Ruling Im/Material Uncertainties

Visual representations for material-based transformations

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Abstract. Visual rules are powerful in loosely capturing the impact of material behavior on form in designer’s hands-on experimentation. They present a first step to translate the causal relations between material and form to computation without sacrificing the uncertainties in the designer’s interaction with the materials. This study investigates how to model the relation between material and form with visual rules so that the model embodies some of the phenomenological aspects of reality, rather than merely reproducing it.

Keywords. Digital materiality; physics-based modeling; abstractions; visual schemas; shape studies.

INTRODUCTION

Recent developments in programming and digital production technologies create a new consciousness within the architectural profession, yielding to new design methodologies. The high level of product precision in digitally calibrated fabrication requires a high level of precision in design representation. This numerical certainty finds its expression in mechanistic design approaches that make use of quantifiable, solid data for performance and optimization. However these approaches mostly adopt the limitations of existing computational techniques instead of exploring design beyond the limits of the quantifiable phenomena.

Digital representations that are constructed with mathematical descriptions of the physical object are only capable of reproducing some part of the reality. The description of a reality limited to its known finite qualities is insufficient for the designer who alters this reality in direct and indirect ways throughout the design process. The designer either interacts with the materials on an immediate level or builds a system of different materials and lets them interact with each other while s/he acts as the observer and the controller of this process. The alteration of the designed form based on these interactions is phenomenological, in that it involves the interpretation of various instances of the materials that are “transcomputable” (Glanville, 1998). In this paper we focus on incorporating the founding relations (Rota, 1997) of form and material to address the interpreted in design representations through visual schemas (Stiny, 2011).

In the following paragraphs we discuss digital and physical experiments. We review preliminary studies firstly in the physical modeling of plaster in elastic formwork and secondly in visual abstractions of this process in different digital modeling approaches. We then develop and present a set of visual schemas to illustrate the physical processes in material based transformations.
ABSTRACTION IS CONTEXTUAL

Abstractions employed in representations are important tools when communicating contextual aspects of represented objects. Building an abstraction requires being selective for features that suit the purpose of a representation. For example, there are many ways to represent a tree in the physical model of an architectural project. Sometimes it does not even have to look like a tree in order to serve the purpose of being a representation of a tree. In the model shown in Figure 1, the house is surrounded by a blurry transparent nature. That nature is represented with individual trees made of a transparent material. The house is visible through the trees. Transparency is an instance of features one could attribute to a tree. It may not be an absolute property of a tree but in a particular setting how we experience it. Through such an illustration of the tree, its relevance to the context and the designer’s intent is communicated.

Differently, a plant ecologist’s diagrammatic pipe model of the tree form reveals the relations between the plant’s growing patterns and the environmental factors (Shinozaki, 1964). This metameric conception of the tree form divides it into its supposed longitudinal parts “unit pipes” that have similar growth behavior and illustrate mechanical properties of the plant (Figure 2).

In each example key features of the tree are defined in relevance to the context and these features are used to build abstract schemas. Both types of models, the scientist’s and the architect’s are enriched by these types of schemas, in that they make exploration and discovery of new realities possible. The representations we seek in our investigation are similarly selective, being particularly based on the material context, instead of being quantitatively accurate models.

PLASTER SHAPED BY FORCES ACTING ON ITS CONTAINER

The research presented in this paper started as part of a graduate design studio where students conducted experiments to trace the emergent properties of various materials. Drawing from one of these experiments, observing the behavior of plaster in elastic molds of party balloons, authors investigate novel ways to represent form’s material causality.

Hand as a Mold

In the preliminary modeling exercise, plaster filled balloons are individually shaped by hand, to be later modeled in the digital environment. This way a direct interaction with the composite material system is provided in the physical experiments. Different shape transformations are observed as different actions of the hands are tried (Figure 3). Digital models are constructed based on the examination of the end products of the physical experiments.

The transformations of the elastic surface are digitally modeled (in Rhino with the Grasshopper plug-in) with a series of straight lines and attractor points that control the geometry of each line. Lines define the surface to illustrate topological transformations of the elastic material in cross-section. As lines morph due to the position of the attractor
points, the density of the lines locally changes (Figure 4). The actions of the hands are to a certain degree abstracted in attractor points. The smoothness of the movement caused by the pressure of the liquid on the elastic surface is acquired with a cosine function. The shape of the bump on the surface could be determined by changing the parameters of the function. In this case the key features of the transformation process that are used to construct abstract models are smoothness of the liquid movement and flexibility of the elastic surface.

Rather than being the exact reproduction of the physical models, the digital model is meant to simulate the interaction with the modeled object. In order to achieve similarity, the manipulation of the digital model must to some degree correspond to the physical material transformations. In the physical environment the designer is able to touch the materials that s/he is working with; this is a direct way to interact with the materials. Commonly used method of attractor points in the digital models is a way to “touch” the models in the digital medium. Still it happens on a symbolic level, and is not as straightforward as it might appear. In order to change the shape of the model by moving the points around the scene, first a mathematical description of the change needs to be made and then the attractor points’ relation to the change needs to be defined. Furthermore, if the user of the plug-in is not very familiar with the analytical descriptions of shapes s/he might have difficulty in controlling the shape changes. Throughout the design process every time the designer changes the model, the model is reevaluated based on the design objectives. This kind of an evaluation comes mostly from intuitive aspects of seeing, and as Stiny (2006) suggests “seeing and drawing work perfectly without rational (analytic) thought”. In computation, analysis is valuable when coupled with seeing. Hence, our analysis aims to sustain the phenomenal aspects in the designer’s interaction with the material.

**Cellular Interaction**

In subsequent investigations, conducted as group work in the graduate studio, plaster-filled balloons are put in a rigid mold and their interactions with
each other and the surrounding rigid mold are observed. Different experiments are held changing the parameters, particularly the number of units in the rigid mold and the amount of fluid in one balloon. The circumstances that caused the shape change are examined in connection with the morphology of the end products (Figure 5).

Two digital models for the project were generated with Grasshopper and Softbody plug-ins of Rhino and of 3dsmax respectively. The end results were very similar as shown in Figure 6. Grasshopper model was generated in a top-down manner by dividing a whole into its part. In this case the modules are handled as parts of a whole defined by the geometry of the rigid mold and division rules of Voronoi tool. In Softbody each module is treated as a consistent whole with predefined properties. Their interaction with each other and the rigid mold is simulated through the behavior of each module.

Softbody plug-in of 3dsmax is a physics-based modeling environment and its interface allows the user to control the material behavior of the modeled objects by changing the parameters like stiffness, damping, friction and the gravity (Figure 7). Physics-based modeling approaches like these have proven to be useful when building lifelike representations of the materials with in the design process. Principally a physics-based modeling environment...
operate on the basis of a simulation algorithm developed for the physical process it represents and the user interacts with the model through visual outputs. Visual schemas play an important role in physics-based modeling approaches. For example the Softbody plug-in of 3dsmax simulates the elasticity of objects through the principles of particle physics in that the surface of a “softbody” is defined with points which are interconnected with hypothetical springs. With the help of this surface abstraction it becomes possible to model the elastic deformation of materials (Figure 8).

**VISUAL SCHEMAS OF PHYSICAL PROCESSES**

The models above are attempts at representing material properties that impact form. They are purposefully incomplete exercises that serve to analyze material properties and to see where digital models may fall short. As seen above, each plaster unit is shaped differently. This unpredictable variability in material transformation is a challenge for representations that are expected to support it. We propose visual rules to achieve this. Stiny’s (2011) definition of general transformation rules and the unrestricted rules suit the variability in question here. An initial shape schema is crucial with parts that could be altered to generate different products of the transformation process. Stiny’s (2011) examples of Goethe’s Urpflanze and Semper’s Urhutte are both archetypal schemas for a class of objects, that are varied and each with definite parts. Our question has been how we can formalize visual schemas for objects without definite parts such as the plaster filled balloons. It is insufficient to observe just the products of the transformation for formalization of such a schema. An examination of the conditions that bring about the transformation is also necessary (Figure 9, 10).

The rules are derived by looking at the transformation process, and the relations between proper-
ties of the components. Key features among the end products of the transformation process are identified to construct abstract schemas. These common features, when varied, are what make the products unique incidents. Figure 11 shows the results of the different transformation processes for plaster in a balloon. It is clearly seen how both materials circumstantially take the shape of each other. For example in the case of half filled balloons shown in figures 11 d and e plaster take the shape of the creases of the balloon, however in the ‘hand as the mold’ model in 11 b with the balloon squeezed liquid plaster stretches the balloon rushing away from the pressure of the hand.

To find out which of their parts make them distinguishable as the products of different processes, first these parts need to be determined. It can be simply done with Hoffman and Richards’ (1983) smooth surface partitioning rule (Figure 12). According to this rule human vision enables recognition of objects by dividing them into their parts. The minima rule states that this partitioning process takes place based on the discontinuities on a surface (Hoffman, Richards, 1983). With this method we divide the surface of the model in Figure 11-a as shown in Figure 13. Parts are recognizable at the contact areas with the other components and they are either concave or flat (Figure 14).

The geometry of the contact areas are determined by the material properties of the components in the system. When two plaster-filled balloons come into contact with one another, the more rigid one imposes its shape on the other. The rigidity in this case is determined by the two factors: the amount of liquid in the balloon and the physical state (liquidity) of the plaster at the moment of contact. Another factor that specifies the geometry of one object is the number of objects that it is in contact with. When we mark the differentiating surface parts on the contact areas with surface partitioning rule, the polyhedron like structure of the remaining parts of the surface is revealed (Figure 14). The more tightly the plaster-filled balloons are packed in a rigid mold, the more angular is the appearance of this polyhedron-like structure. The polyhedron-like structure and surface differentiations at the contact areas are recurring features in each component, whereas the angularity of this polyhedron-like structure and concavity of the differentiating surfaces are varied.

A visual rule illustrates the relation between the shape transformations of each plaster object...
and the way they are packed in a rigid mold (Figure 15). In this rule, the initial shape of the plaster-filled balloon is represented with a circle plane. The right side of it shows the transformed shape while the indicator above the arrow gives us information about the context used in the action. The area of the circle plane corresponding to the volume of a component stays the same during the transformation process.

We vary this rule to capture emergent properties of the plaster-formwork interaction. The rules in Figure 16 display the condition where the outer rigid mold gets smaller while the number of the units in the mold stays the same. The increase in the angularity of the resulting shape is visible as the surrounding units get closer to one another. The rules in Figure 17 show the formation of polygon-like shape of a unit with the increasing number of surrounding units. It also reveals the relation between the number of surrounding units and the number of sides of the polygon. By changing the position and the number of the surrounding units, different shape computations can show the gradual transformation of a unit (Figure 18).

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**Figure 14**
Marking the convex and flat surfaces with smooth surface partitioning method.

**Figure 15**
Visual Rule 1: Gray circle plane represent the initial shape of the plaster-filled balloon and. Red lines stand for the surrounding units of a component in transformation.

**Figure 16**
Visual Rule 1 elaborated: Angularity of the plaster object increases as the volume of the outer rigid mold gets smaller.

**Figure 17**
Visual Rule 1 elaborated: Angularity and the number of the sides of the plaster object increase as more balloons are put in the rigid mold.
The rules presented in Figures 15-18 give a clue about how shapes come about. Nevertheless, it is not possible to fully comprehend the process by just looking at these. The mold of the surrounding pieces shapes the plaster-filled balloon. The rules present the surrounding units as solid shapes, however this is not always the case. Rules still need to reveal the interaction of the neighboring objects.

Further examining the transformation, it is possible to improve the visual rule to contain more information on the process. That leads us to a less general rule. In Figure 19 the visual rule for the schema \( x \rightarrow x - \text{prt}(x) + \text{prt}(x)' \) is presented. Here the transformation of the subtracted part of the initial shape is displayed with parametric variation rule under general transformation rules (Stiny, 2011), for the areas of the subtracted and added parts are equal.

To further enhance the rules, properties could be assigned as weights (Stiny, 1992). As the shape transformations are mainly regulated by the rigidity of each component in the system, it is the first material aspect to be included in the visual rules. In figure 20 the thickness of the line signifies the rigidity of the elastic mold while the grey tone stands for the hardness of the plaster. These are depictive rules. In search for alternatives that can be more generalizable, we also develop the visual rules in Figure 21 that serve the same purpose but more generally to work even for singular objects. They exhibit two different cases of being in a mold. Based on the rigidity of the components, which is represented with line thicknesses, their potential to transform one another is displayed. Different weights (color and thickness) signify properties that undergo transformations. Shapes are generic and can be interpreted to subsume others.

**CONCLUSION**

Current digital modeling environments have the capacity to provide the designer some form of interaction with the model but phenomenal aspects of the physical environment often get lost in symbolic reductions. In most cases the designer interacts with the digital models on a symbolic level and forgoes...
the causality shaping the design. In the digital model, the designer is able to perform transformations on the model by changing some numeric values within set ranges. In addition to this capacity, there is a need for case-specific visual rules. This is to embody the designer’s unique reasoning which feeds from the interaction with the material. The variation of plaster-in-balloon morphologies in Figure 11 illustrates differences between instances. We study a particular hands-on experimentation in order to showcase how visual rules may document the form-material relation with the aim of supporting the interaction of the designer in the digital form-finding processes. We have developed exemplary rules and schemas as general and visual as possible based on parameters derived from hands-on experimentation. There are many parameters that determine the composite behavior of the materials. In this study, they add up to two main features: geometry (curvature) and rigidity. The values indicating material properties of components are employed in the computations of shape transformations.

The rules given in this paper are in no way a complete grammar but are directives for phrases that can belong to a grammar if a designer wishes. These rules are mere instances of how material-based shape transformations can be visualized to be compared with one another, to be manipulated if necessary, and to be understood within a broader picture of how shapes come about. Differently than rules, schemas, as defined and categorized by Stiny (2011), aid in understanding the rules within formal categories that might prove helpful in setting up the support system in the digital platforms. Visual rules, and visual schemas as their more general versions, not only document transformations but also summarize and help systematize the designer’s perception of founding relations of actions. Visual rules presented in this paper also utilize weights that can be used to represent magnitudes of certain material properties.

Further research requires applying these kinds of rules for synthesis, as opposed to for analysis, and in parallel to a design exercise as opposed to a material exploration exercise as the one referred to in this paper. This would help us see how the results correspond to the rich interactions the designer has in the material world. Additionally, since visual rules are specific to case and designer but can be categorized using more general schemas, it is meaningful to pursue a system to support various visual rules in the digital platforms.
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