A Meta-Cognitive Inquiry into Digital Fabrication

Exploring the Activity of Designing and Making of a Wall Screen

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Abstract: The design process is observed in ‘self-reflection’ by an experiment including visual computing, structure design, joint design, and assembly design. The experiment is defined as the making of a self-supporting timber wall screen, which includes laser-cutting and rapid-prototyping. The reciprocal action between the visual and physical realms is observed through the design activity.

Keywords: Fabrication; meta-cognition; self-reflection; visual; physical.

Introduction

In design thinking, a procedural parallelism can be drawn between how physical models and knowledge are built. Today, knowledge building in architecture has been experiencing a major shift by means of its media. For centuries, architecture has long based its inquiry on “vision,” therefore embraced “visuality” as its major tool. This has been an approach where designers focus on visual evaluation in architectural production, both in 2-dimensional and 3-dimensional representations. Today, visuality has been increasingly engaged with the “physical” aspects of architecture. In this approach, the concern is on integrating the tangible substance of architecture to visual evaluation, by contemplating other references, such as architectural materials, unit production, and building assembly. Inherently, architectural practice is seen to adopt digital fabrication in a wide range of building tasks, from scale models to full-scale constructions.

Considering these changes, the purpose of this paper is to investigate how designers are responding cognitively to the physicality of fabrication. This response is observed in a design process including both manual tasks (hand-based) and tasks which include computer-aided manufacturing (machine-based). Fabrication forces designers to take into consideration various questions regarding materials and production methods. This is realized by bringing forward the processes of making and assembly of the object into the process of design. Contrary to their traditional associations with the later stages of design, these decisions are incorporated earlier into design by prototyping.

Research question

The goal of this paper is to ask whether it is possible to observe designers’ design activity and self-reflection in a partially defined problem setting (Schön, 1983). This problem setting involves the making of physical objects. Therefore, the reciprocal activity between the ‘visual’ and the ‘physical’ is emphasized in terms of design decisions and outcomes. For this purpose, an experiment is designed to study this activity between different modalities of thinking. The aim is to examine the situations in which designers
shift to a meta-cognitive stage where they gain the
distance to reinterpret and “debug” their processes
(Kafai, 2006). This paper attempts to observe this me-
ta-cognitive act and how it follows a design process.

**Background for the experiment**

The paper evaluates how designers work with the
physical aspects of architecture and novel manufac-
turing techniques in the theoretical frameworks de-
veloped by other current research. These researches
in digital fabrication and design production (Sass,
2006; Knight et.al., 2008; Cardoso, 2007; Griffith and
Kamath, 2009; Kieran and Timberlake, 2003) have fo-
cused on the problematic collision between design
and construction. The Digital Design Fabrication
Group (DDFG) at the Massachusetts Institute of Tech-
nology (MIT) has been pursuing many experimental
projects. One of the major concentrations is on the
fabrication of 3-dimensional prototypes or full-scale
constructions utilizing 2-dimensional cutting meth-
ods, such as laser cutting, CNC milling, or water-jet
cutting. In this approach, the construction data is
embedded in design by modifying the building ele-
ments so that they would fit in each other without
the use of other joining members. In other words,
the joining members are superimposed with the
construction elements, and the system is based on
friction and gravity. Some advantages of this meth-
od are decreased material costs, rapidity in produc-
tion, and assembly.

The experiment described in this paper is based
on one of the previous research projects of the DDFG
at MIT, which was supervised by professors Terry
Knight and Larry Sass (Knight et.al., 2008). This proj-
et involved the design and building of a wall sec-
tion. The starting pattern for its tile set was chosen
to be a “meander” pattern and the brick system was
systematized by utilizing “shape-grammars.” The first
challenge in the project was solving the interlocking
geometry of the bricks, creating mortar-less con-
nections, and meeting various wall conditions, such
as corners, openings, ground intersections or roof
intersections. The second major questioning was on
the method used for fabricating the concrete bricks.
The solution was innovative building molds, the
geometry of which was created by layered rubber
sheets (Griffith and Kamath, 2009). The geometry
of the rubber sheets was formed by horizontal slic-
ing of the initial block shape according to the sheet
thickness, translating them into drawings and cut-
ting them with the CNC machine. This project clearly
reflects that digital fabrication requires a continual
thinking and shifting between design ideation and
construction. It also shows that making use of shape
grammars as a generative tool helps designers in
systematizing and explicating their processes.

**The experiment**

The experiment described here makes use of the
methods from previous fabrication research. The
task is to design and build prototypes of a wall
screen in various scales, the geometry of which is
tested through plaster and cardboard models. The
experiment hopes to illuminate how the reconcili-
ation between design and construction feeds the
design product. In terms of the design process, the
experiment aims for the ‘self-reflection’ during the
design and prototyping. In other words, the obser-
vation is done by one of the authors (Arpak) on her
design actions keeping focused on reflecting and
learning. The experiment is composed of four de-
sign stages in which the weight has been on a cer-
tain aspect of the design product. However, these
stages are not necessarily distinctive and linear,
rather more continuous and overlapping. The phas-
ing of the experiment’s process in the scope of this
paper is moderately retrospective for the purpose of
documentation.

**Phase one: Pattern selection, visual
decomposition, and recompositions**

Phase one involved the research of a particular style
of pattern from which visual information can be ex-
tracted. After research into Islamic patterns, three
patterns were chosen for further studies (Figure 1). In the selection of patterns, the focus was on compositional qualities, such as proportions, symmetry, formal adaptability, or level of intricacy. The patterns provided the initial visual and compositional layout for the designs. In other words, the aim was to link the physical objects to visual information.

The analysis of the patterns included two-dimensional decompositions into units followed by the rapid-prototyping of blocks to observe the physical results of the visual decompositions (Figures 2 and 3). The pattern composition is rationalized as a unit-based system considering unit complexity, proportions, and unit variability. The decomposition process involved ‘visual computing,’ which introduced ‘multiple ways of seeing’ (Stiny, 2006). It has been observed that when the complexity of the pattern is higher, the visual analysis takes a longer period; on the other hand, the system’s generative potential greatly increases. The factors that contribute to this increase include seeing different shapes and decomposing into different representations, such as planes, lines, or points. The implicit information regarding the making of the artifact seems to alter this phase of design. It has been interesting to see that the presupposition of future fabrication highly affects the way designers visually think. In other words, the visual and the physical start to feed each other at very early stages in design; the mode of thinking for designers is altered accordingly. A second set
of prototypes was produced to test a more refined solution regarding the border conditions for a wall screen (Figure 4).

Phase two: materializing design through visual and structural input
Decomposing with structural concerns brought on more complex geometries. In particular, the idea of structurally interlocking the units brought visually novel and unexpected results (Figure 5). It also offered the idea of layering. The layering idea was tested in two-layered and three-layered structures with laser-cut masonite models and 3Dprinted blocks (Figures 6 and 7).
The system was tested with a 4” tall prototype built with laser-cut cardboard pieces (Figure 9). It revealed that high complexity could be achieved rapidly and small manipulations can be easily incorporated during assembly. The initial purpose of layering has been to liberate the growth of the external layers. Moreover, it introduced a novel result by providing freedom in the treatment of border and opening conditions. The external layers and structural layers are relatively liberated from each other by the placement of joints. Freeing the pattern from the ‘frame’ has allowed new approaches on the edges.

**Phase three: Materials, optimization, and refinement**

The third phase included material choices, specific structural decisions, and joint design. The idea of a self-supporting timber wall brought in the design of friction-fit joints in a layered structure. Additional inspiration for layering came from nature (Figure 8). The idea of layering evolved into a three-layered system: a structural, tessellated layer sandwiched in-between standardized units. Units snap onto the front and back of the structural layer. Depending on the desired complexity, compositional or functional variations, the external layers can be altered. This property of the system provides growth and complexity regarding form. The logic of the façade composition can be random or it can respond to a function. Geometrically the tiles can be customized, or the underlying tessellation can be manipulated. Utilization of different materials – i.e. glass – would enhance complexity.

**Final prototypes**

The final prototypes are 12” high assemblies of laser-cut cardboard (Figure 9). During the construction of the final prototypes, many structural decisions have been refined and optimized (Figure 10 and 11). The order of assembly has been designed at this phase. The system has been satisfactory in providing high
variability both structurally and visually. Obtaining this variability was important as a design decision, but it was also critical in terms of this experiment: a generative system with various possibilities would yield more about designer activity and decision-making, the observation of which was also one of the main goals.

Different compositions exhibited a requirement for local and unique solutions. The final composition with openings would require a number of custom pieces regarding the structure (Figure 12). However, the production of these pieces is straightforward both due to the tessellation, and the rapidness of fabrication tools. Prototyping allows designers to craft these unique solutions into their artifacts.

Prototyping has introduced four aspects that force designers towards ‘productive conflicts’ in their design processes: material choices, structural decisions, order of assembly, and production techniques. The integration of construction and assembly significantly alters the way designers produce. As observed, the visual analyses of the patterns helped to define new structural components and assembly. Meanwhile, the structural considerations produced visually complex and counter-intuitive decompositions. The design process involved a reciprocal action between the visual and physical realms which continuously fed each other, were highly productive, and led to creative novel results. The experiment illuminated that many design ideas and intentions from the early to the late phases overlap. In this sense, designers are increasingly producing in a non-linear way.

Conclusion

Figure 9
(a) First small prototype was produced with laser-cut cardboard pieces. (b) The models demonstrate the decision of geometrically 'de-framing' the structure on the edges.

Figure 10
(a) Final wall assembly of the artifact with custom openings. (b) The order of assembly: 1) The vertical pieces are inserted in the structural units. 2) Structural units are locked with the external unit. 3) The external units are adjusted. 4) Many layers can be defined.
fashion. However, fabrication aids in revealing a great deal of future problems and allow for planning in advance. It offers a more explicit design medium in which designers more easily self-reflect. This synchronous meta-cognitive process offers faster learning. The experiment is composed as a ‘self-reflection;’ therefore observations can be biased. However, the biased behaviors of designers also reflect the effects of their design intentions, conditioned design behavior, previous training, or knowledge about the dealt subject. These studies would help us further understand how designers learn and work in the physical medium, where the experience of the hand and the tactility of objects introduce a different dimension in the perception of making and evaluation of the architectural object. These new dimensions would aid designers in grasping the materiality of architecture and reconcile ‘making’ with the creative aspects of design.

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