DEVELOPING KNOWLEDGE FOR DESIGN BY OPERATIONALIZING MATERIALS

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There is a material side of design that we cannot address through the studies of use and social practice—the properties and potentials of materials, forms, and structures must be explored through another kind of studies. Based on two cases of experimental design research we analyze of what such studies could consist—how we can operationalize material objects by engaging them in situations that give us access to their properties and enable us to explore their potential.

INTRODUCTION

In experimental design research (cf., Binder & Redström, 2006, Brandt & Binder, 2007, Hallnäs & Redström, 2006, Koskinen *et al.*, 2008, Rendell, 2000, and Seago & Dunne, 1999) we see a myriad of different experimental setups. Generally, however, the experiments comprise three elements: a question, an operationalization of the subject matter, and an evaluation of the result. The question can be more or less explicitly formulated. It can be anything from a distinctive hypothesis to a vague conception. Nonetheless, it sets the scene for the subsequent actions. The operationalization is the kernel of the experiment. It is the action in which the answer is sought. It is the action that engages the subject matter in an eligible manner and through the subject matters' resistance gives us access to knowledge about it. For example, when measuring the length of a table with a ruler does the ends of the table provide the resistance that gives us access to its length, or when inviting people to use an artifact their interaction with the artifact will provide the resistance that gives us insight to its usability. Thus the operationalization is formed by the question, but it is also formed by the subject matter. Lastly, the evaluation is a correlation of the question and the result of the operationalization. The result of the operationalization may invite us to reconsider the question and may even constitute an answer. Hence, the type of evaluation depends on both the question and the operationalization, and can be anything from statistical analysis to aesthetic estimations.

In design research it is common to encounter *use* as the operationalization of artifacts (cf., Brandt & Binder, 2007, and Koskinen *et al.*, 2008). For example, when we design an artifact we are inclined to determine its value through exposing it to a situation of use (cf., Routarinne, 2007 or Wensveen, 2002). Such exposures enable us to study how people interact with it, if they use it as intended, or if they perhaps reinterpret the intentions. Another example is when artifacts are employed in situations of use, not to learn about the artifact themselves, but to learn about forms of interaction and the contexts of use (cf., Brandt, or Gaver *et al.*, 1999). In all these types of experiments *users* are employed as the reality whose actions, in the situation of use, constitute the resistance that we measure the artifact against, or the resistance that provides the premises for future designs. Since design always contains an aspect of use these operationalizations are significant in developing knowledge for design. Design, however, is more than use and forms of interactions. Design is also materials, forms, structures, expressions, production techniques etc. Yet, what do operationalizations look like when focus is on these other aspects of design, when materials or forms are the subject matter?

Ezio Manzini argued, “every object made by man is the embodiment of what is at once thinkable and possible” (1989, p. 17). We can push the borders for what is thinkable by making new connections and push the boarders for what is possible by improving our knowledge of the subject matter, and developing new possibilities. All of which, will constitute valid and valuable contributions in a discipline of design research. Indeed, rendering a new area of imaginable possibilities is what is also referred to as rendering a new *design space*. The question remains, however, how do we do that in a material context? What does it take to make probable that the new material connections lead somewhere? How can we obtain knowledge of the materials that are not immediately accessible to us? What does it take to produce the new material possibilities? It seems that conducting experiments is an inevitable strategy to honor these endeavors, and in that light the questions can be narrowed down to: What constitute acceptable operationalizations? When can we say to produce a sufficient and suitable resistance as the basis for developing knowledge?

Through two cases of experimental design research we analyze some examples of operationalizations and discuss how they enable valid and valuable research contributions. First, however, we elaborate what we comprehend by valid and valuable research contributions. Second we present the two cases. The first case is an exploration of textile formations based on acoustic qualities in an architectonic context. The second case proposes a new understanding of the computer as a material for design. Both refrain from any user evaluations, but they do rely on general notions of human perception and sensorial presence in the world.

VALID AND VALUABLE KNOWLEDGE

When conducting design experiments as a research strategy we need to be sure that what we take from these experiments are in fact, valid and valuable knowledge. Experiments in design research do not always hold the same stringency as experiments are expected to hold in science, which is probably resulting from differences in the general research purpose. Where science, roughly speaking, is engaged in revealing the truth about their subject matters design research is engaged in developing ways to make new and better designs. Thus experiments in design research require another way of judging their validity and their value.

Michael Biggs (2006) argues that work is judged as design research based on three necessary and sufficient conditions: its originality, its contextual grounding, and its dissemination to peers. Based on this we could say that a work is a *valid* research contribution if it through dissemination contributes original knowledge on a subject matter. Explicit contextualizing and meticulous studies enable us to determine the originality of a research contribution, but to enhance the chances of originality in the process we are obliged to seek new approaches—to make new connections. Whether the contribution does indeed constitute knowledge is, however, a somewhat trickier question. To ensure this, both in prospect and in retrospect, the premises that the knowledge is founded on must be accessible to us—they must be articulated and substantiated. If they are not immediately accessible, they must be made it through various ways of operationalizing the subject matter as, for instance, through the experiments described above. Furthermore, the *value* of a research contribution can be described as its relevance to the context intended—that it improves the general knowledge of the subject matter. The relevancy is determined by relating the new knowledge to its expressed context either through previous written accounts (i.e., previous research contributions) or through operationalizing the context. The value of a research contribution is, however, not necessarily the same as its applicability in praxis. These are the understandings on which we will judge the work in the following two cases.

CASE ONE: THE TEXTILE FORM OF SOUND

The Textile Form of Sound is a project investigating the relation between sound, textile, and form. The purpose is to study how acoustic and aesthetic desires can be equally obtained through forming and situating textiles in various ways in an architectonic context.

How spatial forms can regulate sound and through that create strong aesthetic qualities has been widely studied within architecture both in theory and in practice (cf., Long, 2006, Rasmussen, 1957, Blesser & Salter, 2007). These studies, however, primarily deal with spatial forms derived from conventional building materials such as stone, glass, and wood, with little or no mention of textiles.

Figure 1 Bagsværd Church, designed by Jørn Utzon is an example of how the regulation of sound have influenced the form of the room especially the ceiling. Photo by: Søren Kuhn

Furthermore, research in acoustic regulation with textiles, has primarily been focused on textiles' inherent acoustic properties meaning the properties procured by virtue of the fibers, their density and weight, and the way they are joined together (cf., Tooming, 2007, Rindel, 1982, Persson & Svensson, 2004). Whereas research, on acoustic properties obtained through forming and situating the textile, has been scarce. Sound, however, is a physical phenomenon dispersed through space, the physical formations of the space are likely to influence it. This makes probable that three-dimensional forms of textiles, and their situations will have an equal influence on the acoustics of the space. Also, when introducing form and situation into textile sound regulation it opens a new realm of aesthetic expressions ready to be explored.

Based on three different experiments this project sets out to study various aspects of the relations between textile, form, and sound. The first experiment investigates techniques to create textile architectonic forms. The second experiment measures the acoustic properties of various textile forms and situations. And the third experiment (still ongoing) combines the results from the others and investigates how textiles techniques can create forms to regulate acoustics and still perform aesthetically in an architectonic context.

Experiment One

In the first series of experiments, we employed different textile techniques to create functional forms yielding to an aesthetic ambition of expressing a spatial sensation. The purpose of these experiments in the overall project was to develop an understanding of textile forms as architectural elements.

Textiles generally consist of fibers woven into each other in a way that forms a plane. The plane appears continuous as a material capable of dividing space, but it is merely an accumulation of small spaces enclosed by material. Inspired by this duality we experimented with different scales and weaving techniques to, on one side, emphasize the perforated structure, and on the other side keep the continuous plane capable of dividing space. Furthermore, a woven textile consists of layers. By separating them and introducing a depth in the plane the textile will literally gain two sides each expressing their aspect of the duality. In a woven structure, however, the threads intertwine in a way that makes them curve. These curves hold together the structure as a plane but counteract the intention of separating the layers to enhance the spatial airy expression. So we developed a special weaving technique, which avoids curving the threads and still created the closed plane. The figure below is a demonstration of the technique used on ten cm wide textile bands as threads.

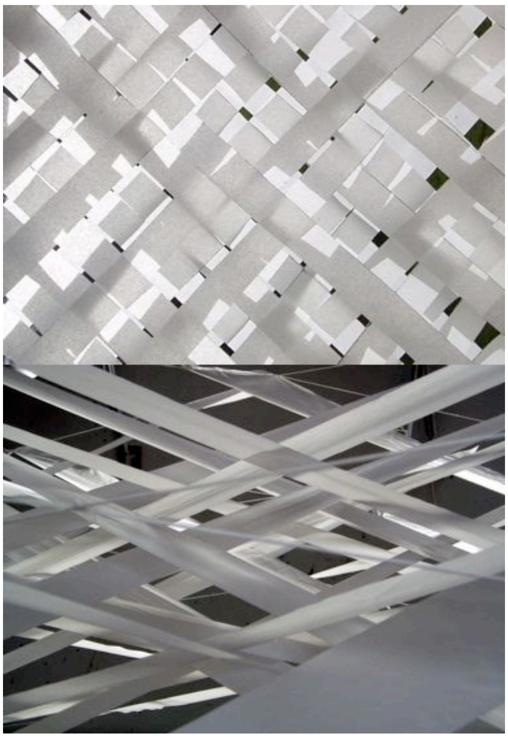

Figure 2 Above: the textile structure is seen from the front. Here it forms an almost closed plane. Below: the textile structure is seen from the side. Here it forms an open matrix of crossing bands.

This weaving technique let us create a textile form in which the space extends into the plane and dissolute it as a continuous element. This textile form blurs the boundary between the spaces on each side, but still it maintains a visual screen between the two. It will let the wind flow through while the sunbeams are withheld.

Experiment Two

The second series of experiments was an investigation of the acoustic importance of textile form and location in an indoor space. The aim was to form a general understanding of the correlations between acoustic qualities of a space and the textile's forms and locations in that space. We conducted altogether 100 experiments.

In one of them, we investigated the acoustic absorption potential in relation to the distance between the textile and the wall. Sound consists of waves, and its frequency determines the wavelengths. The experiment was conducted in a laboratory using a frequency analyzer to measure the reverberation time, meaning the persistence of sound in the room after the original sound was made. When sound waves are absorbed in the textile, the reverberation time goes down. We started by analyzing the most simple textile form—the straight plane, in order to focus on the relations between the situation of the textile and the reverberation time. The textile was a canvas of woven cotton (325 g/m^2) mounted on wooden frames in pieces of five m^2. In the laboratory we placed the mounted canvas in distances of 2, 50, 100, 150, or 200 cm from the wall. The test sound was made blowing paper bags, which created a sound containing the whole spectrum of frequencies.

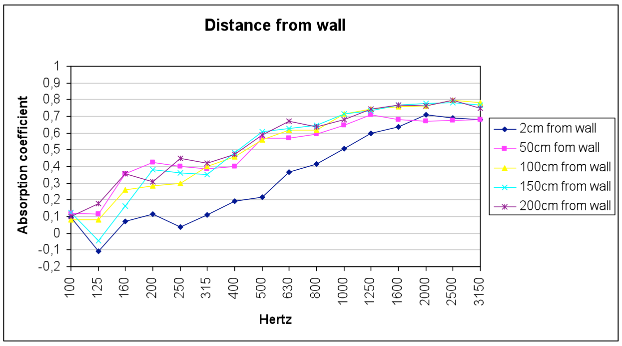

Figure 3 A diagram showing the reverberation results of five different canvas locations

Analyzing the test results it became apparent that the distance between the canvas, and the wall played an important role. The diagram (in Figure 3) shows that the reverberation time is approximately the same when the canvas is placed 50, 100, 150, or 200 cm from the wall. In these locations the canvas turned out to exhibit only little absorption of the low frequencies, more in the middle range while it proved most efficient with respect to the high frequencies. Where the canvas placed two cm from the wall generally exhibited lower absorption abilities—especially regarding the low and middle range frequencies. Thus, the textile plane should be placed above two cm from the wall to exhibit its full potential of frequency absorption. Fifty centimeter, however, is a sufficient distance just as any distance between 50 and 200 cm is equally efficient.

Experiment Three

In the third experiment we combine the knowledge from the two preceding experiments to investigate how to develop textile forms with acoustic regulation abilities suitable for architectonic contexts. This experiment is barely begun.

The architectonic context is narrowed down to three acoustic interesting spaces: multiple divided spaces (e.g., office cubicles), spaces for performance (e.g., auditoriums), and passages (e.g., hallways). The general approach is inspired by Utzon's church (See Figure 1) in the sense that the acoustic effects will lay the ground for the textile's forms and locations within the three types of spaces. The process will be a negotiation between acoustic measures and aesthetic qualities to gradually create textile forms suitable for the chosen spaces. The aim is to explore the textile shape of sound in an architectonic context and thus develop knowledge of how textile forms can enter architecture as more than subsequent acoustic patches.

CASE TWO: COMPUTATIONAL COMPOSITES

Computational Composites is a project about understanding computers in a design context. There are several notions of the computer; for example, as a logic machine, as an instrument to manage complex models and procedures, as a media device, as an information, or communication technology, or as a tool for word-processing, accounting, or drawing. When it comes to understand its role in design, however, there seems to have been more attempts of concealment (e.g., the invisible computer (Norman, 1999), the unremarkable computing (Tolmie, 2002), or the seamless and ubiquitous computer (Weiser, 1991)) than of articulating its inner workings and its properties relevant when utilizing it in designs. With this project we thus, sat out to investigate and articulate the computer in a material and practical context of design.

Computational Composites
The first part of the project was a theoretical comparison of the computer and traditional materials as used for design. The purpose was to see whether a material view of the computer would afford an understanding and enable an articulation suitable for developing new expressions of computational artifacts.

For example, we realized (Vallgårda & Redström, 2007) that a computer in and by itself is worthless and that it always must be in composition with other materials for the computations to come to expression. We derived at this notion from the fact that computations consist of energy manipulated in a delicate system of capacitors and connections and that the binary construct is a matter of whether energy is flowing or not. Though humans possess a sensitive sensory system, we cannot immediately detect whether the energy flows or not—at least not at this level of voltage. From a material point of view this means, that a computer needs to be part of larger material composition to come to expression. Hence, we arrived at the concept of *computational composites*, which is the material form that a computer must always find itself in when it is an element for design. A composite, composed of a computer, and one, or more materials capable of responding to the energy output of the computer and reflect the binary changes accordingly.

Experiment One
The first experiment (Vallgårda, 2008) was designed to ascertain whether the material understanding of the computer appeared advantageous in producing new expressions. The task was to create a computational composite and to do it so it had no immediate or useful functionality but a potential to spark the imagination of other computational composites. To escape the traditional expressions of computations—including the various tangible displays—we chose to take an offset in the other parts of what was to be the composite. The idea was to change the expression of an already familiar and traditional material through the computer's ability to conditionally control changes between two or more states. Also, the expression we sought was to be strangely familiar as an attempt to make the parts and the whole stand out at the same time giving the observers some handles to rearrange the material components in their imagination (cf., Blauvelt's strangely familiar (2003), or Dunne's parafunctionality (2005)).

We chose wood for its tradition, its flexibility, its strength, its natural occurrence, and its general disassociation with computers. As expressive modes we chose a combination of sound and movement creating an almost humanoid cause-and-effect (*if* sound *then* movement). The resulting material (called PLANKS) is a plank of pine gradually bending towards the observer when the sound rises above a certain threshold (adjustable to the context) and gradually rising to a straight position with declining sonic activity.


Figure 4 Nine PLANKS placed on a stand shown from the front and the back with the visible computational layer.

The PLANKS are not displays of computations rather the computations are a way to achieve an expression of the material, in this case, through translating sound into movement in the wood. The PLANKS, however, can be used to build displays, for instance, of the noise in the room, but they can just as well be used to add a non-practical aesthetic expression to the walls of a room. The PLANKS exemplify a computational composite but more than that they hold an expression new to both wood and computers. They exemplify how we can combine different material components in new ways, how we can make ordinary materials behave differently by adding computations to their composition.

Experiment Two
If the first experiment established some ground for the potential of working with the computer as a material it did not give much insight into the computer's material properties. Material properties can be seen as the characteristics of the material that tells us how it will behave and appear in certain situations. Knowledge that is valuable when discriminating one material over another in a design situation.

Hallnäs and Redström (2006) already identified temporality as a significant property of computations.

They argue that as computations are sequences of events in time, any meaningful incorporation of computational technology must adapt a temporal form. More can be said, however, about the potential of the computations in a material context. Through studying the principles of the computer, we can easily determine some properties and infer whether they may play a role in a material context. To be able to understand how they will come to expression as material properties, however, we need to explore them in praxis. With this series of experiments we will study: the ability to control events outside the computer and the ability to form networks with other computers.

Control is about causality. Through more or less sophisticated algorithms (confinements on the energy flow) the computer can exhibit practically any desired cause-and-effect (if X then Y). In a material context this means, for instance, that any normal behavior in a material can be exaggerated, moderated, reversed, or in other ways modified. The only restrain is that there exist elements (transducers) outside the computer capable of sensing the causes and execute the effects on the computers command.

Figure 5 Illustration of a computational composite that turns colder the more you attempt to heat it up.

To experience this property we are in the midst of making a computational composite with the ability to turn cold when warmed up and warm when cooled down. Through using copper, Peltier elements (elements for heating or cooling depending on the direction of the current), temperature sensors, a power source, and a small computer we create a composite material with a behavior contradicting any previous experience with copper and similar metals. The copper still behaves as it always does when exposed to shifting temperatures, but the computer inverts the general behavior through exercising a control over the Peltier elements and thus producing a counter effect.

Connectedness in a material context is traditionally about apparent physical coherence. Introducing the computer's ability to form wireless connections of computations produces an opportunity to form composite materials that are physically divided yet behaves, as were they physically coherent. This could for example be a physically disjoint material behaving thermodynamically as if it were one entity, which would mean that if one part of the material were cooled down all the parts would respond through adjusting to a new equilibrium.

The experiment is designed to explore the experience of the connectedness in a disjoint material. With the same ingredients, as used above, we build a material sample allowing us to explore the relations between the computations and the material.

Figure 6 An example application of a material, which is physically dispersed but thermodynamically coherent. For instance, the warmer the cop is the warmer the back of the seat and the area of the table gets and *vice versa*.

The Becoming in Materials

If these experiments in their ways establish the ground for making the connection between computers and materials, it leaves us obliged to ask what type of material the computational composites are. What have we done to our understanding of materials by including computers?

According to Manzini (1989) we seem to operate with two views of materials: their *being* and their *doing*. The first view especially addresses the generic materials we have known and worked with through generations (e.g., stone, wood, textile, clay). Materials, which can serve many purposes and which properties we know through direct experience. The other view especially addresses the materials developed with designated purposes, materials that are characterized by their functionality (e.g., plastic, electroluminescent film, or self-cleaning clay tiles).

Through experiencing computational composites both the ones made in the experiments, and those done by others (cf., Chronos Chromos Concrete (Ritter, 2007) or smart textiles (Post *et al.*, 2000)), and through contemplating what type of material a computational composite is it becomes apparent that a significant trait in these composite materials is their ability to change expression between two or more states and to do so repeatedly—sometimes in accordance with changes in the environment. We know other materials to patinate, degenerate, and decompose thus; gradual change is not new to materials. We also know materials to repeatedly change expression according to contextual conditions—the most apparent being light, which can change the expression of a surface; for instance, when the sunbeams move over a façade during the cause of the day they change its color drastically. Computational composites, however, invites us to see this behavior in time as more significant as these materials explicitly holds the ability to constantly assume other states (expressions) under certain conditions makes them constantly *come to be* in interaction with their environment. To comprehend these materials' potential we thus need to apply a third to Manzini's two views namely that of *becoming*. Thus the computational composites along with other new smart materials (e.g., shape memory alloys or thermoplastics) emphasize a new aspect of the material world.

OPERATIONALIZATION

These two cases represent a series of different approaches to developing new knowledge for design. Both, however, rely on operationalizations of materials to form the ground for their reasoning. We will in the following sections use the cases to develop an understanding of these operationalizations. How they are designed to ensure suitable and sufficient resistance.

First, however, let us recapitulate what we mean by operationalization. Operationalization is the act of exposing a subject matter to a situation in order to gain access to knowledge about it—its properties and potential. We need various ways of operationalizing the world around us to engage with the parts that are not immediately present or knowable to us. For example, we can immediately see that the leaf on a tree is green, but we need to expose it to various chemicals and study it in microscopes to know why. Operationalization is thus, the act that enables us to present the subject matter as distinctive premises, which then can form the foundation for reasoning. The premises are not independent of the type of operationalization but partly defined by it; for instance, the table length is given in centimeters if the ruler is divided in centimeters. Furthermore, the operationalizations also provide the resistance to shape or reshape our ideas. They can inspire new connections and contribute to developing new possibilities.

There are two main influences on the operational design in a material experiment. The first is the purpose of the operationalization—what type of knowledge is it that we are seeking? The second is the material conditions, what type of material or form are we are dealing with—how approachable is it?

THE OPERATIONAL PURPOSE

In the two cases presented above we see two different purposes for the material operationalizations. One is to explore an idea, either an articulated theory or merely an urge. The operationalization will in this case be a manipulation of materials as a means to form a resistance to the idea, for example, to explore how the idea can be materialized, or merely to exemplify its value through embodiment. This type of operationalization is about forming and exploring a new design space. The second type is formed by a desire to gain a better understanding of the material or form at hand. This type plays a more indirect part of rendering new design spaces, as its purpose is to allude to the spectrum of possibilities through knowledge of what lay before us.

Rendering New Design Spaces

In the first series of experiments in the first case various techniques are applied to textiles in order to create forms that satisfy a rather vague set of aesthetic and functional intentions. Manipulating the textile into a form is the act of operationalizing the material—we engage with the material resistance. In this particular case, it brings forward an architectural form, which explicates a relation between space and material also found in woven textiles. First, magnifying the threads into ten cm wide bands accentuates the spatial relations within textiles and makes them available for direct experience. This magnification also provides the premise on which we can reason textiles' applicability as a spatial element on an architectural scale. Second, developing the new weaving technique, which avoids curving the bands, enables us to create a form that has both depth and width, and which exhibit the almost paradoxical aesthetics of being airy and permeable yet a continuous plane. This textile form suggests a relation between space, material, and scale, which satisfy the intentions of the textile architectural elements. This form, however, is only one in a series of forms that together constitute a more elaborate satisfaction. They claim novelty in their forms and techniques, but they do not claim to be exhaustive representations of the all-possible forms. By embodying some significant aspects of the relation between textiles and architecture, however, they render a new design space—they expand the border of what is *thinkable and possible*.

In the first case's third series of experiments, the operationalization will be to develop textile forms with specific acoustic qualities and to install them in chosen architectural contexts. The operationalization will be to shape and reshape the textile using all the knowledge obtained in the previous experiments and to estimate how the textile forms can find a functional and aesthetic place within the architectural contexts. The purpose of these experiments is thus, also to render a new design space for architectural acoustic textile forms.

In the second case, the experiments are weighted slightly different. First, developing the concept of *computational composites* can in itself be framed as an experiment where the notion of materials is used to explain the computer. This experiment is not a negotiation with materials, but a negotiation between conceptions. We operationalize the notion of computers by exposing it to the notion of materials. Through meticulously explaining every aspect of the computer in terms of material traits the premises for understanding the computer as a material for design are laid out. But, whether this concept hold any value is difficult to judge from theoretical endeavors alone. It is a new way of thinking, and it is possible in theory.

The first material experiment is therefore arranged to evaluate whether the material approach is feasible in practice and whether the concepts can inspire new expressions of computers in a material settings. It is an operationalization, which is to embody the suggested new design space of computational composites. It is a materialization of a computational composite seeking the resistance from the actual construction and from the possibilities rendered by the new concept. The choices of materials and expressive effects are made from the need to achieve a new expression of a material for design. The strategy was therefore; first, to focus on the expression and let the function be secondary, second to aim for something strangely familiar, and third to build a prototype of a material sample that in theory can be utilized in design of something. The resulting composite material is the outcome of a negotiation between the concept of computational composites, the elements of the strategy, and the materials. For example, as a possible offset for the composite we examined wood since it is a material not traditionally associated with technology. We identified some expressions in wood made possible only through a composition with a computer-controlled force. We found that a thin plank of pine had the strength and flexibility that would allow us to continuously flex it to an interesting degree. We estimated that such behavior could create a strangely familiar expression since bended planks represented a common expression, but moving planks did not. The sonic sensitive bending planks embody only few aspects of the new possibilities claimed by the concept of computational composites, but it is sufficient to establish some value of the concept. It is able to link the theoretical articulation of computers as a design material to a practice of design.

Gaining New Knowledge of Materials

In the first case’s second series of experiments, the textile forms are tested for their acoustic qualities. The operationalizations constitute placing the textile forms in the room and expose them to the sound of an exploding paperback, and a specialized instrument catches the outcome of the operationalizations (the reverberation time). Together with acoustic theory this instrument provide an alternative to rely directly on human perception. It enables us to perform the experiment with simpler operationalizations than if we were to rely directly on user experience. The layout of such a study would, most likely, require an experience report from a significant number of users. Instead, we rely on an instrumentalization of the user experience. In this experiment, the measurements serve as the premise on which we can reason about the tested textile forms’ ability to absorb the range of frequencies and the significance of their situation in the room. This type of operationalization enables development of new knowledge of the materials and forms, knowledge which is valuable to render what is possible.

The second case’s other experiments are grounded in the material science tradition of studying the properties of materials—properties being the characteristics that enable us discriminate one material from another. The computer, however, cannot be studied in and by itself due to its lack of humanly perceivable expressions. We are therefore obliged to divide the study of its material properties into a theoretical inquiry of computers to identify possible material properties and a development of material samples especially attuned to express those properties. The two materializations embody only a small sample of what can be done to gain a better understanding of the computer as a material for design, but equivalent experiments will gradually materialize the computational composites as a new material for design. These material samples constitute the operationalization that enables us to discern what is possible with computers in a material context.

The last element of the second case is not an actual experiment, but a reflection on the premises revealed by the computational composites and put in a context of Manzini's notion of material views. The outcome serves as an additional focus on materiality and captures aspects of materials that always existed, but has not been significant to design before the introduction of smart materials and computational composites. Also, placing the new computational composites in relation to other materials contributes to a better understanding of them as materials.

MATERIAL ACCESSIBILITY

Textile is a material directly accessible to us, we can weave, cut, shape, sew etc. and thereby get an immediate tactile experience that helps us form an understanding of the materials potential. Computers, on the other hand, are only accessible to us by proxy and thus, to gain an understanding of its potential we strongly depends on a theoretical superstructure. The two materials thus can be seen to represent each end of a spectrum in terms of accessibility. The two cases also differ in their experimental setups. In the first case the textile allows for an immediacy of testing an idea, just as the ideas seems formulated in more direct negotiation with material manipulations. In the second case the layers between the computer and the researchers affect the ways with which ideas can be formulated and tested. The immediacy is to some extend substituted with theoretical contemplations; thus, the role of the material resistance in developing knowledge of the computational material for design is toned down in comparison, however, still necessary to ensure the validity of the theoretical contemplations and also at times to inspire new ideas.

Another dimension of material accessibility, one less expressed in the two cases, is the matter of skill needed to operationalize them. While weaving and sewing requires some skill it is not hard to master, and merely bending and cutting textile requires no particular skills; thus, operationalizing textile is also in that respect very accessible. In comparison, blowing hot glass into an object requires plenty of training so even if glass is tangible (and breakable) in its cold state it is not accessible to us in terms of operationalizations with same immediacy as textile. Further, the computer's energy flow is generally formed through arranging representations in form of a program, an act which also has undergone some theoretical abstractions to bridge the gap between humans and the inaccessible energy flow. The skill of programming is, because of the abstractions, another reason for the slighter immediacy and more weight on the theoretical superstructure needed to operationalize the computer to gain knowledge about it.

CONCLUSION

In this paper, we have shed some light on what operationalizations in material experiments can look like and how they can produce valid and valuable knowledge. We have, for instance, argued that manipulating textiles into architectural forms constitutes a valid premise for developing knowledge for design _exactly because the material is engaged as a resistance to the ideas. On the same account, we have argued that computational composites constitute a valuable perspective on computers in respect to forming new expressions. We have also argued that the accessibility of the materials influences the means with which we can operationalize them—the less accessible the more weight needs to be given to the theoretical superstructure. The other significant influence on the operational design is the reason to carry out the experiment whether it is a quest for deeper understanding of a subject matter or whether it is a quest for new frontiers.

One point of focusing on the operational part of experiments is the opportunity to show why the material resistance constitutes a valid and valuable foundation for developing knowledge for design in line with, for instance, user studies. Another point is that it enables us to become better attired in subsequent experiments to determine which type of operationalizations will suit the purpose better.

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