ANALYSIS OF THE FORMATION OF USER IMPRESSIONS UPON TACTILE INTERACTION WITH PRODUCT DESIGN MATERIALS

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ABSTRACT
This study focuses on the significance of tactile interaction with product materials for user impressions of products. It aims to propose a method and tools for the assessment of tactile interaction on the basis of user impressions and to investigate the basis of the formation of user impressions of product materials. The study develops a method to assess tactility in interaction with materials, focusing on the inner associative layer of in-depth impressions of this interaction. The method was tested experimentally, and the typology and characteristics of in-depth impressions explain the formation of impressions. The tactual experience provides content to specified concepts in connection with the whole concept of product material, which is a concept that elucidates the successful tactile interface between users and products. Selection of materials in product design should hence be made bearing these considerations in mind, and the formation of impressions deserves attention in future studies. In conclusion, theoretical and practical implications are discussed.

KEYWORDS
Product experience, tactual material properties, cognition of material, in-depth impressions, concept of material

1. INTRODUCTION
The user interface is key to the success of many products. Tactility of product materials is fundamental for the effectiveness of this interface and assessment of an effectively tactile interface is essential for successful product design.

The goal of this study is to propose a method and tools for the assessment of tactile interaction, in order to understand how users form their impressions of this interaction. Not trying to develop a perceptual set, this new method is developed as a tool to assess the product materials’ tactility and can be applied to analyze the formation of user impressions from product materials.

The topic of tactile user-material interaction has been recognized as being of high importance in the experience of man-made objects [10, 19, 29]. Moreover, tactile user-material interaction is critical for building users’ emotions, thus, has fundamental role in emotional engineering [12]. Therefore, it is essential for designers to develop tools and methods that offer a conceptual framework for the tactile sensory experience, particularly with product materials. It has been suggested that the requisite approach can be based on cognitive and perceptual learning ([29], p.62). However, product design practices do not yet offer such tools and methods.

The issues of tactile sensory experience as they relate to the provision of tools and methods are two-fold. The first difficulty lies in understanding the formation of the user sensory experience. The second is in providing an effective approach to assess this experience [7]. A central concern of product design is the designers’ understanding with regard to how user impressions are formed. Such understanding will lead to an effective assessment approach and to
new technology (method), which will contribute to successful global product development and production by fitting products to expected, everyday, tactile experiences. In other words, user impressions and expectations—the human element—must be fully comprehended in order to facilitate the development of omnipresent products.

To address these issues, this study investigates tactile user-material interaction with product design materials through an in-depth analysis of cognitive interactions, providing a method to assess tactile experience and understand how user impressions are formed.

2. SIGNIFICANCE OF TACTILE INTERACTION FOR PRODUCT DESIGN

2.1. Experience of objects

Tactile interaction is a foundation of human embodied and true experience of objects [29]. Karana et al. [19] investigate and identify the complexity of user interaction with product materials. People interact with various materials, perceive various characteristics of materials, create different affects from materials, and create attitudes toward materials [19], ultimately accumulating experiences and building attachments or repulsions to products [27, 31]. Previous studies have shown that user impressions of materials in tactile interactions depend on the level of user familiarity with the material [22]. For example, congruence in perceptions may also facilitate processing and contribute to positive evaluations [32].

In order to increase comprehension and systematize the generation of materials with “sensible” properties, product designers must focus on user interaction with materials and answer questions on how users form impressions of product materials. Previous studies have focused on perception and affect, paying little attention to the cognition of tactile interaction with product materials. Cognition of product materials is a critical conceptual component of user interaction (Figure 1), no less essential than perception or affect. Thus, understanding user recognition is key to providing methods and tools for assessment of tactile interaction. Analysis of perceptual and cognitive processes is the next logical step in product design research.

2.2. Tactile experience

The most cutting-edge research in the field of tactile experience of product materials is concerned with systematic approaches to the sensorial properties of materials [19]. It has been shown that meanings are attributed to materials, depending on factors such as meaning type, material type, the product itself, its usage, and the user’s background. Tools have been developed for facilitation of material selection on the basis of these findings [19].

Moreover, the significance of a deeper understanding of user interaction with materials (particularly in a tactile mode) has been recognized from both user and designer viewpoints [29]. Sonneveld and Schifferstein argue that tactile interaction, as a primal form of experience, comprises a foundational component of knowledge itself. People need to touch to know and understand the man-made objects they are manipulating and ultimately grasp their meaning. The first attempts to penetrate deeper into the topic of tactile experience of product materials show that user impressions depend on how “natural” the material is perceived to be, including how well users are accustomed to it [22]. Moreover, such impressions are related to material preferences [15].

Thus, the significance of the current study lies in its attempt to challenge the formation of impressions of product materials. To understand the formation process, the study focuses on user cognition as a conceptual component describing the interaction with objects (Figure 1), paying attention to the depth of user impressions of this interaction.

2.3. Aims

The aims of this research are:

- To propose a method and the tools for assessing tactile interaction on the basis of user impressions
- To answer the following question: What is the basis of the formation of user impressions in tactile interaction?
2.4. Model of tactile interaction

Previous research on tactile interaction with materials provides clues such as materials that are experienced often (or in other words, which users are habituated to) differ in their impressions and evaluations in comparison with new and tactually unknown materials [22, 23]. Moreover, the constructed meaning of a material depends on factors such as material properties, the product the material is embedded in, how we interact with it, and the context in which the interaction takes place [19]. In light of these factors, an individual’s previous experiences, memories, associations, emotions, and cultural backgrounds influence the constructed meaning. These components are central in the construction of a meaning evoking pattern [19]. Materiality has been studied as material understanding and material strategy for design [30]. Previous experiences, memories, associations and emotions are thought to be critical for the formation of user impression [22, 23]. Thus, in this research we investigate the formation of user impression in light of previous experiences, memories, associations, and emotions and apply a systematic approach and method in order to investigate them.

Tactile interaction is fundamental to user interaction and experience; it is the foundation of feeling and emotion. Touch is a communication channel for affection. However, the key aspect of touch to perception is that as a physical experience it provides verified content to specified concepts [29]. Model of user-product interaction described the products’ evoked associations and user previous experience and knowledge as responsible for interaction on intra-personal level [16].

However, a time-experience model of tactile interaction is needed to explain the formation of impressions as an experience providing content to specified concepts. It has already been suggested that past experiences play a major role in user perception and impression [22]. Thus, this study proposes a model of concept creation (Figure 2). Through (in this case, primarily tactile) interaction with a material, the concept of the material is created on the basis of a formation spiral. We introduce the following definition of concept of material:

**Definition 1.** Concept of material is a specified set of concepts (which can be expressed as words) that are formed on the basis of a user’s tactile experience with product material.

In the perspective of this definition, the current experience is influenced by past experiences of concepts that are based on association, memory, etc. Past concepts influence current experience, which again refers to past experiences and concepts. The final result is the construction of a current concept of the material that includes expectations of future experiences and concepts. In this model, the generation of concepts of materials has been represented as a process of user cognition in which associations based on past experience play a major role. The spiral of past and current interactions creates an expectation (which can also be called a “meaning”) of future tactile experiences.

2.5. Concept of material

As previously noted, the generation of a concept of a given product material is key for the product development process and product design. Moreover, creation of products with new or different material
characteristics will require some amount of insight into how successful concept creation may be facilitated for that material. Proper facilitation would result in a user concept of the material that would include emotional satisfaction and a meaningful experience of the product.

Selection of materials in product design should hence be made with these considerations in mind. Therefore, the implementation of materials in products has to consider the intended concept of a given material as developed through tactile, visual, or other interactions.

3. APPROACH AND METHOD

3.1. Analysis of concept of material with in-depth impressions

Investigating the formation of user impressions and the building of concept of material are challenging tasks. In order to analyze how users form impressions of materials, we focus on the issue of where the impressions come from. An answer to this is that words are connected through user experience.

Experience with words creates a structure, which is associative in nature and is derived from ever-changing experience [4, 6]. It is assumed that dynamic associative structure is created in a type of memory that involves representations of the words themselves, as well as connections to other words, and that this structure plays a critical role in any task involving familiar words [25].

We consider that, on the basis of this associative structure, the experiences can be described as having two layers—a layer of expressed user impressions and an inner associative layer—a viewpoint that has been discussed in previous research [8]. Moreover, we consider the second layer as consisting of in-depth impressions, which initiate the expressed user impressions but remain primarily unconscious to the person who is actually expressing impressions on a particular experience. Thus, we define in-depth impressions as follows:

**Definition 2.** In-depth impressions comprise an inner associative layer of outwardly expressed user impressions of interaction with product materials.

**Definition 3.** Expressed user impressions are verbal impressions that are freely expressed upon interaction with product materials.

Figure 3 illustrates in-depth impressions as such an inner associative layer on the basis of which users establish numerous, rich (metaphorical) concepts (or expressed user impressions). This definition was developed on the basis of previous research [24].

3.2. Methodology of this research

The feasibility of the proposed model was investigated in this research. The previously defined in-depth impressions form the focus of the assessment.

To address the aim of this study, in-depth impressions were analyzed in an experiment on the basis of (A) expressed user impressions and (B) inquiries into user explanations of explicit impressions formed on the basis of tactile interactions with materials. In this experiment, the primary mode of interaction was touch; however, vision was implicitly included in order to simulate actual interaction with product materials.

The methodology comprises the following steps (Figure 4):

**Step 1.** Evaluate tactile interaction of users via protocol analysis of:
- Freely expressed user impressions of tactile interaction with product materials
- Explanatory inquiry to extract users’ own assessment of the reasons for their impressions.

Explicit impressions, explanations, and reasoning were collected in this step.

**Step 2.** In-depth impressions detection and analysis, as outlined in the proposed method of assessment (see next section).

**Step 3.** Further understanding of how impressions are developed through analysis of the explanatory
inquiry, in order to identify the patterns of formation of impressions.

The approach described addresses the problem of understanding how user experiences are formed. Moreover, it provides a methodology to assess user experience on the basis of cognitive interactions.

3.3. Method of assessment

An array of techniques was employed to analyze tactile interactions from a cognitive perspective. Detection and analysis methods of in-depth impressions of the cognitive interactions of users were developed. Accordingly, the techniques used in this method of assessment include (Figure 5):

- Association analysis of expressed user impressions. On this stage, all expressed user impressions were examined for words which they are typically associated from. A list of all such common associative pairs was created.
- Concept network construction. The associative pairs are added to a network structure, which is associative in nature, with two types of nodes—expressed user impressions (receiving connections) and associative nodes (initiating connections).
- Graph visualization of the resultant concept network to detect the in-depth impressions as the nodes initiating the highest number of connections.
- Further analysis of (1) the typology of the detected in-depth impressions (Figure 6) and (2) the conceptual characteristics to identify their common features.

The in-depth impressions identified and grouped by common features provide clues for the nature of user impressions and from what kind of experience these impressions are derived. Additionally, we evaluated in-depth impressions in terms of the conceptual category or component, which is most likely related to (cognition-related or other).

**Definition 4.** Cognition-related impressions are those in-depth impressions that result from acquired concrete knowledge of products or man-made environment objects.

In other words, the cognition-related in-depth impressions result from the knowledge or thinking about concrete products, for example, ‘car’ or ‘house’. We assume that the cognition of such products determines the in-depth impressions associating the particular expressed user impression.
It is noteworthy that all in-depth impressions, including the cognition-related one, are determined by associative connections. More precisely, cognition-related in-depth impressions of products such as ‘car’ create particular expressed user impressions—initiate an associative connection rather than receiving one itself.

Furthermore, perception-related impressions can be considered as in-depth impressions that stem directly from sensorial properties of materials. On the other hand, affect-related impressions are in-depth impressions that may lead to affective responses (i.e., further possible experience of ‘emotions’). However, it is difficult to classify either perception-related or affect-related in-depth impressions in one category—both impressions are related to perception and affect as well as to aesthetic or sensorial aspects of materials. For example, affect always actively influences cognition [3]. Moreover, in the framework of our research—the inner layer of in-depth impressions which are implicit—it may be difficult to evaluate the affective potential of such in-depth impressions. Thus, we focus on the identification of cognition-related in-depth impressions only.

One may argue that owing to the abovementioned characteristics, these definitions may fall into the category of meanings. However, in previous research, meaning was referred to as a general category of user impressions [19, 20]. Moreover, meaning has been referred to as general category of what the object (or material) represents or signifies for the user [14, 31].

The reliability of associative and emotional responses in touch-only interaction has been reported as low [17]. Moreover, in daily life, users rarely interact with materials using only tactile interaction and not a visual one. Therefore, this study focuses on the touch and vision mode of material experience. The touch and vision mode provide the highest consistency in the perception of product materials [18].

4. DETAILS OF THE RESEARCH

4.1. Materials and participants

The specific details of the research are as follows: samples of seven materials from everyday products were used as stimuli. These materials were: aluminium, plastic, and wood (wide application in products that are touched); and cork, glass, rubber, and steel net (narrow application in products that are touched) (Figure 7). These materials have been selected from the products commonly used in daily life, that is, materials that are encountered every day. The material samples were sized approximately 20 × 10 cm each, allowing participants to interact with the samples tactually and freely. We did not apply blind test owing to the difference in blind test and everyday tactile experience of various product materials. Moreover, a blind test would put unnecessary emphasis on sensorial and perceptual properties of material. No particular products were used in order to minimize the influence of the shape or function of the products on user interaction. The study comprised eleven participants (five females and six males).
4.2. Procedure

The material samples were presented in a random order, and two questions were asked regarding the user’s tactile interactions with each material. Participants were instructed to touch the material samples and to provide a detailed answer. The first question was as follows:

(A) What are your impressions and image (imagination) of this material?

We limited the instructions to basic ones in order to minimize the influence of instructions on the interaction [18]. After the participants provided a free and undisrupted verbalization after tactile interaction with material samples, the second question was asked:

(B) What were the reasons for your impressions of these materials?

From the responses of the participants, the expressed user impressions (nouns, verbs, adjectives, and adverbs) were classified on the basis of the material sample and were analyzed.

4.3. Analysis

A few examples of the responses are as follows: (Question A) ‘certainly it is glass…well, could be transparent or not transparent. Can be broken…Like my table, a glass table or such. Familiar…’ for glass material and ‘like a pillar...or... like house floor. ...I get an image like an old porch of a house. ...Once I get the impression, it is like a familiar touch. ...Blocks or... puzzle, light. ... You can use it to cut out a thing like character or name plate ...’.

Protocols of the answers on questions (A) and (B) were analyzed, and in-depth impressions for each material sample were identified with the previously described method. Five-hundred-ninety-seven expressed user impressions as words for the first question were collected and were used in the analysis.

4.4. Tools

For detection of the in-depth impressions, we used the most common applicable associative analysis
tool—associative concept dictionary. The ‘University of South Florida free association, rhyme, and word fragment norms’ database created by Nelson, McEvoy and Schreiber contains very large number of English-language associative words (word-pair associations) [25, 26]. The tool considers nouns, adjectives and verbs in associative pairs and was constructed in a large-scale association experiment. This extensive coverage is suitable for searches of word-association pairs, thus it is used in the current analysis. This tool is widely applicable and contributes to the reliability of the method in this research. Furthermore, for creation of the conceptual networks we used Pajek graph drawing software [2, 28]. From the constructed conceptual networks the in-depth impressions were detected on the basis of their weights (calculated as an out-degree centrality scores, [11]).

In the next step for classifying in-depth impressions, the conceptual hierarchy of the concept dictionary database was used to identify type—using the hierarchy of concepts in the concept dictionary WordNet [9, 33]. The most concrete common types were examined (Figure 6). The WordNet is a common analysis tool used for conceptual classification and conceptual structures in the study of product experience and design [34, 35, 36].

### Table 3  Reasoning about impressions of materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Example reasons in answers of question (B) (form all participants)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>“It is like metal plate used in machinery …”; “I touch and feel cold …”; “The material is not special, but I was scared to touch this material …”</td>
</tr>
<tr>
<td>Cork</td>
<td>“I certainly imagined picture board …”; “I think it can make people to imagine so many things …”</td>
</tr>
<tr>
<td>Glass</td>
<td>“It is used fully in daily life. And because the daily life, there are so many emotions in people’s lives …”; “It was as the glass table I use in my room …”</td>
</tr>
<tr>
<td>Rubber</td>
<td>“… comfortable, but not something that usually touch in life …”; “… fairly smooth, slippery surface that is really something I like …”</td>
</tr>
<tr>
<td>Steel net</td>
<td>“I imagined touched the screen door when I open window …”; “It is like touching something personal …”</td>
</tr>
<tr>
<td>Plastic</td>
<td>“It was as often touched name plate … or plastic plate … but it is hard …”; “… it is a bit stiff as a whole …”</td>
</tr>
<tr>
<td>Wood</td>
<td>“It is warm and I imagined house …”; “It is like natural wood used in many man-made things …”; “… comfortable feel of something traditional …”</td>
</tr>
</tbody>
</table>

### 5. RESULTS AND DISCUSSION

#### 5.1. Typology and conceptual characteristics of in-depth impressions

Examination of all identified in-depth impressions revealed the most concrete common types of (1) Artifact, (2) Abstraction, (3) Substance/Living thing (including natural thing and person)/Phenomenon, and (4) Others/Not classified as appropriate to our case (Table 1).

The in-depth impressions from the category of (1) Artifact were, for example, ceiling, tower, lamp or porch; from (2) Abstraction, they were, for example, shade, truth, aura, or reflection; from (3) Substance/Living thing (including natural thing and person)/Phenomenon, they were, for example, feather, sunshine, sun, or wood.

The obtained proportions found in these classifications show that those materials with narrow applications (cork, glass, rubber, and steel net) contributed to user cognitive interactions in the associative layer of artifacts (Table 1). The materials with wide applications (aluminium, plastic, and wood) create user cognitive interactions in the associative layer of abstraction type.
Figure 8  Examples of formation of the user concept of seven material samples
The study identified in-depth impressions on two groups according to what perceptual component they most likely relate to: (I) cognition-related (e.g. steel, plug, marble, tread, display, stage, sun, etc.) , and (II) other (e.g. rigid, mild, crisp, clear, delicate, cozy, extreme, harsh, unstable, influential, powerful, etc.) (Table 2). Conceptual characteristic analysis shows that the cognition-related conceptual component of the inner associative layer of in-depth impressions is predominant in most cases. The proportionally largest category is shown in bold in Table 2.

The observed large proportion of cognition-related in-depth impressions demonstrates the cognitive conceptual component as fundamental in the interaction with materials.

5.2. Impression formation patterns

Impression formation patterns were drawn on the basis of the participants’ explanations from question (B) (Table 3). These patterns, along with typology and characteristics of in-depth impressions, validate the proposed model (Figure 8).

In Figure 8, some examples of past experiences are visualized on the basis of identified in-depth impressions. The method of the identification of in-depth impressions partially accounts for metaphorical concepts, as metaphors can be included in the associative connections used to identify in-depth impressions, for example, ‘cold’ and ‘person’. For at least partially judging future experiences (expectations and anticipation), we used explicit explanations from the responses of the participants (B). However, a more elaborated approach to analyze future experiences may be needed.

Aluminium and glass, for instance, created different networks. A possible interpretation in terms of tactual properties of these materials can be found in the past experiences of particular products, for example, the tactual properties of products like ‘window’ and ‘table’ create in-depth impressions in the basis of concept of glass material. However, further research is needed to link the concept network structure to the tactual properties of materials.

The past experiences with particular material can be understood on the basis of in-depth impressions such as ‘feather’, ‘delicate’, ‘bedroom’ or ‘damage’ or ‘defrost’. These in-depth impressions reflect into expected future experiences such as ‘comfortable’ or ‘scared’.

The main findings can be summarized as follows. The cognitive component is a major contributor for the creation of concept of material. User impressions of product materials are formed on the basis of associations with past tactile experiences, as well as cognitive interactions with materials of artefacts, which were referred to a number of times during the tactile interaction. Such concepts of materials are often sought in a formation spiral (Figure 2). The newly formed concept of material creates expectations of future tactile experiences of materials.

The spiral has fewer iterations (smaller) in the case of the tactile experience of materials with narrow application in products (cork, rubber, and steel net), while the spiral has more iterations (bigger) in the case of the tactile experience of materials with wide applications (aluminium, plastic, and wood). When a concept of material is formed with less iteration, it is an artefacts-based in-depth impressions.

5.3. Creation of concept of material

Consideration of impression formation is essential for the selection of materials in product design [1]. Provision of method and tools for assessment of this formation is key for product development, especially for the emotional and experiential aspects of product development [5]. We devised a method and tools for assessment on the basis of the creation of concept of materials by the user in tactile interaction with product material. Essentially, we presented a cognition-focused approach to assess the formation of concept of material.

5.4. Conditions for a successful tactile interface

In order to summarize the discussion, we need to answer the main question: what is the use of a successful interface (maintaining intended impressions of a tactile interface between a user and product)? According to findings, the conditions for a successful tactile interface between a user and product are as follows:

- The product uses material according to user preferences and in-depth impressions associated with positive experiences
- Complexity of impression (meaningfulness, recognition, and with fulfilled expectations in future)
- Provision of an answer to the time issue [13] (how to maintain intended impressions of the tactile
experience of a material while the product made from this material is being used)

These conditions require further attention, more extensive research, and tools to aid the considerations of designers in product design and material selection in the future.

6. CONCLUSIONS AND FUTURE WORK

This study provided a method and tools to assess tactile interaction on the basis of user impressions. These method and tools help assess tactile interaction, which can be assessed only on the basis of user verbalizations, without the need of predefined settings or restrictions. The proposed method analyses the free verbalizations obtained on tactile stimuli and identifies the inner associative layer of in-depth impressions. The concept of material (specified set of concepts about material) was investigated on the basis of these in-depth impressions. Further, this study provided an understanding of the formation of user tactile sensory experience through the identified in-depth impressions and the patterns of impression formation that create concepts of material. Awareness of concept of material by designers would improve selection and implementation of materials in products. Understanding how user impressions of materials are formed, designers would identify the concept of material and employ it in the materials selection process.

The assessment method described herein will contribute to global product development and production by fitting products to expected tactile experiences. Ultimately, this study contributed to improve the modelling of the process of formation of users’ impressions of product materials, which is an essential aspect of the human element for product innovation.

Future work will focus on further verification and testing of results as well as development of a tool for employing concept of material in the processes of material selection and product concept creation.

REFERENCES


