



# Touching Materials Visually: About the Dominance of Vision in Building Material Assessment

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Designers' visual way of knowing and working tends to be highly valued in design research. In architecture such an approach is increasingly criticized. Since people experience buildings with all their senses, architects' visual focus is said to run the risk of disregarding non-visual aspects. This study focuses on the visual and tactile assessment of building materials. Analyses show that architecture students assess several experiential qualities differently by touch than by vision. Vision dominates the overall assessment, yet does not always anticipate touch correctly. Moreover architecture students seem to be unaware of how common building materials feel, and are unable to identify them by touch only. This identifies the need for a more elaborate consideration of non-visual aspects during design in general and design education in particular.

**Keywords** – Architectural Design, Built Environment, Design Education, Materials, Perception.

**Relevance to Design Practice** – This study investigates the visual and tactile assessment of materials in an architectural context. The results reveal a dominance of vision and highlight the need for a more elaborate consideration of tactile material aspects in architectural education.

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## Introduction

People interact with the built environment through all their senses: They see the light and colors of a space, hear sound reflections, smell and feel the properties of its materials. Despite all senses being involved in people's architectural experience, during the design process architects often focus on the visual aspects (Pallasmaa, 2005). Numerous design projects are prized for their visual qualities. Nonetheless, some of these buildings, like Jørn Utzon's Sydney Opera House and Zaha Hadid's Fire Station in Vitra, have caused considerable problems for their occupants (Franck & Von Sommaruga Howard, 2010). Whereas the visual way of "conceiving architecture" may be considered as a strength of the design process by the design research community (Cross, 1982; Goldschmitt & Porter, 2004; Lawson, 2000), a multisensory approach to design is more likely to appeal to the building's users.

This paper presents the results of an investigation into what extent architecture students are guided by the senses of vision and touch when assessing materials for indoor wall applications. The study shows that the students' experience of material properties is largely determined by what they see, rather than by what they experience through touch.

## Visual Focus in Architecture

Architecture is a visually oriented discipline. For instance, remarkable buildings are widely documented with pictures and drawings in architectural magazines and on architecture websites. In addition, architects—like other designers—use a number of visual representation techniques (such as sketches, diagrams,

concept drawings) to not only communicate their ideas to others, but also as analytical tools to organize their thinking (Cross, 1982; Lawson, 2000; Schön, 1983). Designers think and work primarily in a visual way. It has been argued that this visual way of knowing and working is a skill specific to designing and distinguishes design from the sciences and humanities (Cross, 1982).

The visual focus in design has been identified as a strength specific to designers in several papers (Cross, 1982; Goldschmitt & Porter, 2004; Lawson, 2000). However, in the context of architecture, this visual focus is increasingly regarded as a weakness as well (Dischinger, 2006; Heylighen, 2011; Pallasmaa, 2005). Whereas the visual provides a practical means to represent and communicate ideas, it increases the distance to how space is actually perceived (Franck & Lepori, 2007; Heylighen, Devlieger, & Strickfaden, 2009). The way a space looks is obviously important, but people's experience of architecture is intrinsically multisensory in nature (Pallasmaa, 2005; Rasmussen, 1962). Space is "a place for many senses: sight, sound, touch, and the unaccountable things that happen in between" (Auping & Ando, 2002, p. 31).

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## Experiencing Materials in Architecture

It is crucial for architects—as for other designers—to anticipate people’s experiences, by being aware of the different sensory inputs and assessing them as such while making design decisions. This is especially relevant in the context of material selection. An architect’s design intention and the materials used to realize it are inextricably bound up with each other. In addition, materials’ inherent and associative qualities carry much of the design content (Malnar & Vodvarka, 2004). For architect Eva Jiricna, for instance, the key early decision is almost invariably about materials: “In a way material dictates the concept . . . and materials are not interchangeable . . . to me the material really is the starting point of the story” (Lawson, 1994, p. 52). The materials architects select during the design process thus contribute significantly to the experience of a space or building. According to Holl (1994) the materials are as important to perception of architectural space as the flavors of authentic ingredients are to the taste of a meal.

The immediate impact of material use on the architectural experience has received only limited research attention. In a study on the symbolism of building materials, researchers found that people attribute personality characteristics such as *warm-cold*, *artistic-nonartistic*, or *tough-tender* to building materials non-randomly, and concluded that certain components of a material’s personality are associated with its sensory qualities

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(Sadalla & Sheets, 1993). In an architectural context, studies about the link between materials and people’s perception mainly focus on the direct impact of color. Color psychology and the meaning of color in different cultures has been studied extensively (e.g., Derefeldt, Swartling, Berggrund, & Bodrogi, 2004; Gao & Xin, 2006; Valdez & Mehrabian, 1994). In addition to the more fundamental color investigations and theories in architecture (Albers, 1971; Itten, 1970), a number of recent studies have focused on the impact of color in specific environments, such as hospitals or educational facilities (e.g., Dalke et al., 2006; Stone, 2001; Yildirim, Akalin-Baskaya, & Hidayetoglu, 2007). Researchers found, for example, that cool colors, such as blue and green, promote relaxation, while *warm* colors, such as red, orange, and yellow, promote physical and social activity (Gulak, 1991).

When architects select materials in the design process, they consider technical and functional aspects, as well as aspects related to sensory effects and experience (Wastiels & Wouters, 2012). It is the context and given condition that drives the architect’s considerations during this selection process and certain projects may invite architects to consider more carefully the (multi)sensory aspects. For example, when designing a concert hall, a performance space, or an auditorium it seems logical to consider the acoustic quality (Heylighen, Rychtáriková, & Vermeir, 2010). In the design of buildings for blind people, e.g., a school (Herssens & Heylighen, 2011) or a rehabilitation center (Nijs, Vermeersch, Devlieger, & Heylighen, 2010), touch is more likely to be taken into consideration explicitly while selecting materials. However, these multisensory considerations of feeling and hearing materials are also relevant in other circumstances. Building occupants tend to touch various types of building surfaces either consciously or unconsciously: People stroll over floors, lean up against walls, or open and close doors. It is up to the designer to account for these different interactions by considering different touch related aspects in the design—like spatial configurations and material parameters such as roughness, warmth, or weight (Herssens & Heylighen, 2011).

Knowing that architects are trained to think and work visually, we are interested in the dominance of vision in assessing materials. To what extent do architects have the tendency to be guided by visual arguments or features while selecting materials? In addition, we are interested in the differences in assessment in the presence or absence of vision. To what extent does the assessment of materials change when being forced to focus on one of the other senses, like touch? This paper explores how architecture students with different levels of educational training assess materials when using vision versus touch and considers the possible dominance of vision in their multisensory assessment.

## The Present Study

The study presented here consists of two parts. In the first part, architecture students were asked to assess a set of building materials by using a list of attributes in three different sensory conditions: (1-VIS) *vision* only, (2-TAC) *touch* only, (3-GEN) *general*, meaning both vision and touch. The list contained visual aspects (e.g., gloss), touch related aspects (e.g., warmth) as well as aspects with an associative character (e.g., lively). In the second

part, participants were asked to provide keyword associations for each material. The setup closely resembled the situation in which architects compare and select materials for a building, based on small-scale samples available from material manufacturers and suppliers, for instance in a showroom. In the light of the discussion above, the results provide insights in how architecture students prioritize their senses when evaluating materials based on small-scale samples.

## Method

### Participants

In the study 116 people participated (60 women and 56 men) with ages ranging from 17 to 25 (mean age 21). The participants were undergraduate and graduate students in architecture (Architectural Engineering, Vrije Universiteit Brussel). Research has shown that architecture students gradually take on language codes and stylistic preferences of architects over the years of their studies, while becoming increasingly remote from the way laypeople describe and prioritize architecture (Wilson, 1996). This suggests that the way experienced architecture students describe and assess materials may largely correspond to that of architects. An investigation of the effect of the years of study on the assessment of the materials will reveal whether the sensory assessment by the architecture students indeed evolves with the years of study.

### Samples

The set of samples consisted of six building materials, commonly used in building projects: blue stone, brickwork, concrete, plasterwork, steel, and wood. They differed in material properties and appearance (thermal behavior, color, roughness) in order to provide different visual and tactile stimuli. Ideally, full scale material walls would have been used for the evaluation. However, due to practical limitations, the samples had a size of 0.4 m × 0.4 m. This implies that the whole hand could be used to touch the surface while differences in surface appearance could be spotted visually. The materials were fixed in white mdf-cases in order to provide a neutral and equal background for all samples. As the focus of the study is on indoor wall applications, the materials were presented vertically, at eye-height.

### Procedure

The experiment was conducted in an isolated test room at the university under controlled lighting conditions. When participants entered the room, all samples were covered with a black cloth. Evaluation occurred for one material at a time; participants were unable to see different materials simultaneously. Participants were asked to imagine the materials to represent a full-scale wall and received instructions on how to interact with the material depending on the assigned sensory test condition. In the general test condition (GEN), participants could freely interact with the material samples using vision as well as touch. In the visual test condition (VIS), participants were kept at a distance of about one meter, which prevented them from touching the materials. In

the third test condition, the samples were covered with a black cloth to focus on how the material feels without being distracted by vision. The latter condition is referred to as the tactile test condition (TAC). Auditory, smell and taste stimuli were constant for all test conditions, which allowed us to ignore their effect when comparing the different conditions.

During the first part of the test, participants were asked to complete, for each material, a list of 13 attribute pairs based on a 9-point itemized rating scale: *unpleasant-pleasant*, *simple pattern-complex pattern*, *not fragile at all-extremely fragile*, *not lively at all-very lively*, *not fresh-very fresh*, *mat-glossy*, *soft-hard*, *not denting-denting*, *not massive-massive*, *obtrusive-neutral*, *smooth-rough*, *textured-flat*, and *cold-warm*. This resulted in a set of quantitative data reflecting the assessment of the building materials in relation to the senses used for evaluation. During the second part of the test, participants were asked to provide three keywords for each material. Thoughts that first came to their mind while interacting with the materials were to be written down. The result was a qualitative data set containing keyword descriptions and associations for each material in relation to the senses used for evaluation. The test setup and procedure are described in more detail elsewhere (Wastiels, Schifferstein, Heylighen, & Wouters, 2012).

### Data Analysis

The quantitative data from the first part of the study were analyzed using the statistical software SPSS. The 13 bi-polar attributes were the dependent variables. Responses on the 9-point itemized rating scales were converted into numbers and analyzed as interval variables. For example, in the *mat-glossy* pair, *mat* corresponds to 1 and *glossy* to 9. Missing values (0.1%) were replaced by group means to allow statistical testing without losing too many observations. The independent variables used in the analyses were: *Material* (blue stone, brickwork, concrete, plasterwork, steel, wood), *Condition* (GEN, VIS, TAC), and *Education* (1<sup>st</sup> year bachelor, 2<sup>nd</sup> year bachelor, 3<sup>rd</sup> year bachelor, 1<sup>st</sup> year master, 2<sup>nd</sup> year master student). The *Material* variable varies within participants, while the other two variables vary only between participants.

First, the effect of the years of study (Education) is discussed. Then, the effects of the senses of vision and touch (Condition) are discussed in relation to the growing critique on architects' visual focus. Subsequently, the qualitative data from the second part of the study are presented. Different categories of material descriptions described in the literature were used to organize and analyze the keyword descriptions in relation to the senses used for evaluation. People describe (their experiences of) materials in different ways, such as naming the material, describing technical, and sensory properties, illustrating the use of materials, or describing the experiential behavior (van Kesteren, Stappers, & de Bruijn, 2007; Wastiels, Wouters, & Lindekens, 2007). Technical descriptions refer to material and manufacturing properties; sensory descriptions to all aspects of materials that can be sensed; descriptions of the material use relate to the usage (van Kesteren et al., 2007). Experiential behavior describes how materials are perceived and includes expressive meanings,

associative meanings, and emotions elicited by the materials (Karana, Hekkert, & Kandachar, 2009). Expressive meanings, such as *modern* or *feminine*, and associative meanings, such as *toy-like*, are not factually part of a material’s physical entity or appearance but refer to the meanings associated with the material (Karana, Hekkert, & Kandachar, 2010). Descriptions of emotions refer to the emotions elicited by the materials (Karana et al., 2009). Table 1 provides an overview of these categories with description and examples as suggested by Karana et al. (2009) and van Kesteren et al. (2007).

**Table 1. Categories of material descriptions used to organize the keywords.**

Categories	Description	Examples
<b>Materials (M)</b>	Naming the material	Plastics, wood, metals
<b>Technical (T)</b>	Material and manufacturing issues	Scratch resistance, strength, conductivity, mass production
<b>Sensory (S)</b>	Aspects of the material that can be sensed	Shiny, smooth, soft, warm, texture
<b>Use of materials (U)</b>	Descriptions related to usage of the material	Used in kitchen, user-friendly, hygienic
<b>Expressive meanings (EM)</b>	Values and personality characteristics attributed to the material	Modern, feminine, sexy, sober
<b>Associative meanings (AM)</b>	Associations requiring retrieval from memory and past experiences	Toy-like, associated with factories, business-like
<b>Emotions (E)</b>	Emotions elicited by the materials	Surprising, boring

## Results

### Years of Education versus Material Assessment

Analyses of Variance (ANOVAs) are used for testing differences in means between different groups. First, we verified whether students with different levels of education assessed the materials differently for the investigated attributes. This was done by performing a doubly multivariate ANOVA (Stevens, 2002), with the ratings on the 13 attributes as multiple dependent measures and *Material*, *Education*, and *Condition* as independent variables. The values of Rao’s F, corresponding to Wilks’  $\Lambda$  are used to report the multivariate effects. *Material*, *Condition*, and *Education* all showed significant main effects ( $p \leq 0.05$ ). Also the *Material*  $\times$  *Condition* interaction effect was significant ( $p < 0.05$ ). No significance was found for any of the *Education* interactions ( $p > 0.05$ ). Hence, only the main effect of *Education* is discussed in further detail to verify the differences in responses related to the years of education.

To further investigate the main effect of *Education*, we continued with univariate analyses for the 13 attributes, with the same set of independent variables. The degrees of freedom were corrected with the Greenhouse-Geisser  $\epsilon$  if  $\epsilon < 0.7$  and the Greenhouse-Geisser and Huynh-Feldt  $\epsilon$ -values were averaged for  $\epsilon > 0.7$  (Stevens, 2002). These analyses showed that the *Education* main effect was significant for *pleasant*, *hard*,

and *flat*. For all other attributes no significant main effects of *Education* were found ( $p > 0.05$ ). Paired comparisons with Bonferroni corrections revealed that first year students evaluated the materials to be *flatter* and *harder* than the more experienced students. For *pleasant* no significant differences were found between the different years of study. The latter outcome can be explained by the fact that the Bonferroni test is very strict, which might conceal the significance of certain paired comparisons. Given the few differences found between first year students and the other students (only for the attributes *flat* and *hard*), we can conclude that the years of architectural education hardly affected the participants’ assessment of building materials concerning the attributes under study.

### Visual, Tactile, and Multisensory Assessment of Attributes

#### Overall ANOVA

The *Material*  $\times$  *Condition*  $\times$  *Education* repeated measures ANOVA also provides insights in the roles of the different senses in the assessment of building materials by investigating the effects of *Condition*. The *Condition* main effect was significant for five attributes (*complex pattern*, *glossy*, *massive*, *rough*, and *warm*) and the *Material*  $\times$  *Condition* interaction was significant for 11 attributes (all except *fragile* and *denting*, see Appendix 1). These results reveal that the test condition—and thus the sense(s) used for evaluation—has a major impact on the assessment of the building materials. More detailed comparisons of the general and visual evaluations provide insights in the dominance of vision (or not) in the assessment of building materials. Comparisons between the visual and tactile assessment of materials reveal to what extent the assessment by touch differs from the assessment by vision.

#### Condition main effects

Paired comparisons with Bonferroni corrections allow us to investigate the main effect of *Condition* for the five attributes that showed significant differences between the test conditions (Table 2). We found no significant differences between the general and visual evaluations of the materials ( $p > 0.05$  for all attributes). This indicates that the participants’ visual (VIS) and multisensory (GEN) evaluations are similar for all attributes.

**Table 2. Paired comparisons with Bonferroni corrections: presenting the differences between the individual test conditions.**

Dependent variable	Paired comparisons		
	GEN-VIS	GEN-TAC	VIS-TAC
	<i>p</i>	<i>p</i>	<i>p</i>
simple pattern-complex pattern	1.000	0.000 *	0.001 *
matt-glossy	1.000	0.002 *	0.004 *
not massive-massive	1.000	0.015 *	0.046 *
smooth-rough	0.208	1.000	0.225
cold-warm	1.000	0.003 *	0.001 *

\* Effects significant at 0.05-level.

The tactile assessment (TAC) of *complex pattern*, *glossy*, *massive*, and *warm* was significantly different ( $p \leq 0.05$ ) from the evaluations where participants used vision (both GEN and VIS). For *rough* no significance was found. These results suggest that the sense of touch picks up different sensory cues than vision while assessing a material's *pattern*, its *gloss*, its *massiveness* and its *warmth*. The materials are generally perceived to be less massive during tactile evaluation than in the other conditions (Figure 1a). For the other attributes, the differences in assessment are material dependent (Figure 1 b-d), e.g., the pattern of wood and blue stone is perceived to be far more complex when using vision, whereas the pattern of plasterwork seems more complex when using touch.

### Material × Condition interactions

In order to conclude that the GEN and VIS conditions produce similar assessments for all attributes, we should also investigate the significant *Material × Condition* effects of the overall analysis in more detail. These interactions are most likely due to deviant responses in the TAC condition, but some might be due to differences between VIS and GEN for some specific materials. Therefore, we performed *Material × Condition × Education* ANOVAs with the data from the GEN and VIS conditions only. In the latter analyses, the *Material × Condition* interaction was significant for only 4 of the 11 attributes (*lively*, *glossy*, *rough*, and

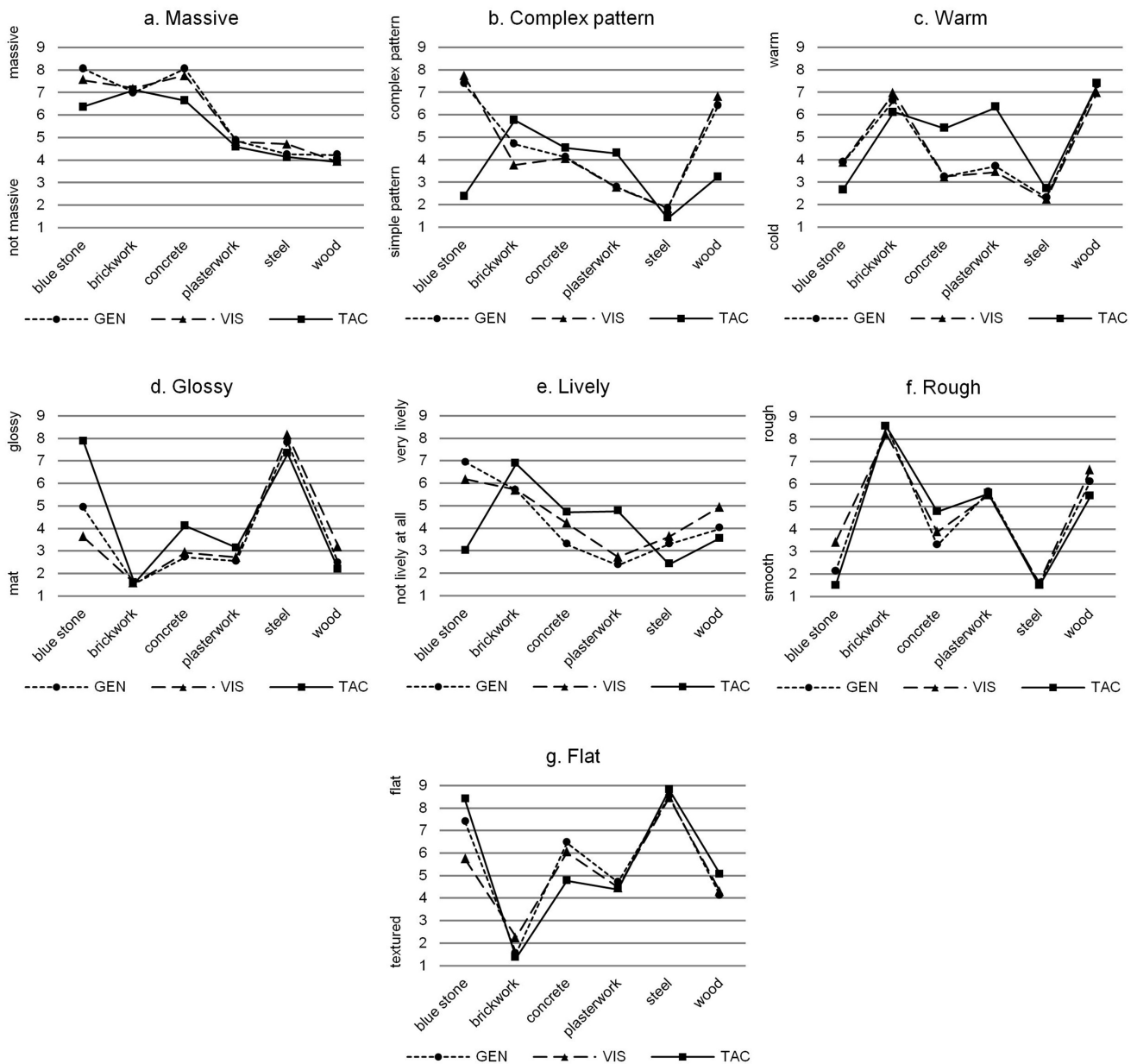


Figure 1. Mean responses to the different attributes, varying between 1 and 9, for the investigated building materials, according to the three test conditions (GEN, VIS, TAC).

Represented attributes: (a) Massive, (b) Complex pattern, (c) Warm, (d) Glossy, (e) Lively, (f) Rough, (g) Flat.

*flat*). Mean responses for these attributes (Figure 1 d-g) generally revealed similar responses in the general and visual test condition for the different materials. Nonetheless, we can see some small deviations, especially for the blue stone sample, which appears to be assessed differently for these attributes. Despite these few instances of deviations, our overall conclusion remains that participants' assessment of building materials generally does not change when being allowed to use both vision and touch compared to vision only, which indicates that the architecture students' general assessment of these aspects for indoor walls is dominated by vision.

### Keyword Associations

Different categories of material descriptions (Table 1) were used to investigate the kind and number of keyword descriptions in relation to the senses used for evaluation. The *Use of materials* and *Emotions* were described only incidentally by the participants and, therefore, they will not be discussed here. All other categories of descriptions can be richly documented by the data.

### Naming materials

Participants used material names, such as *concrete*, *metal*, or *wood*, to describe the materials they were seeing and/or touching. These material labels were found in all test conditions, but were clearly used more in the tactile test condition, *e.g.*, steel was labeled with a material name by 40% of the participants using vision only, but by 80% of the participants using touch only. The test condition related significantly to the number of material labels named by the participants,  $X^2(2) = 97.9, p < 0.001$ . One fifth of the descriptions were material names in the tactile test condition (21.0%), whereas this was only 4.8% in the general test condition and 7.0% in the visual test condition. This suggests that the desire to identify the material is larger when not being able to see it.

Another difference found between the sensory conditions concerns the correctness of the material labeling. Table 3 shows the material names the different samples were associated with by at least two participants. In the conditions where participants were able to see (GEN and VIS), all material labels corresponded (closely) to the actual material being assessed. When participants relied on touch only (TAC), many material labels did not match the material being assessed. During tactile evaluation the concrete sample was commonly associated with *wood*, for example, and *glass* was named repeatedly in association with the blue stone

sample. Only the steel sample was correctly identified as a metal during blind assessment. Whereas it was relatively easy to identify the material by vision, participants seemed to be misled when relying on touch only.

### Technical and sensory descriptions

A number of aspects of the materials' behavior were mentioned throughout the different test conditions by use of technical and sensory descriptions. Examples for each material are provided from the data in Table 4. The data showed a significant effect of the test condition,  $X^2(2) = 53.8, p < 0.001$ . Technical and sensory descriptions were used more frequently in the tactile condition (43.9%) than in the other conditions (28.4% for GEN, 22.2% for VIS).

Whereas certain aspects appear to be related more to vision (*e.g.*, color) or to touch (*e.g.*, warmth), these sensory descriptions were not that strictly bound to the respective senses used for evaluation. Concrete was, for example, most commonly associated with *cold* during the evaluation in the visual test condition, whereas none of the participants taking the tactile test mentioned *coldness* in their associations. In all test conditions brickwork was associated with *rough*, blue stone with *cold*, steel with *glossy*, and wood with *warm*. And although color cannot be perceived by touch, several participants named color properties in association to the materials they touched blindly.

### Meanings

Participants described expressive characteristics and associative meanings of the materials throughout all sensory test conditions. Examples of expressive characteristics are *cozy*, *industrial*, or *modern*. Associations were made to typical building applications and functions (*e.g.*, kitchen, façade, floor), objects (*e.g.*, snake skin, chocolate, lego), places (*e.g.*, Flanders, home, church, beach), persons (*e.g.*, mason, Le Corbusier, doctor), activities (*e.g.*, adventure, vacation), and atmospheres (*e.g.*, work atmosphere, coziness). More examples of expressive and associative meanings from the study are presented in Table 5 per material. A significant effect of the test condition was found,  $X^2(2) = 86.5, p < 0.001$ . Expressive and associative meanings—mostly relating to participants' personal experiences—were mentioned only to a limited extent by the participants in the tactile test condition (34.6%), but came up frequently when they used vision for the assessment (65.7% in the general test condition and 69.3% in the visual test condition).

**Table 3. Materials associated with the different samples during visual, tactile, and general evaluation by at least two participants.** Number of participants naming the association are given between parentheses.

Materials	General evaluation (GEN)	Visual evaluation (VIS)	Tactile evaluation (TAC)
<i>Material descriptions</i>			
brickwork	brickwork(6), stone(2)	brickwork(4)	brickwork(16), concrete(4), stone(3)
blue stone	marble(4)	marble(5), (natural) stone(5)	glass(10), metal(3), plastic(3)
concrete	concrete(9)	concrete(7)	wood(11), (natural) stone(3), gypsum(2)
plasterwork		gypsum(2)	wood(11), (wall) paper(3)
steel	aluminum(3), metal(2)	metal(7), aluminum(4), steel(2)	metal(22), aluminum(3), steel(3)
wood	wood(3)	wood(4)	wood(19), fabric/textile(6)

**Table 4. Examples of technical and sensory descriptions associated with the different samples during visual and tactile evaluation.**

Materials	General evaluation (GEN)	Visual evaluation (VIS)	Tactile evaluation (TAC)
<i>Technical descriptions</i>			
brickwork	strong(2)	good insulator(1), fire resistant(1)	grainy(2)
blue stone	expensive(4), heavy(3)	expensive(4), sturdy(3)	brittle(1), polished(1)
concrete	sturdy(4), bad insulation(1)	unfinished(3), strong(2), cheap(1)	heavy(4), fibres(2), thick(2)
plasterwork	unfinished(2), brittle(1)	light weight(2)	painted(3), cheap(2), bad insulation(1)
steel	flexible/bendable(4), sturdy(2)	bendable(1), thin(1)	painted(1), water repellent(1)
wood	unfinished(1)	light weight(4), unfinished(4), splinters(2)	fibrous(6), light weight(4), splinters(4), hairy(3), thin(2)
<i>Sensory descriptions</i>			
brickwork	rough(9), hard(3), warm(3)	warm(6), rough(3), red(2)	rough(10), hard(4), red(4), texture(4), massive(3)
blue stone	cold(8), dark(4), hard(3), smooth(2)	cold(5), dark(2), hard(2)	smooth(10), cold(9), glossy(7), massive(3), white(3), hard(2)
concrete	cold(7), hard(2), rough(2), soft(2)	cold(7), massive(3), rough(3), warm(3)	smooth(6), soft(5), hard(3), massive(2), rough(2), warm(2)
plasterwork	light(7), white(4), bright(3), cold(2), rough(2)	clear(3), white(3)	hard(7), white(4), warm(3), mat(2), rough(2), soft(2), uneven(2)
steel	cold(9), glossy(5), reflective(3), shiny(2)	cold(15), smooth(5), reflective(3)	cold(11), smooth(9), glossy(8), reflective(3), grey(2), hard(2)
wood	warm(11), soft(5), rough(3), pale(2)	warm(9), soft(1)	soft(9), rough (2), warm(2)

**Table 5. Examples of expressive and associative meanings mentioned by the participants during their visual and tactile evaluation of the building materials.**

Materials	General evaluation (GEN)	Visual evaluation (VIS)	Tactile evaluation (TAC)
<i>Expressive meanings</i>			
brickwork	trendy(1), modern(1), busy(1), aggressive(1)	enjoyable(2), traditional(2), modern(1), simple(1)	aggressive(1), traditional(2)
blue stone	luxurious(4), old(4), old-fashioned(2), lively(1), sad(1)	pleasant(1), classic(1), luxurious(4), sensual(1)	neutral(1), impersonal(1)
concrete	industrial(2), modern(2), open(1), sad(1), old(1)	unpleasant(2), simple(1), industrial(1), lively(1)	cozy(1), old(1)
plasterwork	neutral(9), pure(3), sterile(1)	neutral(4), simple(3), pure(3), modern(2), new(2), timeless(1)	neutral(1), banal(1), simple(1)
steel	industrial(7), modern(5), unpleasant(3), energetic(1)	industrial(3), modern(3), pure(1), austere(1)	clean(1), distant(1), industrial(1)
wood	natural(4), pleasant(3), neutral(1), fragile(1)	enjoyable(2), natural(2), honest(1), lively(1), playful(1)	(un)pleasant(2), cozy(1)
<i>Associative meanings</i>			
brickwork	house(8), façade(4), wall(4), outdoor(4), loft(1), lego(1)	house(9), façade(7), bricklayer(3), outdoor(2), nature(2), tradition(2), wall(2), red desert(1)	wall(5), house(3), pain(3), sanding paper(3), façade(2), tradition(1)
blue stone	nature(5), kitchen (counter)(5), floor(4), grave stone(3), aquarium(1), court building(1)	nature(3), kitchen counter(3), floor(3), rock(2), water(1), Rome(1), antique(1), grave(1)	ice(2), ice skating(2), mirror(2), bathroom(2), decoration(1)
concrete	industry(2), loft(2), structure(2), parking space(2), Tadao Ando(1), fossil(1), Russia(1)	industry(4), construction(2), modern architecture(2), garage(2), depot(2), structure(1)	animal (skin)(2), table(2), fur(1), stone-like(1), fireplace(1)
plasterwork	hospital(5), emptiness(4), modernism(2), snow(2), basic(2), cloud(1)	empty(5), museum(3), snow(3), hospital(3), wall(3), new building(2), doctor(2), Greece(1)	panel(3), toys(2), door(2), indoor(1), chalk board(1), crocodile(1), emptiness(1)
steel	industry(5), mirror(5), kitchen(3), bookshelves(3), car(3), construction(1)	industry(4), mirror(3), magnetic board(2), pot or pan(2), car(2), bookshelves(2), electricity(1)	fridge(2), boat(1), drum set(1), metal shovel(1), garage door(1)
wood	nature(7), furniture(6), tree (house)(5), garden shed(5), children(2), fire(2), chalet(1)	tree (house)(5), nature(4), scale model(2), sauna(2), fire(2), furniture(2), chalet(2), vacation(1)	clothing(3), furniture(2), couch(2), curtain(2), mustard(1), kiwi(1), carpenter(1)

## Discussion

### Tactile Evaluation Differs from Visual Evaluation

In this study we investigated to what extent the senses used for evaluation affect architecture students' assessment of materials. The results of the first part of the study showed that most attributes are scored differently when using vision versus using touch for evaluation. Only for *fragile* and *denting* no effects of the test condition were registered.

As the same list of attributes was used for the different test conditions, this result suggests that a distinction can be made between *visual* and *tactile* perceptions of the attributes. These perceptions may be affected by parameters that differ between modalities. Changes in color and/or lightness across the surface, for example, influence the *visual pattern* of a material. For instance, the graining of the wood and the stained surface of the blue stone are likely to have contributed to the high scores in terms of pattern complexity. Because variations in color and light cannot be perceived by touch, the *tactile pattern* of a surface will be determined by other aspects, such as changes in surface texture or roughness. The even and (relatively) smooth surfaces of the wooden and blue stone samples may explain the low scores on *complex pattern* during tactile evaluation. Because the perception of an attribute depends on the senses used for evaluation, it is important for architects to be aware of both visual and tactile aspects of a material when assessing and selecting materials.

The qualitative analyses showed that when participants use vision, they make associations to aspects, objects or situations the material reminds them of: *construction site, industry, outdoor*, etc. Participants relying on touch make associations that describe the material itself: *smooth, soft, heavy*, etc. Judging from these descriptions, participants mainly seem to describe the physical characteristics of the material when evaluating a material by touch only, whereas the actual physical behavior loses importance and participants start to associate meanings to the materials when using vision. This suggests that when using vision participants are guided more by personal experiences than the momentary physical/sensory observation and this corresponds to the finding that visual information leads to more cognitive interpretations and less sensory impressions (Hinton & Henley, 1993).

The fact that concrete was evaluated to be colder when using vision compared to using touch can be explained by a combination of the findings mentioned above. First, one can distinguish between *visual* and *tactile warmth*. *Tactile warmth* refers to how cold or warm a material feels to touch (Ashby & Johnson, 2002). Concrete's thermal properties play an important role in this warmth perception and explain why concrete feels rather warm to the touch (see Figure 1d). When including vision for the assessment, visual parameters such as gloss or color influence the warmth perception. This way, the cold grey color of concrete contributes to the perception of coldness during visual evaluation (Wastiels et al., 2012). Second, participants are guided more by cognitive interpretation when using vision: The associated meaning that concrete is a cold material, appears to take dominance over the actual physical characteristics and

sensations when vision is included for the evaluation. Finally, the actual warm feeling (during blind touching) might explain why participants associated the sample with wood. In addition, the hairiness of the surface—associations such as *hairy, little hairs, tickling, threads* or *fur* were made—probably also contributed to warmth perception and/or the idea that one was touching a wooden surface.

### Vision Dominates Material Assessment

In a balanced multisensory assessment, one expects the consideration of both visual and tactile aspects to have an impact on the overall judgment. The results of our study show that the visual and tactile assessment of a material can lead to distinctively different results. Importantly, the tactile components (*e.g.*, the thermal properties or the complexity of the tactile pattern) appear to be disregarded completely by participants when including vision for the evaluation. The fact that no substantial differences were found between the visual and general assessment for any of the attributes suggests that vision is by far the dominant sensory modality when assessing materials. This finding corresponds with the general finding that many objects are perceived first and foremost visually (Schifferstein & Cleiren, 2005; Schifferstein, 2006).

In the present study, the identification of materials on the basis of touch was in many cases inaccurate, while visual identification was, in the main, accurate. These findings contrast with observations for the identification of entire objects, where the performance for touch comes close to performance for vision (Klatzky, Lederman, & Metzger, 1985; Klatzky, Loomis, Lederman, Wake, & Fujita, 1993; Schifferstein & Cleiren, 2005). It would appear that the identification of materials alone on the basis of touch is much more difficult than the identification of objects, where also shape information is available. This seems to hold, even though the sense of touch has been shown to be more suitable for the precise assessment of material properties than the sense of vision, which is better equipped for the assessment of geometric properties (*e.g.*, Lederman & Klatzky, 1987, 1997; Lederman, Summers, & Klatzky, 1996).

The present study was not designed to evaluate the architects' material selection process, but to investigate the perception of materials. Hence, the roles of tactile, auditory, and olfactory perception during materials selection remain to be established. During the process of selecting materials for a specific application within a specific project, architects possibly pay more attention to the different sensory implications than when they evaluate building materials in an existing building. A study investigating architects' real-life material selection process for a project could provide a more realistic representation of the importance of the senses while selecting materials. Our study made use of small-scale samples and focused only on the role of vision compared to touch in the assessment of building materials. Future research using larger samples applied within concrete architectural settings or spaces could provide further insights in the perception of full-scale walls and should include all the senses.



## Attention for Non-Visual Material Aspects in Architectural Education

As the participants for this study were students in architecture, the findings presented here are relevant in the context of architectural education. The statistical analysis of the quantitative data revealed that the years of study of the participants (ranging between one and five years) hardly affected the way the different materials were assessed: Only the first year students produced systematically different results for the assessment of *flat* and *hard*. This suggests that, from their 2<sup>nd</sup> year on, students' visual and tactile assessment of the experiential qualities of materials does no longer evolve during their training. The fact that the number of years of training hardly affected the outcomes of the current experiment might imply that professional architects may have similar perceptual biases as naive consumers. In the context of the importance of the senses, this implies that vision dominates their experience of building materials and wall coverings.

In product experience research, Fenko, Schifferstein, and Hekkert (2009) observed that the sense of vision dominated the buying process for several products, but that the relevance of the other senses increased during the use stage. As architects and designers are expected to be able to anticipate the future use and experience of what they design, they should be trained to go beyond the initial distraction of vision. Whereas this study focused on interior walls, the tactile aspects of materials are likely to gain importance in architectural elements where the use of touch is more explicitly present, like floors being walked on, handrails guiding people along a staircase, or doors being pushed and pulled by people's hands or arms. For these elements, the dominance of vision may become problematic and begs the question for more conscious consideration of touch in materials selection and architectural design in general.

## Practical Implications

This study suggests that architecture students are mainly guided by vision when assessing building materials, even for outspoken tactile aspects like material warmth. The finding that vision steers their perception of building materials is in line with observations on consumers' perception of industrial products, suggesting that vision seems to capture the majority of people's attention during user-product interactions and, thereby, distracts from the other senses (Schifferstein & Desmet, 2007). In fact, our observation that the number of years of training hardly affected the outcomes of the current experiment might imply that professional architects may have similar perceptual biases as naive consumers.

The finding that several building materials were assessed differently when excluding vision for the evaluation illustrates the need for a more elaborate consideration of the non-visual senses during design as argued by Pallasmaa (2005). When selecting materials for a building project, architects should consider both visual and other sensory aspects of the material, keeping the final application and (sensory) interaction with the user in mind. In doing this, it is important to be sensitive to the different sensory

cues that may affect the experience and be conscious about the different meanings or interpretations of certain aspects. Looking for a massive material or one with an outspoken pattern, for instance, should be considered both in a visual and tactile way. The extensive use of visual representations in architecture unfortunately does not really help in taking these aspects into further consideration. As several design tools already allow for a multisensory approach, e.g., the material palette (Nijs et al., 2010) or Schifferstein's (2011) *Multi Sensory Design* approach, a first step towards a more sensitive approach to multisensoriality in architectural design would be to become more aware of what exactly architects assess when they select materials.

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## References

1. Albers, J. (1971). *Interaction of color*. New Haven, CT: Yale University Press.
2. Ashby, M. F., & Johnson, K. (2002). *Materials and design: The art and science of material selection in product design*. Oxford, UK: Butterworth-Heinemann.
3. Auping, M., & Ando, T. (2002). *Seven interviews with Tadao Ando, November 1989 - April 2002*. Surrey, UK: Modern Art Museum of Fort Worth.
4. Cross, N. (1982). Designerly ways of knowing. *Design Studies*, 3(4), 221-227.
5. Dalke, H., Little, J., Niemann, E., Camgoz, N., Steadman, G., Hill, S., & Stott, L. (2006). Colour and lighting in hospital design. *Optics & Laser Technology*, 38(4-6), 343-365.
6. Derefeldt, G., Swartling, T., Berggrund, U., & Bodrogi, P. (2004). Cognitive color. *Color Research and Application*, 29(1), 7-19.
7. Dischinger, M. (2006). The non-careful sight. In P. Devlieger, F. Renders, H. Froyen, & K. Wildiers (Eds.), *Blindness and the multi-sensorial city* (pp. 143-176). Antwerp, Belgium: Garant.
8. Fenko, A., Schifferstein, H. N. J., & Hekkert, P. (2009). Shifts in sensory dominance between various stages of user-product interactions. *Applied Ergonomics*, 41(1), 34-40.
9. Franck, K. A., & Lepori, B. (2007). *Architecture from the inside out*. London, UK: Wiley.
10. Franck, K. A., & Von Sommaruga Howard, T. (2010). *Design through dialogue: A guide for clients and architects*. London, UK: John Wiley & Sons.

11. Gao, X., & Xin, J. H. (2006). Investigation of human's emotional responses on colors. *Color Research and Application*, 31(5), 411-417.
12. Goldschmitt, G., & Porter, W. (Eds.). (2004). *Design representations*. London, UK: Springer Verlag.
13. Gulak, M. B. (1991). Architectural guidelines for state psychiatric hospitals. *Hospital and Community Psychiatry*, 42(7), 705-707.
14. Herssens, J., & Heylighen, A. (2011). Haptic design research: A blind sense of place. In *Proceedings of the 7th International Conference on Architectural Research*. Washington, DC: Architectural Research Centers Consortium.
15. Heylighen, A. (2011). Studying the unthinkable designer. In J. Gero (Ed.), *Design computing and cognition '10* (pp. 23-34). Dordrecht, the Netherlands: Springer.
16. Heylighen, A., Devlieger, P., & Strickfaden, M. (2009). Design expertise as disability and vice versa. In *Proceedings of the Communicating (by) Design Conference* (pp. 227-235). Brussels, Belgium: Hogeschool voor Wetenschap en Kunst St.-Lucas (Belgium).
17. Heylighen, A., Rychtáriková, M., & Vermeir, G. (2010). Designing spaces for every listener. *Universal Access in the Information Society*, 9(3), 283-292.
18. Hinton, P. B., & Henley, T. B. (1993). Cognitive and affective components of stimuli presented in three modes. *Bulletin of the Psychonomic Society*, 31, 595-598.
19. Holl, S. (1994). Questions of perception: Phenomenology of architecture. In S. Holl, J. Pallasmaa, & A. Pérez-Gómez (Eds.), *Questions of perception*. Tokyo, Japan: a+u Publishing.
20. Itten, J. (1970). *Kleurenleer*. Utrecht, the Netherlands: Cantecler.
21. Karana, E., Hekkert, P., & Kandachar, P. V. (2009). Meanings of materials through sensorial properties and manufacturing processes. *Materials & Design*, 30(7), 2778-2784.
22. Karana, E., Hekkert, P., & Kandachar, P. V. (2010). A tool for meaning driven materials selection. *Materials & Design*, 31(6), 2932-2941.
23. Van Kesteren, I. E. H., Stappers, P. J., & De Bruijn, S. (2007). Materials in product selection: Tools for including user-interaction in materials selection. *International Journal of Design I*(3), 41-55.
24. Klatzky, R. L., Lederman, S. J., & Metzger, V. A. (1985). Identifying objects by touch: An "expert system." *Perception & Psychophysics*, 37(4), 299-302.
25. Klatzky, R. L., Loomis, J. M., Lederman, S. J., Wake, H., & Fujita, N. (1993). Haptic identification of objects and their depictions. *Perception & Psychophysics*, 54(2), 170-178.
26. Lawson, B. (1994). *Design in mind*. Oxford, UK: Butterworth Architecture.
27. Lawson, B. (2000). *How designers think: The design process demystified* (3rd ed.). Oxford, UK: Architectural Press.
28. Lederman, S. J., & Klatzky, R. L. (1987). Hand movements: A window into haptic object recognition. *Cognitive Psychology*, 19(2), 342-368.
29. Lederman, S. J., & Klatzky, R. L. (1997). Relative availability of surface and object properties during early haptic processing. *Journal of Experimental Psychology: Human Perception and Performance*, 23(6), 1680-1707.
30. Lederman, S. J., Summers, C., & Klatzky, R. L. (1996). Cognitive salience of haptic object properties: Role of modality-encoding bias. *Perception*, 25(8), 983-998.
31. Malnar, J. M., & Vodvarka, F. (2004). *Sensory design*. Minneapolis, MN: University of Minnesota Press.
32. Nijs, G., Vermeersch, P.-W., Devlieger, P., & Heylighen, A. (2010). Extending the dialogue between design(ers) and disabled use(rs): From conversation to embodied skill. In *Proceedings of the 11th International Design Conference* (pp. 1817-1826). Glasgow, UK: Design Society.
33. Pallasmaa, J. (2005). *The eyes of the skin: Architecture and the senses*. London, UK: Wiley-Academy.
34. Rasmussen, S. E. (1962). *Experiencing architecture* (2nd ed.). Cambridge, MA: MIT Press.
35. Sadalla, E. K., & Sheets, V. L. (1993). Symbolism in building materials: Self-representational and cognitive components. *Environment and Behavior*, 25(2), 155-180.
36. Schifferstein, H. N. J. (2006). The perceived importance of sensory modalities in product usage: A study of self-reports. *Acta Psychologica*, 121(1), 41-64.
37. Schifferstein, H. N. J. (2011). Multi sensory design. In *Proceedings of the 2nd Conference on Creativity and Innovation in Design* (pp. 361-362). New York, NY: ACM.
38. Schifferstein, H. N. J., & Cleiren, M. P. H. D. (2005). Capturing product experiences: A split-modality approach. *Acta Psychologica*, 118(3), 293-318.
39. Schifferstein, H. N. J., & Desmet, P. M. A. (2007). The effects of sensory impairments on product experience and personal well-being. *Ergonomics*, 50(12), 2026-2048.
40. Schön, D. (1983). *The reflective practitioner: How professionals think in action*. New York, NY: Basic Books.
41. Stevens, J. P. (2002). *Applied multivariate statistics for the social sciences* (4th ed.). Mahwah, NJ: Erlbaum.
42. Stone, N. J. (2001). Designing effective study environments. *Journal of Environmental Psychology*, 21(2), 179-190.
43. Valdez, P., & Mehrabian, A. (1994). Effects of color on emotions. *Journal of Experimental Psychology*, 123(4), 394-409.
44. Vermeersch, P.-W., Strickfaden, M., Herssens, J., & Heylighen, A. (2009). Architects and visually impaired people. In *Proceedings of the 17th International Conference on Engineering Design [CD ROM]*. Glasgow, UK: Design Society.
45. Wastiels, L., Schifferstein, H. N. J., Heylighen, A., & Wouters, I. (2012). Relating material experience to technical parameters: A case study on visual and tactile warmth perception of indoor wall materials. *Building and Environment*, 49(3), 359-367.
46. Wastiels, L., & Wouters, I. (2012). Architects' considerations while selecting materials. *Materials and Design*, 34(2), 584-593.

47. Wastiels, L., Wouters, I., & Lindekens, J. (2007). Material knowledge for design: The architect's material vocabulary. In S. Poggenpohl (Ed.), *Proceedings of the 2nd Conference of the International Association of Societies of Design Research* [CD ROM]. Hong Kong, China: Hong Kong Polytechnic University.
48. Wilson, M. A. (1996). The socialization of architectural preference. *Journal of Environmental Psychology*, 16(1), 33-44.
49. Yildirim, K., Akalin-Baskaya, A., & Hidayetoglu, M. L. (2007). Effects of indoor color on mood and cognitive performance. *Building and Environment*, 42(9), 3233-3240.

## Appendix

### Appendix 1

**Appendix 1. Results of repeated measures ANOVAs (Material x Condition x Education): presenting the main and interaction effects of the material and the test condition.**

Dependent variable	Material			Material x Condition			Condition	
	F-value	p	*	F-value	p	*	F-value	p
unpleasant-pleasant	10.799	0.000	*	7.122	0.000	*	0.661	0.519
simple pattern-complex pattern	81.494	0.000	*	29.913	0.000	*	10.419	0.000 *
not fragile at all-extremely fragile	34.801	0.000	*	1.256	0.255		0.632	0.533
not lively at all-very lively	53.832	0.000	*	19.484	0.000	*	1.395	0.253
not fresh-very fresh	42.981	0.000	*	17.835	0.000	*	1.478	0.233
mat-glossy	241.406	0.000	*	14.059	0.000	*	7.981	0.001 *
soft-hard	79.689	0.000	*	1.900	0.047	*	0.084	0.919
not denting-denting	43.712	0.000	*	1.104	0.359		2.213	0.115
not massive-massive	96.926	0.000	*	1.936	0.041	*	4.490	0.014 *
obtrusive-neutral	40.544	0.000	*	13.246	0.000	*	0.529	0.591
smooth-rough	303.768	0.000	*	5.235	0.000	*	3.202	0.045 *
textured-flat	240.970	0.000	*	7.939	0.000	*	1.577	0.212
cold-warm	143.905	0.000	*	10.696	0.000	*	8.193	0.001 *

\* Effects significant at the 0.05-level.