search in a design space may miss the wildcard that comes with perceptual richness and unlimited ambiguity. Perceptual diversity means we can change the search space, blend it, and redefine it.

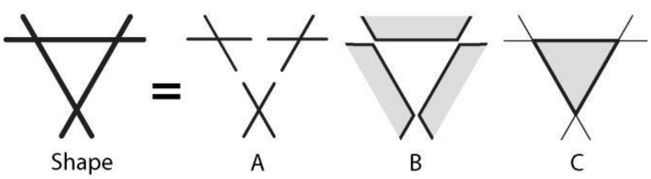

Figure 7: Shapes are relentlessly ambiguous. What is **Shape** composed of? Is it 3 X's (A); 3 clipped hexagons (B); or 1 triangle and 3 small V's (C)? (Adapted from Stiny, 2006).

Value of Multimodal Interaction

Another value of physically working with blocks is that we can probe emerging structures tactilely and kinesthetically. The object of visual exploration is the visible; the object of manual exploration is the tangible and movable. Sometimes these complement each other. For instance, when playing with blocks it is natural to bring two faces together and translate one over the other. When the edges meet it is natural to consider rotating them as if on hinges. We might spin a block on its vertex on the surface of another. Each of these physical operations has a nice counterpart in the formal theory of shapes and volumes (Stiny, 1980). We can see these relations visually and so we might not need the benefits of touching our models to wonder whether they might give us design ideas, though the complementarity is helpful.

But sometimes it may be easier to stumble on generative ideas by working with things physically. Consider limits. A standard heuristic in solving problems is to examine the behavior of a system at its limits. When we make blocks touch as completely as they can, or when they touch only on an edge or a point, we are exploring limits. When we start with two blocks behaving as if hinged on a shared edge and then we rotate them around that edge from one extreme to the other – like a door opening wide and closing shut – we are exploring limits. Exploring forces in the world naturally leads one to explore limits. Keep pushing until you can't anymore. At first this may seem just a vision complementary action. But such a world highlights compliance and inertia, and compliance and inertia are *not* visual concepts.

Accordingly, they may give rise to thoughts we might not consider when thinking visually (Martin and Schwartz, 2005). For instance, when a block becomes unstable there is a discontinuity that is immediately felt. Given the interaction between shape, center of mass, and world, these discontinuities—which may be visually beautiful because we may sense a tension—are nonetheless virtually impossible to locate visually. We need to find them haptically first and then we see them.

The Role of Mediating Structures in Thought

Playing with blocks is about working with external objects that can mediate thought. For Vygotsky the "rational, intentional conveying of experience and thought to others requires a mediating system, the prototype of which is human speech" (Vygotsky, 1962, p. 6). Vygotsky also held that "works of art; writing; schemas; diagrams; maps and mechanical drawings" (Vygotsky, 1981, p. 137) are semiotic systems that can mediate thought too. What is used outside can be internalized for use inside. Hence visual mental images in addition to auditory images can mediate inner thought. Yet why stop there? Why not talk about physical objects, such as blocks or shapes as mediators in spatial or manipulative cognition? Presumably these too give rise to inner kinesthetic mediators that function when we are thinking about spatial and manipulative activities.

Our conjecture is Vygotskian in spirit with a distributed twist: when people work with an object mechanically they operate as a joint system to cognitively probe a domain. Blocks are tools of thought, much like writing and working with maps are tools, but blocks are absorbed into the bodies of their users so that a) the block deforms the user's body schema, (Kirsh, 2013) and b) body and block become as cognitively active as gesture. If humans can think with gesture they can think with blocks or many of the other objects they might hold.

Conclusion

By creating a playground for architects to develop design ideas about a dream house we hoped to learn something about the cognitive role that tangible objects play in design thinking. The stakes are high. Beyond the value that pure inquiry holds for science, technologists want to understand what 'cognitive extra' comes from manipulating physical things, especially for creative cognition. They want to incorporate these factors into digital systems for architects to work with. Architects want new technical systems to expand design potential in terms of novel processes and products.

We found that even relatively simple volumes have a visual complexity that surpasses what most architects can anticipate and that manipulating objects is essential to see the shapes that emerge. Manipulation is vital in cases where balance and tension is important. As so many others have said, design ideas come from exploration and opportunistic discovery. Because of the relentless ambiguity of shapes opportunistic discovery of an unanticipated shape or relation can lead to reframing ideas about the space of possible shapes and relations, which in turn can lead to new design ideas.

Our experience with blocks highlights some key drawbacks of working with non-tangible things. Chiefly these have to do with thinking about load, resistance, balance, force and inertia. We found that even with 3D objects it can be hard to build block towers out of parallelepipeds – not because the shapes are especially complicated but because it is hard to predict the center of mass and the effects of putting one more block on the pile. It is important to feel the give and take, the sense that the pile might soon fall. See Stack in Figure 4. With fingers and hands it is easy to find nuanced ways to nudge a block or shift several together. Subjects seem to be able to think about stability intuitively.

By contrast, when building a tower of blocks in 3D modeling software it is hard to predict stability and even hard to find the actions to put blocks in the right orientation. Most of the manipulations that our subjects do with real blocks – rotating, flipping, aligning faces, edges and corners—is clumsy and disorienting in software. That affects train of thought. Moreover, architects regularly move their body and head position to look at structures while simultaneously manipulating shapes. This is a key interactive strategy that helps develop one's sense of space that is unavailable in visualization software.

For these and other reasons we think that using tangible objects to think with is a central part of architectural creativity that should be expanded (Brillhart, 2011). The way to augment architectural thought is through physical computation: using robots, environmental sensors and integrated electronics to increase our manipulative power. With new bodies we will have new thoughts.

Acknowledgments

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