INVITED PAPER

A Model for Haptic Aesthetic Processing and Its Implications for Design

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ABSTRACT | Research in aesthetics typically focuses on static stimuli or stimulus properties from the visual domain leaving unanswered a great many questions on haptic aesthetics. This paper aims to give a short impression of the relevance of aesthetics for design and everyday-life decisions, then focuses on phenomena concerning haptic aesthetics in particular, for instance, top-down processes and mere exposure effects. Based on empirical findings and theoretical considerations with regard to haptic research, the paper develops a functional model of haptic aesthetics, which is explained step by step. This model assumes a continuous increase of elaborative processing through three subsequent processing stages beginning with low-level perceptual analyses that encompass an initial, unspecific exploration of the haptic material. After a subsequent, more elaborate, and specific perceptual assessment of global haptic aspects, the described process enters into deeper cognitive and emotional evaluations involving individual knowledge on the now specified haptic material. The paper closes with an applied view on design issues to explicate the importance of integrating haptic aesthetics into corresponding approaches.

KEYWORDS | Aesthetics; appreciation; art; cognition; cross modal; haptics; liking; perception; pleasure; preferences; sensitivity; tactile

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I. INTRODUCTION TO EMPIRICAL AESTHETICS

A. Relevance of Aesthetics

Empirical aesthetics is a young science but a very old subject of human interest. To understand what people appreciate, like, love, or prefer, and why they do so is of essential relevance for everyday life events where a clear rational basis for decision making is often not available. For instance, aesthetic aspects play a dominant role in choosing specific food or beverages: attractive, immaculate tomatoes might be preferred just because of their level of color saturation while important factors like price, ecological footprint, or amount of contained vitamins are ignored—a reason why companies have developed the use of special illumination in the fresh food sections of supermarkets to accentuate the offered tomatoes' reddishness and to reduce the visibility of visual flaws on their surfaces. In sectors where products are quite interchangeable as a consequence of similar technical specifications, consistent legal requirements, and production constraints, aesthetic aspects are particularly powerful [1]. Technical innovations in cars, to mention just one example, can spread from one company within a short period of time due to the taking out of patents by competitors or the cloning of innovative technology. Most car brands, however, still have an idiosyncratic "Formensprache" (design vocabulary) [2] which is a key indicator of brand identification and, thus, can be utilized to generate important brand associations. In fact, a significant number of everyday decisions that are clearly more important than rather trivial product selections are made on the basis of aesthetic factors, e.g., the decision about where to settle, which politician to elect, or with whom to start a family [3]. In this paper, the term "haptic aesthetics" is defined as capacity (of materials and objects) to please our haptic system [4].

B. The Goal of This Paper

In most areas of perceptual sciences, the scientific effort made to systematically understand different phenomena is dominated by research on visual dimensions. This also holds true for empirical aesthetics: Most aesthetic theories are consequently inspired by visual phenomena and are only tested with regard to visual effects. This paper aims to extend this vision-centered view and proposes the integration of a haptic perspective. Even early pioneers like Johann Gottfried Herder [5], who discussed the relevance of touch for sculptures, mentioned that the impact of the sense of touch is underestimated in society. This statement is also true several hundred years later. Therefore, we will: 1) give a brief overview of aesthetic phenomena in the haptic domain; 2) develop and explain in detail a functional model of haptic aesthetics; and 3) develop an applied perspective of haptic aesthetics with regard to design-relevant questions, including a case study to demonstrate the impact of haptic aesthetics on a specific design issue.

II. HAPTIC AESTHETICS

A. An Extraordinary Modality: Haptics

In addition to its important role of a protector against negative environmental influences, skin provides a variety of powerful detectors, among them detectors that constitute the tactile, tactual, or haptic sense. Due to its early onset during intrauterine development, the haptic sense enables first contact and communication with the external world. Even at this early point, an essential aspect of the nature of the haptic sense becomes apparent: its inherent responsive and reflexive quality. As soon as you touch (something or somebody) you will in turn be touched yourself [6]. Thus, every haptic inspection directly affects the inspected target as well as the inspecting agent. The emerging direct feeling might be one reason for the occurrence of strong personal experiences linked to touching, and consequently being touched, and might further create the implicit need for touch that can, for example, often be observed in museums: We stand in front of a sculpture that has an "inviting" surface or intricately arranged curves, but which is accompanied by a "Don't touch!" notice presented in big letters (see also [7])—and we nevertheless feel that it is necessary to touch the object; and consequently, we end up doing so.

Why is the need for touch [8] often so imperative? Why are we not able to resist touching in so many instances? Why do we need to touch in order to gain real proof of certain product qualities? The answers are certainly manifold, but there are two candidates that seem to be very promising: 1) haptics' interactivity; and 2) haptics' multimethodologies.

1) Haptics' Interactivity: Haptics is the only human sensory modality that can rightly be thought of as being "active." Whenever haptic processing is needed, we actively inspect an object and, by doing so, get in physical contact with it. Quite academically, Gibson [9] differentiated between active and passive touch: active touch refers to the concept of *touching* (the perceiver brings about the tactile impression on the skin herself), whereas passive touch refers to *being touched* (the perceiver's tactile impression is induced by an external object). The real magic behind both concepts is their inherent interactivity, as both kinds of touch are in fact not fully separable. Touching is always accompanied by being touched (and *vice versa*); in fact, this is the reason why we can use the haptic sense for refining and reprogramming our motor programs. Equipped with such a capable sense, we mainly use it in an exploratory manner. If we encounter a totally dark, silent, odor-free environment, we can rely on haptics to grasp the unknown. We still rely on haptics, even if we have the opportunity to refer to many other senses: if, for instance, we sit in a brand new car and process the characteristic smell of the polished wooden cockpit panel, while visually scanning the clear grain of its surface that reminds us of walnut, only the haptic inspection of the material will finally inform us that the design feature is essentially made of plastic. Only by use of haptics do we feel the physical link to the outer world providing strong evidence that "real" is *real*, which of course still remains an idea created by our specific constraints and our mental capabilities. In any case, even highly skeptical people often become convinced about physical properties they would not trust on the basis of mere visual impression when they touch an object with the "naked hand," thus experiencing their ability to directly manipulate their environment. The power of manipulating can serve as a means to gain further knowledge of the physical conditions of the outer world, but also to obtain feedback about personal physical and volitional conditions.

2) Haptics' Multimethodologies: Haptic exploration is not only marked by interactivity but also by high complexity as humans can process haptic qualities in a multimethodological way. Sonneveld and Schifferstein [6] offer an overview of different approaches of haptically exploring the world based on Lederman and Klatzky's [10] exploratory procedures (cf. [11]). Typical exploratory movement patterns are:

1) *lateral motion* for scanning texture;
2) *pressure* for revealing hardness;
3) *static contact* for assessing temperature;
4) *unsupported holding* for estimating weight;
5) *enclosure* for investigating global shape and volume;
6) *contour following* for detecting the shape.

These clearly distinguishable, but at the same time combinable, explorative procedures are enabled by a complex interplay of processes in cutaneous channels (mechanoreceptors and thermoreceptors located in the skin) and kinesthetic or proprioceptive receptors (located in the muscles, muscle spindles, and tendon organs) [12], [13].

B. Haptic Aesthetics

Haptic aesthetics is one important aspect of the more general mechanism of haptic processing or "tactual" experience [14] that has the potential to create the typical "gut feelings" marked by clear-cut evaluation and qualification of the material without the need or ability to use complex verbal descriptions as in visual aesthetics [15], [16]. Such gut feelings are often relevant for product experience and, ultimately, for selecting specific target products in a real-world context. One main reason for the direct effect via haptics might be direct physical contact with [17] as well as direct physical feedback from the inspected object [18]. Several experiments have demonstrated the strong impact of haptic aesthetics on consumer choice and consumer preferences. For instance, barriers fixed to constrain touching at retail displays can inhibit the principal possibility of appreciating and evaluating on a haptic level, which leads to less confidence in product evaluations [19]. Retailers can directly benefit from allowing customers to touch their products, as it also can positively affect the costumers' persuasion [20], [21], a finding already revealed by several experimenters in the 1980s. For example, Mehrabian [22] showed that active approach behavior can positively influence liking, preference, and attitude toward objects. Heslin and Alper [23, p. 63] proposed that "touching does, indeed, cause liking." Revealing that consumers with a greater need to touch avoid buying products on the Internet purely because of the lack of opportunity to evaluate them on a haptic aesthetics basis, Citrin *et al.* [24] explicated a major challenge for retail concepts that work on a solely virtual basis.

Despite the clear relevance of haptic aesthetics with regard to appreciation in general and appreciation of design products in particular, systematic knowledge on this topic is quite sparse and a widely accepted framework theory of haptic aesthetics is still lacking. A Web of Science literature search conducted on April 27, 2012, yielded only two research papers on *haptics & appreciation* and four on *haptics & aesthetics* (combined title search). In this paper, we would like to establish the idea as well as the concrete technical term of "haptic aesthetics." As a theoretical framework for this specific part of aesthetics, it is imperative to obtain a more holistic view on aesthetics and product experience. Furthermore, we will develop a functional model of haptic aesthetics.

III. A FUNCTIONAL MODEL OF HAPTIC AESTHETICS

To meet the obvious importance of haptic aesthetics for adequately understanding and describing the process of object or product evaluation, it is essential to establish a framework model offering a basis for explaining typical phenomena of haptic aesthetics—thus, providing a framework for systematic future research. Further, such a model should enable the assignment of different subprocesses to well-defined processing stages for which the complex, interactive, and integrative process resulting in a haptic aesthetics experience is built up.

A. General Structure of the Model

The "functional model of haptic aesthetics" (see Fig. 1) is structured as a series of processing stages marked by a continuous increase in specificity, complexity, and elaborateness. Therefore, it focuses on the internal processes of a perceiver. Importantly, besides feedforward processing, recursive loops can change the current process via top–down control resulting from successful processing of main aspects of the regarding stage. These loops are defined with regard to the aspects of *context*, *expectation*, *integration*, and *familiarity*. The input of the model is a haptically unspecified object; the output after three levels of elaboration is the haptically specified object. To roughly outline the content of the proposed stages and their connection to existing directions in haptic research, the first two stages (low-level analyses: exploration; and midlevel analyses: assessment) refer to basic local and global processes in haptic perception in accordance to psychophysics dating back to the famous studies of Ernst Heinrich Weber, but also more recent haptic object recognition theories (see the following section for more details). The third level (high-level analyses: evaluation) discusses cognitive and emotional aspects in processing. It is the one connected mostly to the aforementioned early directions in philosophy such as Herder (aesthetic evaluation), but it is also related to approaches in product design (utilization and aesthetic evaluation) [4], [6], [25], [26], [27]. The present selection of variables is based on the currently existing findings in haptic aesthetics but mostly on those in visual aesthetics [28], [29].

B. Three Levels of Elaboration and Their Feedback Loops

Feedback Loop 1 (Context Feedback Loop): The initial input of haptic aesthetic processing is an object that has not yet been haptically specified, but that is accompanied by important information provided by the context. The context can be given by the situation in which the object is processed, the place where it is situated, the task the perceiver has to fulfill, the cultural setting the perceiver is in, or simply by any kind of information communicated about the current object. These contextual cues have the potential to change the initial processing of the object itself by providing information that leads to a specific way of processing, to change the entry point of processing, or even to cancel further processing due to avoidance.

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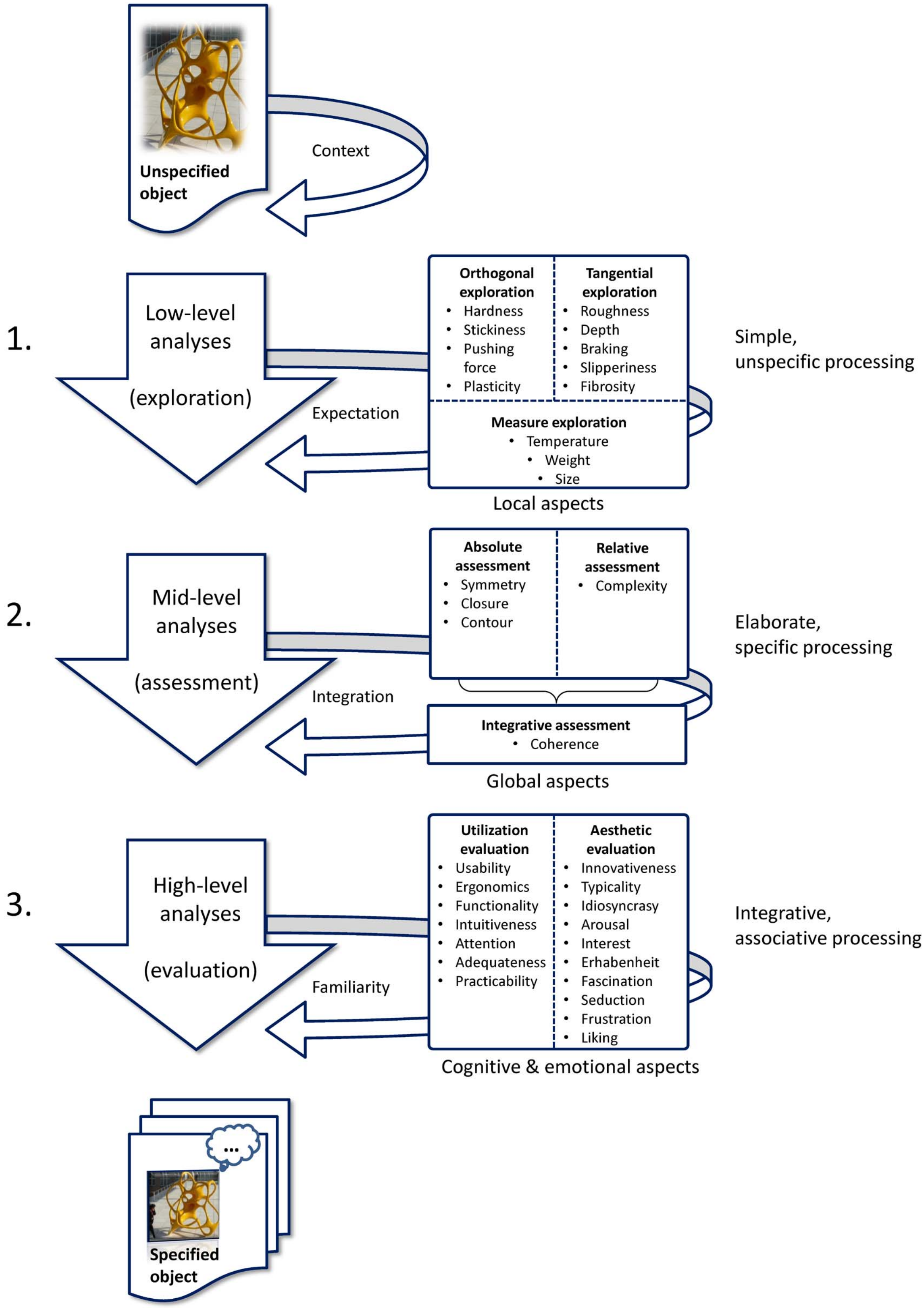

Fig. 1. ***The functional model of haptic aesthetics.***

An example of how contextual cues can influence the way of processing an object from the start was shown by Jakesch *et al.* [30], [31]. They demonstrated in a within subject design that identical materials received different aesthetics and material related judgments according to the absence or presence of specific "scenarios" (contextual

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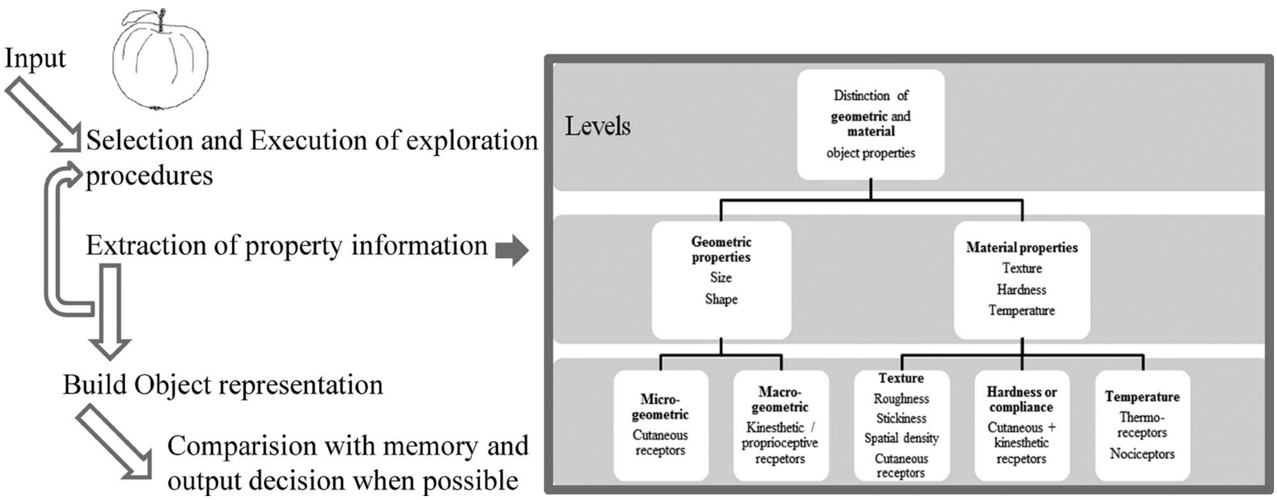

Fig. 2. *Schematic overview of the hierarchical processing of the haptic system based on Klatzky and Lederman [32].*

cues, e.g., steering wheel) under various modality conditions (haptic, haptic plus vision, vision). Less positive contextual cues may result in an abortion of processing, e.g., ignoring the stimulus if not enough interest is induced or the person in charge fears penalization (e.g., because touching the object is forbidden) or danger (being hurt by touching the object). Typical effects of this kind demonstrate the context feedback loop in action. Thus, as a result of contextual information, the very same object can be perceived and processed differently resulting in correspondingly varying aesthetic responses. The impact of context will be shortly discussed also in the level descriptions.

Level 1: Low-Level Analyses (Exploration): The first level of elaboration can be described as simple, unspecific processing encompassing all kinds of low-level perceptual analyses that can be executed without specific knowledge of the target object. Based on different approaches to classify tactual exploratory strategies, mainly inspired by pioneering work of Klatzky and Lederman [32], [33] (see also Fig. 2) and recent descriptions by Sonneveld and Schifferstein [6] combined with haptic procedures described by Renault's patented Sensotact tactile test system (see [31], [34], and [35] for details and evaluations of this reference system), we differentiate between three main types of low-level analyses in which haptic qualities are processed in a relatively local fashion.

These three main types of analyses are termed *explorations*, as the quality of object processing is quite unspecific.

1) *Orthogonal exploration:* Orthogonal exploration refers to all haptic qualities that can be detected and explored by orthogonal finger or hand movements, for instance, hardness (force required to slightly compress surface), stickiness (force required to separate fingers from surface), pushing force (degree of force needed to oppose a product's compression), and plasticity (capacity to regain shape after having been deformed).
2) *Tangential exploration:* Tangential exploration refers to all haptic qualities that can be detected and explored by tangential finger or hand movements, for instance, roughness (detection of relief, particles, harshness, etc.), depth (differences in haptically detected height), braking (force required to move forward on the surface), slipperiness (ease of ensuring continuity in sliding along the surface), and fibrousness (possibility of detecting fibers on the product's surface).
3) *Measure exploration:* Measure exploration refers to all haptic qualities that are typically explored by taking the object in the hand or enclosing it [32], [33]. This kind of exploration aims to determine properties that could also easily be measured by means of standard instruments like a thermosensor (perceived temperature or thermal conductivity), a scale (weight), or a linear measuring tool (size).

Only a few studies examined aesthetic responses to specific haptic qualities: Ekman *et al.* [36] reported preferences directly proportional to the *softness* of various sandpapers, cardboard, and paper stimuli. Hilsenrat and Reiner [37] investigated preferences for the dimensions *compliance* (hardness) and *roughness* by using a forced choice paradigm, showing that softer (88.5%) and smoother (92.3%) surfaces were preferred. These results are supported by a recent study of Klatzky and Peck [38, p. 146] who measured the "touch ability." Touch ability was defined as "extent to which a pictured object invites contact." Smooth surfaces and simple shapes of abstract objects also received higher touch-ability scores than rough, complex shapes. Thus, visual previewing provides information about haptically perceivable characteristics; see also [39].

Expectations based on visual previewing will be discussed in the second feedback loop. To subsume, smooth and soft surfaces seem to be preferred when no specific contextual cue is given (e.g., abstract stimuli, sandpaper and paper stimuli). According to Klatzky and Peck [38], some local or structural features have more "touch ability" or affordance character than others. Future research should therefore address such specific hedonics of surfaces. As noted, contextual cues can change or influence the way of processing at each level. Therefore, preferences can be modulated based on, e.g., specific information or a specific situation. The discussed general preference toward smooth and soft surfaces can change due to the aim of the task or the intentions/goals of a person. Aesthetically evaluating the very same smooth surface as either being part of a book cover or being part of a hammers' handgrip section will receive very different, if not contradictory, outcomes [40].

Feedback Loop 2 (Expectation Feedback Loop): When low-level haptic analyses are executed, expectations can shape anticipatory procedures affecting sensory and motor processing. Such effects are particularly strong when the to-be-explored object can be visually inspected prior to haptic exploration [39]. For instance, if people visually perceive a car door handle that has a metallic look, they expect high thermal conductivity; any deviation from the expected values as a result of haptic exploration will lead to an increase of attention and, most likely, to further explorative effort with the aim of revealing the origin of this deviation. Expectations also provide important presettings for motor actions accomplished during the exploration procedure, for instance, the anticipation of a hard surface will increase muscle tension in order to make adequate contact with the material.

Level 2: Midlevel Analyses (Assessment): The second level of elaboration is still quite simple for the most part, but it already includes steps further specifying the object. Compared to the first level, more global aspects are now assessed requiring temporal as well as spatial integration of local aspects. Consequently, we term the processes of the second level *assessments* to stress a more elaborate way of processing. They can be divided into three different types of operations.

1) *Absolute assessment:* An absolute assessment is, by definition, a process that assesses global haptic qualities on an absolute basis without comparing them to qualities of other objects. Examples are symmetry, closure, and contour, which are all qualities that can be directly assessed through integrating local haptic aspects. These variables are well-researched factors in visual aesthetics and are candidates for also influencing haptic aesthetic responses. We know that haptic shape assessment is processed similarly to the visual domain [41]. Symmetry can likewise be assessed accurately under haptic conditions [42]. Visual findings indicate that symmetrical patterns [43]–[45] or symmetrical faces (e.g., [46] and [47]) are preferred compared to nonsymmetrical versions. Similarly to the studies reported at the first level, a visual preference bias toward curved objects (variable contour or angularity) was reported by several studies [48]–[50]. Recently, Jakesch and Carbon [51] replicated the effect under haptic conditions with 3-D plotted stimuli but also revealed results that indicate high degrees of idiosyncratic processing. Similar to the first level, contextual cues might influence the processing of symmetry and contour. The preference bias for curved objects might be overwritten when specific goals concerning ergonomic aspects are more relevant. The preference can also be changed over a series of elaborate contacts with new forms via adaptation effects [52]. An extreme example is the creation of cuboid watermelons from Japan's Zentsuji region for better transportation. In the next section, relative assessment is discussed. "Relative" refers to the fact that some properties cannot be assessed in an absolute fashion, but in relation to other items. This is true within a set of stimuli presented in the laboratory but is also influenced by the context: the subjectively perceived complexity of an object is supposed to change according to its surroundings.
2) *Relative assessment:* Berlyne [53] termed complexity a *collative* variable as it refers to a property that is related to another property. *Complexity* cannot be directly assessed on an absolute level but only in comparison to other items or another property; therefore the assessment of complexity is subsumed under the processes of relative haptic assessment. *Complexity* plays a fundamental role in visual as well as in haptic aesthetics.

   For visual stimuli, Berlyne [53] supposed, on the basis of the Wundt curve, an inverted parabolic relationship between complexity and appreciation with a maximum level of appreciation for medium levels of complexity (as defined by the number of features, alignment of features, order of features, etc.), an assumption that cannot be reliably replicated in most aesthetic domains (see [54] and [55]).
3) *Integrative assessment:* Under the term integrative assessment, we subsume processes that operate on a more global level and aim at the retrieval of information about the coherence of an object's haptic qualities by integrating local aspects into a global Gestalt. As many different haptic dimensions have to be taken into account in parallel, this process seems to be quite elaborate and specific already. Paradigmatic members of this category

are variables such as harmony, balance, and rightness, which are of great importance with regard to aesthetic appreciation [56], [57]. In the visual domain, Arnheim [58] suggested that "good Gestalts" are generally more aesthetically appealing. Haptic grouping effects (grouping based on proximity and similarity) have already been tested to investigate if the haptic perceptual organization is similar to the visual perceptual organization [59]. Grouping based on similarity speeded up the performance in a haptic search task, whereas proximity did not influence the performance. Based on these results, future studies might examine the aesthetic appeal of such Gestalts in a systematic and elaborate way.

Feedback Loop 3 (Integration Feedback Loop): Midlevel haptic analyses are shaped and retuned by an integration feedback loop where local aspects are integrated with regard to time and space to obtain assessments of more global aspects of the object. An even deeper level of integration will be reached when these more global aspects are themselves integrated to assess information on the coherence of such aspects.

Level 3: High-Level Analyses (Evaluation): The third level of elaboration refers to the last step of haptic aesthetic processing. It combines further integrative cognitive as well as emotional aspects: the haptic object that has been preprocessed during the preceding (perceptual) phases (exploration and assessment) is now associated and linked with other material, thus becoming integrated into the haptic habits (cf. [60]). The resulting final product of this process is the haptically specified object. For so-called *evaluations*, a term we will use here to indicate deep processing, cognitive as well as emotional aspects will be processed. On this level of processing, two types of evaluative operations are available.

1) *Utilization evaluation:* Utilization evaluation refers to all haptic qualities that are linked with practical issues or the handling of the object, e.g., usability and ergonomic aspects as well as properties associated with functionality and intuitiveness of usage (see [61] for an overview). It also extends the analysis to attention-drawing properties, adequateness, and practicability of the haptic design.
2) *Aesthetic evaluation:* Aesthetic evaluation encompasses those kinds of evaluative processing of the object's haptic qualities that concern variables commonly linked with aesthetic value. The term aesthetic in this context is defined in accordance to Desmet and Hekkert [4] as capacity (of materials and objects) to please our haptic system. Besides explicit aesthetic measures like preference, appreciation, and liking [62], interest [63], fascination, seduction, and frustration [4], [64], more implicit measures like cognitive and emotional arousal (as is, for instance, generated by uncertainty, ambiguity, understanding, or surprise) [65], innovativeness [60], and typicality and idiosyncrasy [66], [67] are candidates for aesthetic evaluation.

Feedback Loop 4 (Familiarity Feedback Loop): In accordance with theories on visual perception stating that object identification and recognition will not occur until high-level aspects have been processed [68], we propose that identificatory processes take place at the point of high-level cognitive analyses of the haptic object but not before. As soon as an object is processed on such a subordinate level [69], important information on its specific properties are available and the object becomes familiar. Familiarity and associated concepts of fluency and (proto)typicality are strong predictors for liking [67], [70], [71] and continuously contribute to further modification of the high-level process of evaluation. Specific research on according effects in the haptics domain is still rare, but recently it was found that phenomena like the mere-exposure effect can also be demonstrated for haptics. For complex stimuli, Jakesch and Carbon [72] found effects of exposure frequency leading to a significant increase in liking from fully unfamiliar via slightly familiar (touched twice before) to highly familiar (touched ten times before) objects that had only been haptically inspected. The reason for such familiarity effects might be that familiarity activates specific knowledge of the recognized object and associated requirements and demands, which consequently leads to tuning, shaping, and biasing the initial evaluation. In the case of new products, familiar parts activate stored concepts, e.g., of specific brands [73], and reshape evaluative processes and consequently aesthetic as well as utilization responses. A coherent context might foster the detection of familiar elements or the general categorization of an object being familiar, whereas a dissonant context might slow down or even hinder the feedback loop process.

IV. IMPACT OF HAPTIC AESTHETICS ON DESIGN ISSUES

A. Necessity of a Haptic Aesthetics Perspective

In this paper, we want to stress the necessity of integrating a haptic aesthetics perspective into the analysis of the qualities and the utility of products. Undeniably, there are strong movements and efforts toward integrating considerations of haptic functionality into the development of new products. Important examples from an applied perspective are given, inter alia, by contributions in this special issue on perception-based media processing, for instance, force feedback interfaces for increasing the validity of data entries [74] or haptic rendering as an effective feedback modality for the emerging area of haptic media

[74], [75]. Future product developments already show strong reliance on haptic controls using the "sense of touch" [76], although most efforts are in regard to utilization effects, still neglecting important effects of haptic aesthetics. As systematic knowledge as well as research on haptic aesthetics is still quite rare, future efforts should be strongly directed to this specific dimension of design qualities in general and haptic qualities in particular.

B. Creative Ways to Sensitize People to the Relevance of Haptic Aesthetics

Helpful inspiration for how to sensitize people to the relevance of haptic aesthetics comes from the domain of art. Louvre's "Tactile Gallery," opened in 1995, explicitly allows haptically *exploring*, *assessing*, and *evaluating* artworks. The hereby evoked strategies for achieving knowledge of the pieces of art reflect the different levels of analysis figured out by the functional model of haptic aesthetics proposed in this paper. Illustrating that aesthetic experience is far stronger, livelier, and more sophisticated when the sense of touch is integrated into the perception of complex objects, the exhibition furthermore stresses the importance of systematically developing a specific theory of haptic aesthetics.

C. Cognitive and Emotional Aspects

A product can communicate through many different channels, and haptic aesthetics in this context seems to be particularly qualified for evoking cognitive as well as emotional reactions. With regard to typical human–product interactions, the following aspects seem to be relevant. Haptic evaluation of products creates great opportunities to induce deeper cognitive processing of a product. If a product cannot be integrated into the "haptic habits" (compare "visual habits" in [60]) as a consequence of an excessively high degree of novelty, it might be labeled as innovative or it might remain uncertain. If expectations concerning the product are not met by the haptic evaluation (e.g., when it is discovered that the surface material of a premium car's dashboard has in fact a low haptic quality), (negative) surprise is produced. Haptic qualities that are not easily understandable and overstrain the perceiver's processing abilities will probably lead to frustration (cf. Mikulincer [77] who found a clear relation between failure in problem solving and frustration). Interest, in contrast, will result for haptic stimuli that induce low levels of understanding but are, at the same time, fascinating to the perceiver. Long-term fascination might yield seductive potential and lead to sustainable liking.

It is important to note that visual compensation for lacking or absent haptic information, i.e., a visual aesthetic compensation for low amounts of haptic aesthetics information, can hardly be an adequate strategy. This effect, which is particularly strong in people with a high "need for touch" [8], can be explained by Klatzky *et al.*'s [78] "visual preview model" that assumes a two-step processing of stimuli perceived on a visual and haptic basis. First, vision provides an optical snapshot of the haptic qualities; because of their inferential character, this information is neither very reliable nor very fine graded, but it meets the simple criteria required for generating a preliminary overview of the object's haptic structure. Second, haptic qualities will be analyzed by the haptic sense itself, which provides much deeper and elaborated information further enriched by so-called autotelic touch information [79]. Autotelic touch information includes, e.g., haptic pleasure, an important aspect of haptic aesthetics.

D. A Case Study for Haptic Aesthetics in Consumer Products

To demonstrate the impact of haptic aesthetics on a specific design issue, we will shortly discuss a case study from the consumer product industries: typical control elements that automobiles are equipped with.

In the automobile sector, main goals with regard to constructing control elements are ensuring safety of usage, reducing cognitive demands for controlling processes, high perceived quality, and pleasure of using. Goals related to safety and cognitive demands are requirements typically covered by ergonomic visual, but foremost haptic, design. Goals related to perceived quality and pleasure, to which we will shortly refer in the following, are directed mainly toward haptic aesthetics.

Perceived quality: The perceived quality of a product reflects the perceiver's opinion about the product's quality independent of the product's actual physical qualities. High perceived quality will most often lead to high levels of liking, satisfaction, or even fascination. In the given context, haptic aesthetics are of importance with regard to the design of knobs, buttons, and switches [31], [80], as well as concerning the materiality of the main interior elements for interactive usage (steering wheel, gear switch, door handles) and the overall impression of base materials such as the roof liner or the seat cover; more specifically, to sketch an example related to the proposed functional model, the evaluation of various seat fabrics. Local aspects (like fibrosity, stickiness, plasticity, roughness/relief, or perceived temperature) of the fabric's surface are used as the basis for high-level analyses. Based on previous experiences, actual needs, and intentions (sporty interior versus family-friendly interior, etc.), the same texture parameters will be evaluated differently with respect to quality as discussed in the context feedback loop.

Pleasure of using: Pleasure of using is hard to realize in an automobile as a consequence of strict safety guidelines that prevent overly playful gimmicks, but nevertheless specific haptic properties can lead to high aesthetic evaluations and can thus even create pleasure. There are several levels on which pleasure can be induced; important aspects are, among others, particularly comfortable or interactive seats, very intuitive and high-quality haptic control elements, or material of extraordinary haptic quality.

Implementing according elements can create high levels of haptic aesthetics, bringing about fascination and pleasure. Haptic response in terms of haptic feedback, as realized by BMW's haptic selector called iDrive, first introduced in the E65 7-series and further developed and integrated in other components by BMW's CCC and CIC systems, gives adaptive feedback to the regarding user mode. iDrive's controller knob integrates most of the configuration possibilities into one central system. As all systems to be coordinated during driving potentially draw attention away from the core job of a driver, i.e., the safe and precise handling of a car, haptic feedback is essential to distribute attention and cognitive processing on different modalities [81]. Haptic feedback also offers the pleasure of handling as the user gets a direct response from the system about the successful execution of a task.

E. Concluding Remarks

Real fascination with a product often originates at a level that throughout this paper we call "haptic aesthetics." This is quite impressively documented by the ongoing market success of products of Apple Inc. that are emotionally charged due to an intense focus on haptic aesthetics. As mentioned above, visual compensation (or compensation by any other sensory modality) is often not very successful, as fascination, interest, or aesthetic appreciation might just arise from one single, but spectacular haptic dimension or haptic feature.

Therefore, it is time to try and better understand the level of haptic aesthetics, and the pleasure that is frequently associated with it. Haptic research should, consequently, try to intensify investigative efforts as well as undertake the advancement of methods and the development of processing models for this thrilling and future-oriented domain. ■

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