Touch, See, Make

Employing Active Touch in Computational Making

ABSTRACT

In architectural education and practice, we don’t come in physical contact with what we make until the later stages of the design process. This vision-oriented approach to design is something deeply rooted in architectural practice: from Alberti’s window to the screens of our computers, design has traditionally been more of a visual and less of a hands-on process. The vision of the presented study is that if we want to understand the way we make in order to improve tools for computational design and making, we need to understand how our ability to make things is enhanced by both our visual and tactile mechanisms. Bringing the notion of active touch from psychology into the design studio, I design and execute a series of experiments investigating how seeing, touching, or seeing and touching exhibit different sensory competencies, and how these competencies are expressed through the process of making. The subjects of the experiment are asked to tactiley, visually, or tactiley and visually observe a three-dimensional object, create descriptions of its composition, and to remake it based on their experience of it using plastic materials. After the execution of the experiment, I analyze twenty-one reproductions of the original object; I point to ways in which touch can detect scale and proportions more accurately than vision, while vision can detect spatial components more efficiently than touch; I then propose ways in which this series of experiments can lead to the creation of new design and making tools.
INTRODUCTION
From Sensing to Perceiving to Making
Seeing is to perceive space, objects and information using our eyes; touching is to perceive the same things using our hands; making things in the physical world is the act of forming space and objects using both our eyes and our hands. In architectural education and practice, we don’t come in physical contact with what we make until the later stages of the design process. We mostly see things through pictures, drawings, CAD files, simulations, or images of things that we envision in our minds.

This vision-oriented approach to design is something deeply rooted in architectural practice: from Alberti’s window to the screens of our computers, design has traditionally been a visual process. Since its introduction in the early 1970s until now, computer-aided design has been establishing the process of making as less tactile and more visual. For some designers, this is considered a shift; for others, a kind of deprivation.

Research in the field of hands-on making in design education and practice is limited, but provides critical insights to the problem described above. Smith (2004) argues that physical interaction with models has been used as a mechanism for inventing, understanding and demonstrating architectural concepts from antiquity until today, giving designers the opportunity to “think while they are making” and to reflect while giving shape to their ideas. From a more abstract, computational perspective, McCullough (1996) views hands as part effector, part probe organs, demonstrating ways in which they can function as mediums for experimentation and creative expression through their involvement in computational design tools. However, he proposes a way of imitating hand functions through abstract design operations, rather than introducing a way to physically involve them in the design process: “hands are underrated because they are poorly understood,” he notes, suggesting that computational design applications leave little room for physical interaction with designers and makers.

Vision: Understanding Making
The vision underpinning the presented study is that if we want to understand the way we make, we need to understand how our ability to make things is enhanced by both our visual and tactile mechanisms. Focusing on a practical potential of the use of touch in design education and practice, I design and execute a series of experiments investigating how seeing, touching, or seeing and touching exhibit different sensory competencies, and how those competencies are expressed through the process of making; I point to ways in which touch can detect scale and proportions more accurately than vision, while vision can detect spatial components more efficiently than touch; I then propose ways in which this series of experiments can be used to investigate weaknesses of computational design software, and ways in which it can lead to the creation of new design and making tools.

BACKGROUND: ON ACTIVE TOUCH
The experiments I present in this paper came after my study of J. J. Gibson’s (1963) research on the relationship between sensing object properties and perceiving them. Following the observations of earlier psychologists David Katz and Géza Révész, according to which tactile perception lies in the movement of the hand (Katz 1989), Gibson (1962) developed the concept of active touch, notably defining it as “what is ordinary called touching, rather than being touched.” He characterizes active touch as a performatory and exploratory sense that allows the observer to detect surfaces, edges, interspaces, objects and motions in the neighborhood of his body, or make changes in a given environment with regards to the object’s geometry and properties.
For example, in one of his experiments on active touch, Gibson asks subjects to feel an object with their own hands under a curtain, and then asks them to match it with one out of ten similar objects. He demonstrates that the ordinary observer, after some practice, can match the tangible objects to their visible replicas with little error (Gibson 1962). In his later research, he adds to his observations that the haptic system is sensitive to the variables of the exploring hand, explaining specific properties that it can detect; these properties are the slant of a surface, the convexity or concavity of a surface, the edge or corner at the junction of two or more surfaces, and the separation of two edges (Gibson 1963).

Researchers after Gibson have studied how an observer can recognize—without the mediation of vision, or enhance in the presence of vision—the properties of an object held in the hand by performing simple movements such as yielding and hefting (Turvey and Carello 2011; Turvey 1996). In contemporary research in psychology, Gibson’s active touch has been examined as a powerful modality that can endow robots with tactile sensing capabilities (Prescott, Diamond and Wing 2012), or as a process that can inform the design of sensor technologies.

METHOD: EMPLOYING ACTIVE TOUCH IN MAKING
Within the framework of the present experimental study, active touch is considered as a modality that, when combined with vision, can enhance spatial perception. My aim is to bring Gibson’s observations into the context of design and making, and examine how the feeling of an object’s properties using touch, vision and a combination of the two results in the observers’ more accurate and coherent understanding of the object’s form. Within the context of the experiment, the perception of the spatial properties investigated by Gibson is examined using active touch, with and without the mediation of vision, or using vision without active touch.

Hypothesis
The hypothesis of the experiment is that observing an object through different types of sensing creates a different understanding of its physical properties. These types are: (i) active touch without the mediation of vision, (ii) vision without active touch, and (iii) active touch and vision combined. The hypothesis was tested by asking 21 designers with advanced experience in model-making to reproduce the object after experiencing it through only one type of sensing described above.

First, the experiment examines how the properties perceived through different types of sensing are expressed through the subjects’ description of their sensory experience, and second, how this experience is reflected in their models. In contrast to experiments designed within the fields of psychology that usually ask subjects to select choices from within a limited set of options, the understanding of the subjects’ perception was examined based on its physical reproduction.

Subjects
Participants were 6 female and 10 male volunteers, each second- or third-year Master of Architecture students, ranging in age from 21 to 29 years old. The students had backgrounds in architectural practice, academic and professional, were familiar with model making, and were fluent English speakers. They were recruited by personal communication. During the development of the experiments, they were divided in three groups of 7 participants each: group A (the touch group), group B (the see group), and group C (the touch-see group). Using subjects of
An observer looking at one object and feeling another. Gibson’s experiments on active touch (1963) show that an ordinary observer, after some practice, can distinguish between the tangible object and its visible replica with little error.

Turvey and Carello’s experiments on the sensing capabilities of dynamic touch. In those experiments, an object is wielded out of view (a), while perceived properties are in the scale of actual properties (b).

Constantin Brancusi, Tête, 1920, Bronze, 7 1/2 x 9 1/2 x 11 3/4 inches.

The 3D printed replica of Tête used in the experiment.

Similar backgrounds and skill levels was used as a way to validate the results of the experiment.

Experiment Design
The experiment was executed in two parts. In part I, subjects of group A (touch group) were given an object and asked to explore it with their hands and out of their view; subjects of group B (see group) were given the same object, but were asked to explore it while holding it with only one hand and with limited ability to rotate it; subjects of group C (touch-see group) were asked to observe the object fully using vision and touch. Subjects of all groups were asked to talk aloud about what they felt during part I. In part II, subjects of all groups were asked to reproduce the object using plastic materials and some basic modeling tools. For part I, subjects were given three minutes, and for part II they were given twelve minutes.

Each of the 21 experiments happened in separate times, with the author present each time. The subjects were not aware of the purpose, the hypothesis, the elements and the design of the experiment before participating. Also, the subjects were not aware that they were going to reproduce the shape from part I during part II of the experiment.

Apparatuses
In part I, I used a 3D-printed physical composition made of complex configurations of simple three-dimensional solids. The composition was a scaled reproduction of Romanian artist’s Constantin Brancusi, titled Tête. The sculpture was selected among a series of 3D objects used during preliminary versions of the experiment for its elaborate, geometrically rich yet abstract form. The size of the reproduction, which was modeled using Rhinoceros 3D CAD software, was approximately 2 x 3 x 7 inches. I used an audio recorder to document the subjects’ observations.

In part II of the experiment, I used approximately 64 ounces of oil-based, non-hardening modeling clay divided into 21 chunks and some basic modeling tools. In particular, every subject was given a 12” x 18” vinyl cutting mat, a 6” long plastic sculpture knife, 4 ounces of clay, and a wooden rolling pin to facilitate the sculpting of the clay.

Execution
In part I, whose duration was approximately 3 minutes, subjects of the three groups were given instructions adapted to each sensing type:

Subjects of group A (touch group) were asked to close their eyes and were given the object in their hands. They were verbally given the following instructions:

“Feel and explore this object with your hands and try to understand its shape; please talk aloud as you do so.”

After the end of the 3 minutes, the subjects were asked to give the object back to the author, keeping their eyes closed. The object was posed in an opaque box and the subjects were asked to open their eyes.

Subjects of group B (see group) were told that they would be asked to look at something for several minutes while holding it with one hand, and that they should not touch it with both hands or change the position of their hand while holding the object.

They were given the object and the following instructions:
“See and explore this object with your eyes and try to understand its shape; please talk aloud as you do so.”

Subjects of group C (touch-see group) were given the object and the following instructions:

“Explore this object with your eyes and with your hands and try to understand its shape; please talk aloud as you do so.”

**Evaluation Method**

The 3D models produced in part A were examined as parametric variations of the original object. This interpretation is analyzed into three aspects of perception, how they are expressed through the subjects’ verbalization of their experience, and how they are reflected in the models. These aspects are the spatial components, the spatial relations, and the spatial scale and proportions, which are all analyzed into various subsidiary aspects shown in Figure 7. In particular:

- The spatial components included the base cylinder, the top dome, the top section, the side parallelepiped, the front section set, the back section set and the saddle bottom.
- The spatial relations were analyzed into the chord relationship between the top cut and the top dome, the tangency between the base cylinder and the parallelepiped, the vertical and the horizontal alignment between the top section and the side parallelepiped, the vertical and the horizontal alignment between the side parallelepiped and the front cut set, the degree of the front and the rear angle, the symmetry between the front and rear cut, the rotation of the parallelepiped.
- The spatial scale and proportions were analyzed into the overall width of the composition, the overall height, the height, width and length of the parallelepiped, the openings of the back and front cut sets, and the width and the proportion between the overall width and height.

To evaluate the perception of each of the above elements, I built an analysis schema by plotting different values found in the subjects’ models into a group of dispersion fan diagrams (Figure 7). In particular, I used three fan dispersion fan diagrams for each group: one illustrating spatial components, the second representing spatial relations, and the third one illustrating scale and proportions. Every fan chart is divided into slices representing the subsidiary aspects of each category (for example, parallelepiped for components, width/height for scale and proportions etc.). The radii of the circles are equal to the number of subjects.
in each category, and are filled in the case where the subject captured the features shown in the chart.

**Results**

A critical part in the analysis of the results were the descriptions produced by the authors during part I of the experiment. The descriptions were used for two different reasons: first, for helping subjects remember what they felt during part I, a facility that was discovered in a series of previous experiments designed and executed by the author; second, for evaluating the models produced during part II. In particular, comparing descriptions given during part I and components produced during part II helped in identifying whether the absence of a component happened because the subject didn't notice it, or because of a lack of tactile or visual memory. Among the descriptions, there were common terms such as "prism," "surface" or "plane," "cuts" or "sections," "boolean operations" or "symmetry," articulated in different ways within the subjects' descriptions.

Below we see three example descriptions that were given from participants from group A (touch), group B (see) and group C (touch-see) respectively, while at the end of this section I draw some general observations on each group's descriptions related to their experience of the object.

“Primarily, it's a cylinder that is an inch and a half in diameter; on the one end it has a half-sphere cap, and on the other end it's kind of skewed and it has two or three cuts booleaned out and there's a rectangle that is glued on top of it; at the end of the cap there is a wedge.”

This description is given by a participant from the see group (group B), who made the model shown in Figure 9. The subject mainly identifies parts, such as the cylinder and the top dome, without focusing on spatial relations. He measures the correct width size but not the correct length size, as we see in the picture. He first experiences the main part of the sculpture, which is the cylinder, and continues with the other parts.

“It seems to be 3D printed and it seems to be a composite shape that has been booleaned out; seems like it can stand in some positions and that it can't stand in others. It's interesting because some of the booleans seem to be flat but others are planar; at the same time, it gives the impression that it's been cut out. But it could also have been the case that this part (showing the bottom part of the sculpture) is a truncated cone that has been combined with this part (showing the top part of the sculpture); that is suggested by this rectangle; it's vague in that sense. It has been printed in a way that it could stand.”

The above description is given by a participant from the touch-see group (group C), who made the model shown in Figure 10. The subject starts by observing the texture and by describing the object's orientation. She continues by observing relations between parts; even when she speculates on how the form was produced, she describes parts based on the process that shaped them.

The descriptions of the subjects' experience are similar in their articulation and length. In particular, participants from the touch group based their descriptions on spatial relations with regard to
parts (e.g., “the pill-shaped volume with the angular cuts”), while participants from the see group focused on parts (e.g., “the bowl end” or the “extrusions that are glued on the top of it”). The touch-see group’s descriptions, (e.g., “the truncated cone that has been combined with a cubic part”). The descriptions did not vary only in style, but also in length; the majority of the participants from the touch group spent over two and a half minutes from the whole time given, which was three minutes, while the see group spent less time on average. In particular, two subjects from the see group spent three minutes describing their experience of the object, four of them spent two minutes, and one of them reported that “it is an interesting object,” but refused to provide any further description.

The models produced by the three different groups varied in part distribution, spatial relations and scale/proportions. The analysis of the models and the evaluation method were developed using the schema described in the “Evaluation Method” section. Comparing the sculptures shown in Figure 11 before applying the analysis schema shown in Figure 12, we can observe some basic differences between models of the different groups. For example:

- the touch group’s models were more similar to the original object with regards to scale and, in some cases, the basic spatial relations.
- models of the see group resembled the original models with regards to parts and, in some cases, spatial relations, however, they missed the object’s scale.
- models of the touch-see group represented the scale nearly as well as the touch group did and the parts nearly as well as the see group did, and, in most cases, represented the spatial relations as they appear in the original object.

**Touch Group**

Applying the analysis schema in the models of the touch group, we see that subjects were moderately successful in perceiving the spatial components, which were represented in a rather abstract and imprecise way, while they were more succesful in capturing the scale and the spatial relations between them. In particular, participants captured components such as the front and the back section sets, the base cylinder and the side parallelepiped, while most of them missed details such as the saddle bottom. Regarding the spatial relations, subjects captured the angles of the sections very well, in addition to the chord relationship between the top section and the top dome. The perception of the scale and the proportions was very accurate too; proximity to the middle circle in the right charts shows proximity to the actual dimensions. As we see, the touch group’s representations were quite accurate with regards to the width/height proportion, the back and front sections’ width, and the objects’ overall dimensions.

11 The models produced by the three groups of the experiment.
See Group
Applying the analysis schema in the models of the see group, we see that subjects were very successful in perceiving the spatial components, which were represented in much detail, while they were not so successful in capturing the scale and the spatial relations between them. In particular, in Figure 12 we see that the see group captured the majority of the spatial components, while it exhibited poor performance in capturing the spatial relations. Regarding scale and proportions, some subjects captured the overall dimension very well, but the majority of them represented the object’s height as more elongated than it was.

Touch-See Group
Applying the same analysis schema for the touch-see group, we see that this group was very successful in perceiving spatial components and spatial relations, while it wasn't so successful in perceiving scale and proportions. In particular, regarding the spatial relations, subjects captured specific relations very well, such as the chord relationship between the top section and the top dome, or the tangency, rotation and alignment of the parallelepiped. The perception of the scale and the proportions was in some cases quite accurate; however, there were some cases where the object was perceived as larger or smaller than the original one.

While in groups A and B subjects performed similarly when representing spatial components, relations and scale/proportions, in subjects of group C, no particular perceptional pattern was observed. For example, some subjects who captured the spatial components only represented some of the scale/proportion aspects accurately; on the other hand, some subjects who captured the overall scale and proportions of the object failed to capture the spatial components. Observations like this, which can be made by comparing the models of the groups in Figures 11 and 12, indicates that the two types of sensing used in
group C did not function additively, but rather as independent, supplementary senses for spatial perception, which don't always work well when combined.

Comparing Sensory Competencies
Figure 12 indicates that every sensing type used in the experiment offered different information to the subjects. In particular:

- The touch group had an increased understanding of spatial relations, but not components. The perception of the measurements was very accurate compared to those of the original object.
- The see group had an increased understanding of components, but not spatial relations. The perception of the measurements varied, and the proportions were different than the ones of the original object. Also, the see group perceived different spatial relations compared to the touch group.
- The touch-see group had an increased understanding of components and spatial relations. The perception of the measurements varied, and the proportions were not always similar to the ones of the original object. The measurements were more accurate than those of the see group, and the spatial relations represented were different than the ones represented from the other two groups. In Figure 12 we can see that this combined modality helped subjects perceive spatial components and spatial relations more accurately than isolated vision or isolated touch did. At the same time, we see that subjects from the touch-see group did not represent scale and proportions as accurately as subjects from the touch did.

CONCLUSION
The study I presented in this paper comes from the observation that, in computational design and making, an important amount of information about the objects, materials and tools we are designing with is lost due to the absence of physical, hands-on interaction, in favor of vision. The series of experiments I presented provide answers to several questions regarding the type of information lost through this absence, information that can be obtained without the mediation of touch, and types that are more thoroughly perceived when touch and vision are combined.

Contributions
If we want to understand the way we make and improve tools for computational making, we need to understand how the ability to make is developed through different sensory modalities. As such, I developed an empirical study comparing the ability of the tactile and the visual modalities to capture properties of objects such as components, scale and spatial relations, and how these modalities can enhance spatial perception when isolated or combined. Hence, with this work I contribute to the field of design research in the following ways:

- I examined active touch, a modality used in psychology, within the context of making, introduced it as a modality that, combined with vision, can enhance spatial perception within the context of design and making.
- I designed and executed an experiment investigating how this type of sensing enhances material perception. Through the experiments, I investigated how active touch and vision capture different spatial properties when it comes to form an understanding of objects, and I demonstrated different competencies exhibited by each type of sensing.
- I demonstrate, through an analysis of the experiment results, that touch and vision can function as supplementary rather than as additive mediums for spatial perception.

Future Steps
The results show that whereas vision is more effective in recognizing three-dimensional shapes, touch is more effective in perceiving scale, proportions and relations between three-dimensional objects. The study also demonstrates that touch and vision do not always function additively: they are rather supplementary modalities for spatial perception. Those results suggest that, in order to employ both of them towards enhancing our perception when designing or making, we need to find an interface that allows their integration.

The development of this interface is a next step for this research. In particular, future work will be developed on applications involving the tactile sense along with the visual in the design and making process, and on experiments that will investigate how the sensory competencies identified by this research are exhibited through the interaction of users with those design and making applications. Building an interface of communication between the tactile and the visual sense will make those experiments not only more information-rich, but also more meaningful in terms of their relevance to design practice. While the presented study was implemented using a specific, static design object, future interface-based experiments will involve the participants’ creativity, design capabilities, and crafting skills in a new paradigm for tangible and visual computational making.
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REFERENCES


IMAGE CREDITS

Figure 3: © American Psychologist, New York.

Figure 4: Turvey and Carello, 3 October 2011.

Figure 5: © Paul Kasmin Gallery, New York.

All other drawings and images by the author.

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