Aesthetic heuristics for design: perceptual and absolute standards of beauty determinants

Abstract

The extraction and formalization of design heuristics used in design is an increasingly important area of research because of their multiple possibilities of application, especially for design practitioners. However, most of the attention has been paid to design heuristics for designing the product's functionality, usability, or architecture, three design tasks where plenty of methods are already successfully used. On the contrary, aesthetic design is an area where intuition is the prevalent method used to seek the generation of aesthetic pleasure for the user. Some methods exist but they are rather of descriptive nature, stating what to do, but without explaining how to do it. To tackle this problem, this paper describes a method to extract and validate a set of 223 aesthetic design heuristics obtained from textbooks and scientific literature. These heuristics were validated through the analysis of 50 products winners of design awards; 123 were coincident and 36 new. Out of the 123, 46 heuristics were randomly selected and validated by analyzing the interrater agreement of an experts' survey (n=24). Eighteen aesthetic design heuristics resulted in potentially increasing the users' aesthetic pleasure.

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Heurísticos estéticos para el diseño: determinantes perceptuales y estándares absolutos de belleza

Resumen

La extracción y formalización de heurísticos de diseño utilizados en el diseño es un área de investigación cada vez más importante debido a sus múltiples posibilidades de aplicación, especialmente para los profesionales del diseño. Sin embargo, la mayor parte de la atención se ha enfocado al diseño de heurísticos para diseñar la funcionalidad, usabilidad o arquitectura del producto, tres tareas de diseño en las que ya se han utilizado con éxito muchos métodos. Por el contrario, el diseño estético es un área donde la intuición es el método predominante para buscar la generación de placer estético para el usuario. Existen algunos métodos, pero son de naturaleza descriptiva, en los que se indica qué hacer, pero sin explicar cómo hacerlo. Para abordar este problema, este artículo describe un método para extraer y validar un conjunto de 223 heurísticos de diseño estético obtenidos de libros de texto y literatura científica. Estos heurísticos fueron validados mediante el análisis de 50 productos ganadores de premios de diseño; 123 fueron coincidentes y 36 nuevos. De los 123, se seleccionaron al azar 46 heurísticos y se validaron mediante el análisis de la concordancia entre evaluadores de una encuesta de expertos (n = 24).

Key words:
estética, diseño estético, extracción de heurísticos estéticos.

Introduction: The problem of aesthetic heuristics

The importance of aesthetics in design

Aesthetics is important to design: it can increase the variety of products in saturated markets (Matzler and Hinterhuber, 1998), helps to understand the functionality of products, provide satisfaction and well-being, (Hekkert, 2015), and generate aesthetic pleasure for the users. Aesthetic pleasure, an aesthetic response, is "the pleasure people derive from processing the object for its own sake," (Dutton, 2009), by gratifying the senses, and occurring when the product is pleasing to see, beautiful, and attractive (Blijlevens et al., 2014). Arguably, in product and industrial design, aesthetic pleasure is the most important among the aesthetic responses (Thurgood et al., 2014).

Aesthetic design variables groups

In aesthetic design, the designer manipulates the properties of the form (shape, volume, color, texture, etc.) (Hekkert and Leder, 2008) and the aesthetic variables, which are the determinants of aesthetic pleasure (Jacobsen, 2010). In this way, any **aesthetic response** is caused by properties of form that convey values for those aesthetic variables (a certain degree of symmetry, proportions, continuity, and so on). The latter are internal conditions on the subject or external conditions on the object or surroundings (Hekkert, 2014).

A theoretical framework of aesthetic design comprises around 43 aesthetic design variables classified into four groups: (i) absolute standards of beauty, (ii) perceptual, (iii) cognitive, and (iv) socio-cultural (Hekkert and Leder 2008, Crozier 1994, Berlyne 1966, Crilly et al., 2004, Bloch 1995, Veryzer 1993; Arnheim 1974, Tinio and Smith 2014). In this work we are focused on the first two groups because they are the most fundamental for design, traditionally

treated in design textbooks and in design education, but, at the same time, neglected from a methodological point of view as we will explain later. Moreover, the huge extension of the literature encompassing the four groups is not conducive to a unified publication.

Absolute standards of beauty

This group of about 12 standards is presented in table 1. They have been proposed through history as beauty standards by artists, architects, and philosophers. Arguably, they are not standards, because in many applications, although the rule establishes, for example, to apply a ratio of 1:1.61 to the general proportion of an object, this is not always the case. For instance, cigarettes packages are cited frequently as having the golden proportion, figure 1. However, actual packages show proportions near the golden proportion but not exactly 1:1,61.

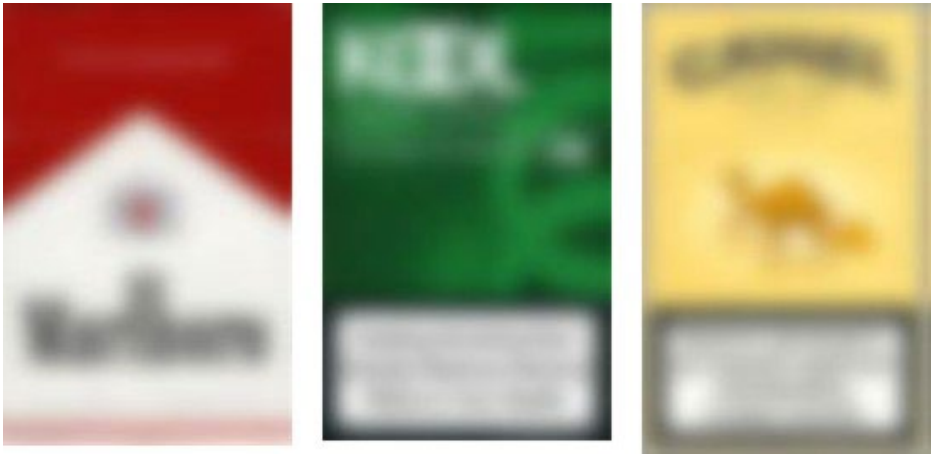

Figure 1. The cigarette-boxes of these famous brands present proportions of 1:1,56, 1:1,53 and 1:1,59.
Source: authors.

Table 1. Absolute standards of beauty

Absolute standards of beauty	
Variables	Definition
Good proportion	A proportion, different from the golden section, and considered aesthetically superior for a specific product category (Hekkert, 1995).
Balance	Visual weight affected by the position, size, color, value, and degree of details (Zelanski and Fisher, 1984).
Harmony	The orderly arrangement of the product elements that shows consistently mutual relations such as color or shapes and differences (Puhalla, 2011).
Hue	The color as such (Camgöz et al., 2002).
Saturation	The amount of grey in a color (Camgöz et al., 2002).
Brightness	The amount of white or black mixed in the color (Camgöz et al., 2002).
Golden Section proportion	Shapes with a ratio of 1:1.618 (Fechner, 1876).
Dynamization	Preference for shapes with a curved contour (Bar and Neta, 2006).
Elegance	"It is a kind of fluidity, smoothness of surface and style" (Rahim and Jamelle, 2007).
Naturalness	The use of natural elements as a source of inspiration (Dutton, 2005).
Sophistication	The tendency to prefer a product for its unique characteristics (Hammill, 2010).
Fibonacci sequence	Application of Fibonacci sequence (1, 1, 2, 3, 5, 8, 13,…) to the product proportions (Elam, 2001).

Source: authors.

Perceptual variables

This group of around 15 variables (some from Gestalt psychology), summarized in Table 2, share the same human biological functional basis, related to form perception (Hekkert and Leder, 2008). They describe how humans group visual elements to create a perceptual order and to understand what we see, looking for patterns (Smith and Ehrenfels, 1988). There are other aesthetic perceptual variables not considered in Gestalt psychology but studied from other psychological areas.

Table 2. Perceptual aesthetic variables

Perceptual variables			
Variable	Definition	Variables	Definition
Good Continuation	Grouping the elements on a line or curve (Duke, 1992).	Metaphor	Taking an attribute(s) from an inspiration source and transferring it to a product (Cila, 2013). Metaphorical meanings are tied to perceptual embodied experiences (Lakoff and Johnson, 1980).
Closure	To complete enclosed spaces and ignoring gaps in figures (Ncube and Crispo, 2007).	Conjunctive Ambiguity	A design that can be interpreted in several compatible and jointly effective ways (Boselie and Leeuwenberg, 1985).
Common fate	The tendency to perceive elements moving in the same direction as a unitary entity (Wertheimer, 1923).	Contrast	The use of opposite colors or qualities among shapes to create emphasis (Wallschlaeger et al.,1992).
Parallelism	The use of parallels lines or parallels contours (Wagemans et al., 2012).	Isolation	A similar element but placed apart from the group (Fiore, 2010).

Prägnanz	Grouping elements with maximum simplicity and balance (Wertheimer, 1923).	Solving Puzzles	The preference to see connections (Hekkert and Leder, 2008).
Similarity	Grouping elements with similar characteristics (shape, colors, shadings, orientation, texture) (Goldstein, 2010).	Peak shift	The inclination to respond positively to exaggerated stimuli beyond a usual threshold (Hekkert and Leder, 2008).
Symmetry	Match of size, shape, and position of two or more elements (Wertheimer, 1923).	Variety	The use of elements with perceived differences (Berlyne, 1966).
		Unity in Variety	Perceiving as much variety as possible to produce interest, while perceiving unity to generate a sense of understanding (Hekkert, 2015).

Source: authors.

Manual Aesthetic design procedures

In doing manual aesthetic design designers can use one of these three procedures:

First, use their intuition. Aesthetic design is mostly an intuitive process supported by biological evolutionary mechanisms allowing us to prefer some properties that we recognize with higher aesthetic value (Grammer et al., 2003). Hekkert and Leder (2011) argue that "designers do not need to know the aesthetic principles to apply them; they intuitively design accordingly since the principles are as much part of their creative nature as they are of the observer's aesthetic perception." Intuition is a way of processing information based on automatic, affective-personal standards, but it is not the opposite of rationality (Tonetto and Tamminen, 2015). Intuition is a prevalent method in

design but has many limitations, especially for novice designers (Badke-Schaub and Eris, 2014), which restrict design possibilities. Because of the intricate and tacit nature of the mechanisms behind the psychological-aesthetic response, these mechanisms are difficult to access and understand through reflection or introspection, even for expert design practitioners.

Second, use manual aesthetic design methods based on 2D drawing and imaging and 3D physical models (Eissen and Steur, 2014). For instance, Rowena Reed proposed a methodology named "structure of visual relationship" to develop designer skills to define product shape through the manipulation of abstract shapes (Hannah, 2002). However, she only explicitly considered some absolute standards of beauty and some Gestalt variables, without contemplating other perceptual variables. Wallschlaeger et al. (1992) developed a model that explains the product form based on the articulation of the shape elements (line, contour, volume, etc.). Even so, their method is extremely complex and comprises not only aesthetic but communicative, productive, or ergonomic aspects as well. Different design textbooks (Elam, Zelanski, Bern, Lauer) propose proportion and visual coherence tools such as the golden section, Fibonacci sequence, and the dynamic root rectangles. Nevertheless, they do not explicit how these tools can be applied beyond the general proportions of the product and how these tools are related.

In conclusion, many texts of basic education in design explain that the laws of the Gestalt and the absolute standards of beauty have an important influence on the perception of the object. However, first, they do not link that perception with the aesthetic response and, second, they do not show any method explicitly about how to control and/or design such determinants in the product being designed and, third, less common Gestalt laws and other perceptual determinants of the aesthetic response (conjunctive ambiguity or peak-shift for instance) are not even mentioned. Consequently, their design is not done or

it remains tacit. Moreover, other methods have a global nature, which impels designers to get an aesthetic response but without considering the determinants behind it. Even if we have identified dozens of aesthetic design methods and if a literature review of this subject is needed, these methods are limited because they only consider some aesthetic design determinants and they are rather descriptive.

Third, using heuristics: these are rules or short-cuts that can be effective to generate acceptable solutions when the product cannot be formally derived, i.e., in a structured or logical way (Yilmaz, 2010). There is ample literature evidence that demonstrates the application of heuristics as a support of the design process. The designer could consciously or not deploy a heuristic. Heuristics coming from different sources have been proposed to support the design process (Yilmaz, 2010): presumably, a heuristic is easily applied, as opposed to more structured methods requiring training to use them (Yilmaz, 2010). Therefore, we define an aesthetic design heuristic, (from now on we will say *heuristic*, unless other meanings are explicitly stated) as a simple rule that supports the aesthetic designer to get closer to a certain aesthetic response for the product's user. Accordingly, most absolute standards of beauty are of a heuristic nature, because, for instance, applying the golden proportion to an object does not guarantee that it is going to generate aesthetic pleasure in the user (Hekkert, 1995). Aesthetic design principles can be expressed as heuristics rules: "*as Ramachandran and Hirstein (1999) claim for artists, these rules or principles are 'a set of heuristics that artists either consciously or unconsciously deploy to optimally titillate the visual areas of the brain"* (Hekkert and Leder, 2011). Most design heuristics are originated in professional practice and practitioners apply them in a tacit or explicit way.

Designing with heuristics has benefits: their flexibility allows the designer to generate diverse ideas without affecting the intuitive process, considering

that aesthetic decisions are usually automatic (Tonetto and Tamminen, 2015). Therefore, although heuristics do not guarantee to design "the most beautiful product", they allow implementing aesthetic design determinants into the design process, looking to obtain aesthetic pleasure, as it happens in any regular intuitive design process. Moreover, the aesthetic design process is highly complex, therefore designing with heuristics could be a suitable solution to the problem of how to consider, explicitly, many aesthetic design determinants, that have been neglected by design scholars and practitioners alike. Additionally, applying these heuristics may lead to exploring previously neglected zones of the aesthetic-design solution space (Gero, 1994), enhancing the intuitive-explorative approach to form-giving, while acting directly upon the aesthetic determinants instead of exploring in an open uncertain way.

Up to date, no studies are attempting to build a set of heuristics for designers considering absolute standards of beauty and perceptual aesthetic determinants, so designers can understand and apply them during aesthetic design. Hekkert and Leder (2008) argue that "designers do not need to know the aesthetic principles to apply them; they intuitively design accordingly", but we disagree. Consequently, the question tackled in this work is: which could be a set of heuristics that the designer could consciously deploy to generate aesthetic pleasure in the user? Therefore, our objective is to show the development of a set of heuristics for perceptual determinants and absolute standard of beauty supporting the aesthetic design process to increase the aesthetic pleasure products generate on their users. Specifically, through different methods: (1) extract heuristics for perceptual variables and absolute standards of beauty from design and scientific literature, (2) translate them in terms understandable for designers, if necessary, (3) validate them by finding out if they are present in renowned design products, (4) validate if they would be apt to generate aesthetic pleasure by asking design experts. We must emphasize that our objective is to extract and validate the aesthetic heuristics

that already exist in the literature and not to identify knowledge gaps as can be done with a Literature Review.

For this purpose, we present in section (ii) a state of the art of aesthetic design heuristics and heuristics extraction and validation, in section (iii) a method for extracting aesthetic design heuristics from literature, in section (iv) a method to verify the extracted heuristics with an analysis of design awarded products, in section (v) an experts' validation of the application of some of extracted and verified heuristics and in section (vi) we present the conclusions.

Extraction and application of Aesthetic Design heuristics: state of the art

Most design heuristics studies focus on very specific domains, for instance, the mechanical design of helicopter turbines (Calle et al., 2016). Yilmaz et al. (2010) have extracted 77 heuristics, mainly of application in conceptual industrial design, whether concerning the functionality, usability, or architecture of the product, but only five concern directly product aesthetics: *Add features from nature, Bend into angular or rounded curves, Mirror shapes for symmetry, Twist geometric forms to add variation, Visually separate similar functions*. Anyway, the success of the application of design heuristics relies on their extraction and validation (Yilmaz, 2010).

After an exploration of different design heuristics extraction methods, we found four ways to extract them: The study of designers' design process (Ramirez, 2014), the analysis of award-winning products (Yilmaz, 2010), the study of design heuristics from design cases (Potter et al., 2003) and the systematic literature review (Cadavid et al., 2016). In conclusion, some authors have already made an initial work to try to identify heuristics used by designers but focusing on design practice to extract them or on the function, usability, and product architecture rather than on aesthetics. Our study is important because

no efforts have been made before to identifying and extracting these heuristics from aesthetics design literature, a rich but very large corpus of knowledge.

Besides its novelty, this research topic is important because applying the heuristics enrich the results of aesthetic design; moreover, they can provide a basis for more structured methods for aesthetic design, supporting and complementing intuition by exploring or designing the product along with the determinants of the aesthetic response, and this, in an organized way. They can also shed light on the psychological mechanisms behind the aesthetic design process. Finally, the whole validated heuristics set could serve as a basis to create a methodological heuristics toolbox, complemented by choosing method to support design students and professional designer's work alike.

Research Methodology

The research methodology is composed of three steps: Figure 2: 1, Extraction of the heuristics, 2, first validation through design-award winner products, and 3, second validation through an expert survey. The extraction method was already published elsewhere (Cadavid et al., 2016). In summary, based on the results of the literature review, the most suitable method to extract heuristics is through a systematic procedure from design and scientific literature. A second method followed to conduct the first validation to determine if the first extraction heuristics were also present in some selected award-winning products. The second method also allowed to extract a new set of heuristics (36) identified during the validation process and that did not appear in the first set. These two methods are qualitative and seek to explore the aesthetic design determinants and to articulate them as heuristics rules. Finally, as second validation of the heuristics, an expert survey was conducted by asking if a random selection of aesthetic design heuristics were conducive to generate aesthetic pleasure in the user.

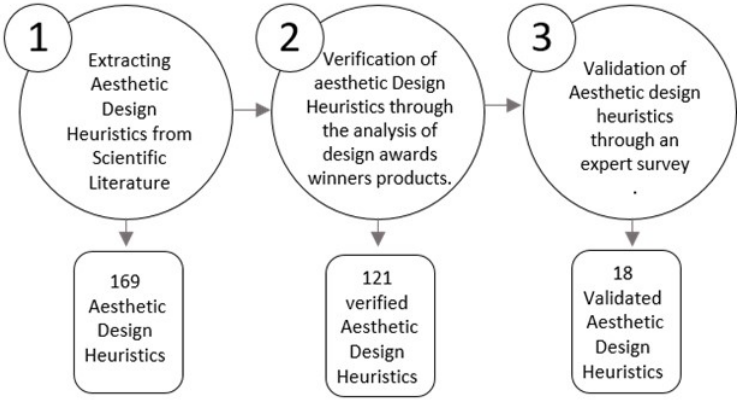

Figure 2. Research methodology.
Source: authors.

Extracting aesthetic design heuristics from scientific literature

Method

These three-phase method, (see Figure 3), is fully explained in (Cadavid et al., 2016). Thus, we only show the results.

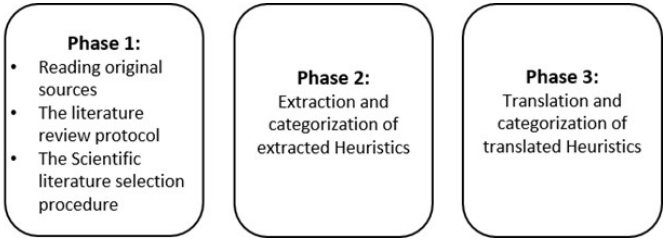

Figure 3. Method phases.
Source: authors.

- **Phase 1:**

  The literature review and the selection procedure took more than 1,200 hours (around eight full-time work months). It resulted in 156 scientific articles: 65 corresponding to absolute standards of beauty determinants and 95 to Perceptual.

- **Phase 2: Extraction and categorization 1.**

  We extracted the heuristics by evaluating in the article the characteristics expected to be met by any heuristic. A common structure for a heuristic is Verb + Complement (including the determinant) +To or For + Result (in terms of an aesthetic response).

  We obtained 223 heuristics from all the aesthetic design determinants studied. We had to classify them to facilitate their understanding and use. First, we classified them into two groups according to their compliance to the heuristic common structure. This classification criteria were poor, so it was dismissed. Then two new criteria were proposed:

  Application Heuristics: Heuristics supporting the design process. 169 were obtained.

  Heuristics relating two aesthetic determinants: Heuristics containing two determinants that share similar characteristics. Eight were obtained.

  Heuristics that explain the phenomenon: Heuristics that have a definition of the determinant or explain its relationship with aesthetics. 46 were obtained.

- **Phase 3: Translation and categorization 2.**

  In this phase, the 169 heuristics "Application heuristics" were rewritten by the first researcher in more clear terms for designers, avoiding scientific jargon, so, these could be applied by designers. It was the only rewritten heuristics category, as these are, presumably, the most useful during the aesthetic design process. See the "metaphor" example in *table 3*. The translation process was checked by researcher two.

Table 3. Translated Heuristics

Reference: The use of metaphors in product design (Cila, 2013)	
Text	Translated heuristic
"A product metaphor also consists of an "association" between a target and a source. The target is the "product" that is employed in a metaphor (…), and the source is the remote entity associated with the target to assign a particular meaning to it."	Apply metaphorical elements, (animals' forms, sounds, movements, smells, etc.) to create different expressions and meanings in the product.

Source: authors.

The 169 translated application heuristics were re-categorized into two new categories to facilitate the heuristics selection process:

Inspiration category: heuristics aiming to discover a design challenge and new design perspectives

Ideation category: help to generate ideas (and solutions) to aesthetic design problems.

See an example of inspiration heuristics and ideation heuristics in table 4 and table 5.

Table 4. Examples of aesthetic design "inspiration heuristics" and "ideation heuristics" for some aesthetic design determinants

Aesthetic design Determinant	Inspiration heuristics (IN)	Ideation heuristics (ID)
Symmetry	Apply symmetry to all the product parts to create an easier-to- understand product.	Use radial symmetry to create energy in the design.
Good Continuation	Distribute the product elements on continuity lines to create a sense of order and unity.	HGoodContinuation: Distribute the product elements on continuity lines to create a sense of order and unity.
Closure	Use a shape with unclosed outlines to create interest.	Use closure lines to give unity to the product.
Proximity	Place the similar product elements at a close distance, to see it as a unit, and reduce visual disorder.	Place the elements with similar characteristics close to each other to form groups.
Metaphor	Create deeper levels of meaning using metaphor in the design of the product.	Transfer the interaction of an inspiration source to the product.
Unity in Variety	Structure the variety of product buttons, dials, and lights into a coherent design using unity.	Use regular geometric shapes in complex structures to decrease visual complexity.
Dynamization	Use curve lines to increase the product harmony.	Use shapes with curved contour lines to increase the product appeal.
Sophistication	Use handmade details to create a sophisticated product.	Use technological materials, and processes to apply a sophisticated identity to the product.
Variety	Increase the variety of elements and colors to increase visual complexity.	HVariety: Use diversity and variety of design components to generate contrast and differences in the product form.
Peak shift	Exaggerate the feminine or masculine characteristics of the product to increase the interest.	Exaggerate the product's color or hue to attract the user's sight.
Isolation	HIsolation: Isolate product elements that you want to highlight or create a focal point.	Separate functions by similar shapes, sizes and colors.

Aesthetic design Determinant	Inspiration heuristics (IN)	Ideation heuristics (ID)
Conjunctive Ambiguity	Create a product that can be visually interpreted in several compatible and effective ways.	Create a product with different interpretations to increase the interest in it.
Brightness	HBrightness: Use low brightness to express the feeling of simplicity, determination, and mystery in the product.	Increase freshness and decrease saturation to get brightness.
Saturation	Use unsaturated colors to highlight the product's efficacy.	Design large or bulky products using less color saturation.
Contrast	Use contrast in the product colors to intensify the meaning.	Use different shapes and contrasting colors to easily detect contours, depth, and shapes.

Source: authors.

Table 5. Examples of Aesthetic design heuristics of the determinant "metaphor"

Aesthetic design determinants: Metaphor	
Ideation heuristics	**Inspiration heuristics**
Transfer the properties representing particular product characteristics from a source (i.e. animals), to create a metaphorical product.	Create deeper levels of meaning using metaphor in the design.
To create a metaphorical product, take an association between a product and a source that have a particular meaning according to the product.	Use a metaphor with the product name. When transferring the form of the source you can also transfer the source name.

Source: authors.

The heuristics without the "to" particle are not focused only on the aesthetic response making them of flexible application.

Validation of aesthetic design heuristics through the analysis of design award winner products

Method

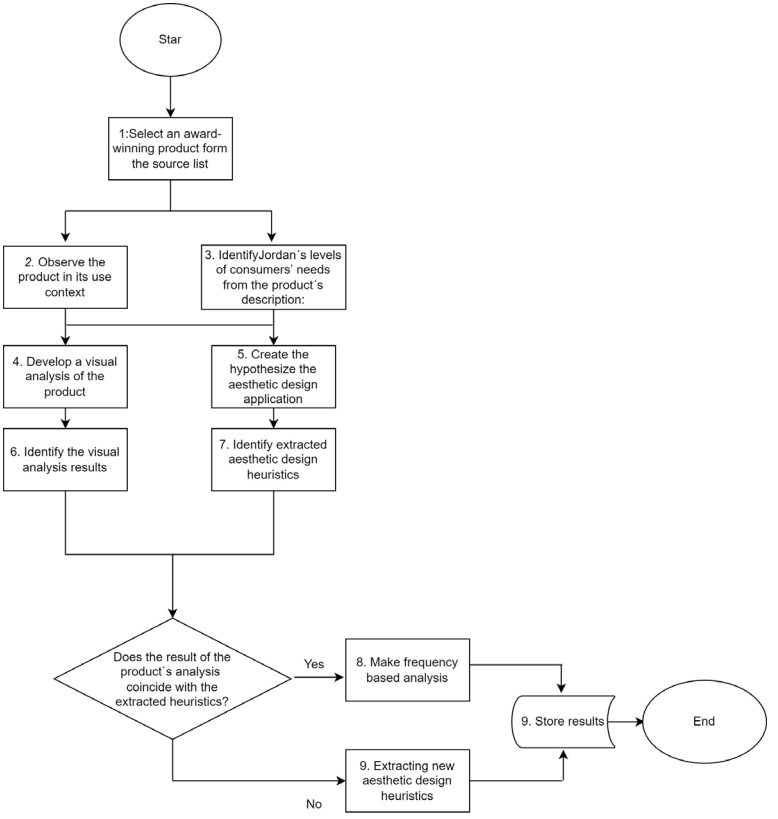

Figure 4. Flowchart describing the verification method of extracted aesthetic design heuristics.
Source: authors.

To validate if the heuristics found are present in product design practice, we developed a method based on Yilmaz (2010) and "the compositional interpretation" method by Rose (2016). Our method aims to verify if the heuristics extracted are present in the analysis of a sample of 50 renowned design award-winner products.

The extracted heuristics were compared with those extracted from 25 products from Red Dot Design Awards and 25 from A'Design Award & Competition. The method was composed of the 9 steps, presented in *figure 4*, as follows:

- **Step 1: Select an award- winning product**

  The analyzed products were randomly selected from different categories of each design award, then, we selected two products per category, every five products.

  An example of each of the steps will be explained below.

  Figure 5 illustrates "Edyn" information, Red Dot 2015 winner.

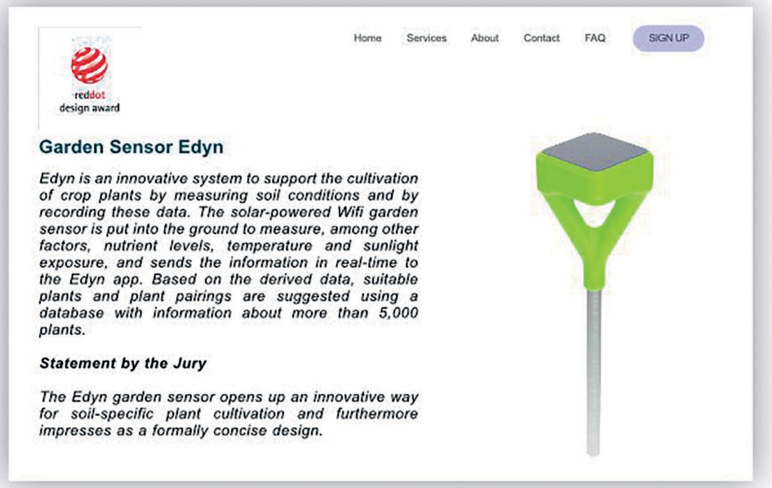

Figure 5. Images similar to the original for illustrative purposes. Edyn, a garden sensor, winner product from Red Dot Design award 2015. Source: Image created by Juan Felipe Sanchez Arbelaez based on https://www.red-dot.org/project/edyn-32860.

- **Step 2: Observe the product's use context.**

We searched for additional product images from sources other than the design awards page to better understand how the product characteristics were related to the context of use. Therefore, the product characteristics identified were the product size and proportion, color contrasts, shape patterns, product lines, textures, visual weight, balance, the product's scale, and visual movement. For instance, in *Figure 6* and 7, we can identify that Edyn's proportion, scale, and color combination are appropriated to the context considering its use in gardens. Additionally, the horizontal balance is similar to the plants around it.

- **Step 3: Identify Jordan's (2002) hierarchy of consumer needs from the product description**:

  This step is conducted to get a concise understanding of the product function, its relationship with the user, and its aesthetic, emotional, and semantic levels. We reviewed each product's description according to this hierarchy:

  (i) Functionality: the product core function, its technology, and performance Usability: the user's relationship with the product, the easiness to use, and understandability

  (ii) Pleasure: the meaning transmitted by the product, the aesthetic pleasure, and the emotion the user feels with the product.

  (iii) For instance, for functionality: “Edyn” is an innovative system to support the cultivation of crop plants by measuring soil conditions and by recording these data”. For usability: “Edyn” sends the information in real-time to the Edyn user's app”. For pleasure: “Edyn Impresses as a formally concise design”. The product characteristics recognized in the product's aesthetic level allowed us to understand the aesthetic proposal the designer wanted to convey through the product's design.

Figure 6. The product "Edyn" in its use context.
Source: Image created by Juan Felipe Sanchez Arbelaez.

1. Proportion (cm)	Depth: 7	Width: 7	Height : 30
2. Color and color combination			
3. Patterns inside or around the product	Symmetrical elements		
4. Product´s shapes.	 The recognize shapes are square, circle and rectangles		
5.location of product elements	Every elements are located in one axe (Unity)		

Figure 7. Results of the First process of the product visual analysis.
Source: authors.

Step 4: Develop a visual analysis of the product

After recognizing which aesthetic characteristics influenced the aesthetic response, we identified the aesthetic design characteristics presented in each of the products, following two steps: First, we identified the general product‘s characteristics related to the specific aesthetic design determinant, extracting five data about the product: (i) proportion, (ii) color hues and color combination (iii) patterns inside or around the product (iv) product's shapes and (v) location of product's elements. Second, we traced lines of continuity, and we highlighted the location of elements such as the logos on the product's image, and the product's shapes to identify the line orientation changes, the contrast among colors, the variety of shapes, and other product details. The results of this step were reported in a “visual analysis result” list.

With these product characteristics, we identified that the product had vertical symmetry, a proportion ratio of 1:428 (dynamic rectangle √2); highly contrasted colors (yellow and black), and a variety of canonical shapes. The aesthetic characteristics found in this second process are presented in *Figure 8*. We could find that the product edges are curved, the product is like the flowers around it and its shapes change around its body.

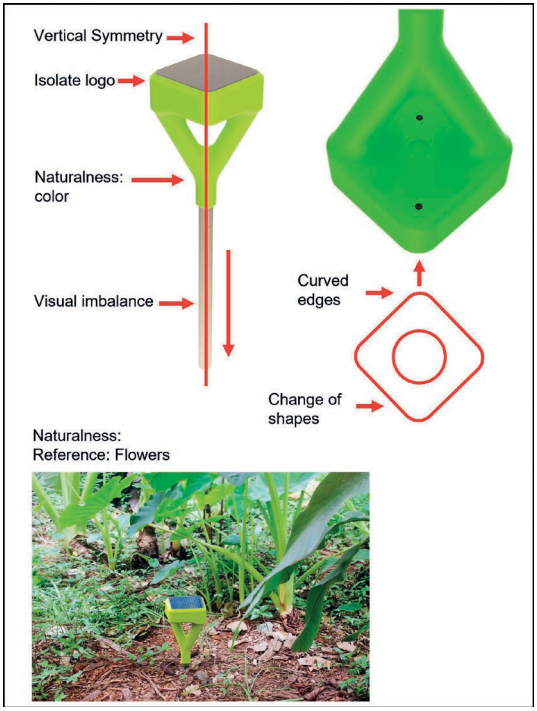

Figure 8. Second process of the product visual analysis.
Source: Image created by Juan Felipe Sanchez Arbelaez.
(add Naturalness: color and presence of branches; organic shapes, at least for the stem and branches to Figure 8).

- **Step 5: Create the hypothesis of aesthetic design application**

  We formulated a hypothesis about the designer's intention (the message the designer wants to communicate through the product (Crilly, 2011)). For example, the designer wants a stable, durable, friendly-looking product, etc. Therefore, we gained insight into the aesthetic design determinants the designer used.

  Although speculative, the hypothesis had to be reasonable and based on the evidence provided by the physical supports of the product's form. For instance, for Edyn, the visual analysis evidenced that the product has a certain resemblance to flowers. Thus, the hypothesis states: "The designer seems to use a natural reference as inspiration (flowers' color and shape), to create a friendly product according to the product context of use and function." We identified vertical balance too. Therefore, another hypothesis is: "The designer wants to keep the visual unity and to generate a security sensation."

- **Step 6: Report the results of the visual analysis of the product**

  For Edyn:

  (i) The product has a certain resemblance to flowers (naturalness, metaphor)
  (ii) The product has a vertical symmetry (balance, symmetry)
  (iii) The colors and shapes are according to the context of use (naturalness)
  (iv) The product has rounded edges (Dynamization).

- **Step 7: Identify aesthetic design determinants**

  In this step, we extracted the aesthetic design determinants previously identified in the hypothesis and verified if the heuristics extracted from the literature coincided with those of the product's visual analysis. If coincident, we could proceed to step 7. Otherwise, we had to continue to step 8.

  Identify extracted aesthetic design heuristics.

  According to the product visual analysis results and the hypotheses we could recognize the aesthetic design heuristics presented on each of the analyzed products.

  For Edyn, we recognized: balance, dynamization, symmetry, naturalness, and metaphor. We compared the results of the product visual analysis with the extracted heuristics. See some examples in *Table 6*.

Table 6. Comparison of aesthetic design heuristics

Aesthetic design determinant observed in Edyn	Heuristics extracted
Balance	Use vertical balance to produce a sensation of security.
Dynamization	Use shapes with a curved contour line.
Symmetry	Create harmony in the product, creating lines, form, shape, space, color, and texture in balance.
Naturalness	Take natural elements to design a product.
Metaphor	No heuristics related to the product analysis.

Source: authors.

- **Step 8: Make frequency-based analysis**

  One hundred twenty-one heuristics out of 169 occurred in the analyzed products, multiple heuristics occurred in some products. The most common heuristics between the literature and the products were identified through a frequency table.

- **Step 9: Extract new aesthetic design heuristics**

  Important products characteristics identified during the visual analysis allowed the extraction of new heuristics not present in the literature extracted heuristics. Therefore, 36 new heuristics were identified. For example: "Apply contrast materials (wood and quartz) to create interest in the product."

- **Step 10: Store results**

  We stored the obtained heuristics in a database as an ordered set.

Validation of Aesthetic design heuristics through an experts' survey

The Method

To validate the application of some heuristics, we asked an expert panel, through a web survey, to what extent they considered that the application of 46 out of the 121 extracted heuristics could increase the user's aesthetic pleasure.

- **Data collection process**

Survey Methodology

The survey was composed of two parts: The first explained the terms "heuristics" and "aesthetic pleasure" (Blijlevens et al., 2014). An example of the application of aesthetic design heuristics in a product design was included, Figure 9. Then, it was requested to indicate the years of experience: (i) 3 or fewer years, (ii) 3 to 5, (iii) 6 to 10, and (iv) more than 11.

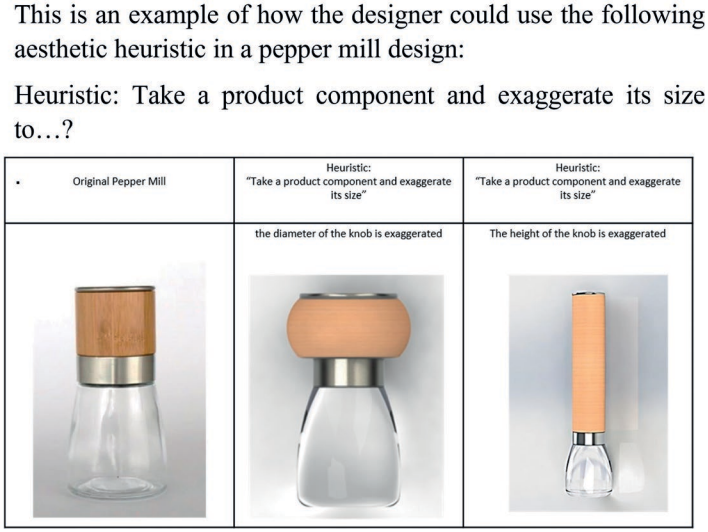

Figure 9. Application example of an aesthetic design heuristic.
Source: authors.

In the second part, respondents were asked to indicate to what extent each of the 46 extracted heuristics contributed to increasing the level of aesthetic pleasure for a product's user (Blijlevens et al., 2014). We used an ordered categorical scale: High (the respondent strongly agrees), Medium (agrees), and Low (weakly agrees). In some cases, it was necessary to use a diagram to explain the aesthetic design heuristics. *Figure 10 presents an excerpt of the survey instrument.*

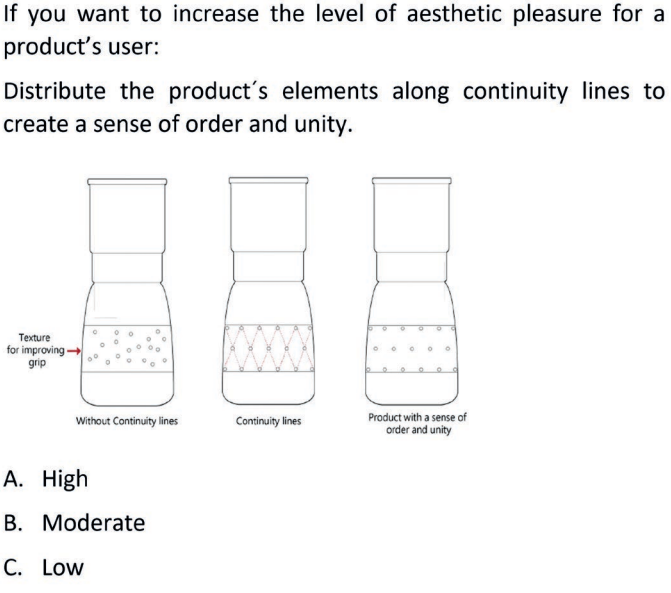

Figure 10. Aesthetic design Heuristics at the survey.
Source: authors.

Sample of participants
A design experts' sample with different years of experience and specialized in different product categories was assembled.

The survey was sent to 52 design experts and was answered by 24: 6 (25%) 3 to 5 years of experience, 11 (45%) 6 to 10 years, 7 (30%) with more than 11. They design different products: household appliances, lamps, furniture, children's toys, interactive exhibitions, among others.

Data analysis process
The experts' opinions may differ, consequently, we developed a systematic decision process on the extracted-validated heuristics. Therefore, two criteria were considered: (i) The heuristic can be accepted; high level of agreement between the experts, (ii) The longer the experts' experience, the higher the importance of their response. Consequently, we analyzed the frequency of occurrence of each answer option (low, medium, high) per heuristic per experts' category.

Example:
Heuristic 1: “Use Symmetry on the product to create a unity effect”

	Frequency			
Years	**High**	**Moderate**	**Low**	**Total**
3-5 years	4	2	0	6
6-10 years	7	3	1	11
11-20 years	4	3	0	7
More than 20	0	0	0	0
			Total	24

Two steps were followed for the heuristics selection: (i) heuristics rating, and (ii) heuristics selection. For (i), we rated each heuristic per category of expertise on a scale of three scores: -1, 0, 1. Therefore, the set of decision rules presented in Table 7 was defined and used as selection criteria. For example, a particular heuristic was rated as 1 if, "High">60%, AND "High">"Medium", AND "High">"Low". We set a threshold of 60% to be conservative and to ensure that only those heuristics in which more than 60% of the experts (belonging to a specific category) considered them as increasing aesthetic pleasure were rated as 1. Once all the heuristics were rated by category we conducted a weight-based analysis to decide about those heuristics in which the decision of all the categories did not coincide at all. Then we gave a weight of 3 to the experts with 3 to 5 years of experience (C_1); a weight for 6 to 10 (C_2); and a weight of 7 to the experts with more than 11 experience years (C_3).

Threshold	**60**	
Experience	**Weight**	**Heuristic 1**
3-5 years	3	1
6-10 years	5	1
>20 years	7	0
	Total sum according to weight	8

The following equation was used for the selection process:

$$R_{h_i} = \sum_{j=1}^{3} (W_{C_j} \times r_j)$$

R_{h_i} is the general rate of heuristic i, where $h=\{h_i \mid i = 1,\ldots,46\}$; W_{c_j} is the weight given to category j, where = $\{C_j \mid j = 1,\ldots,3\}$; and r is the rate given to the heuristic h_i by the experts belonging to C_j during the heuristic rating (whether -1, 0 or 1). All the heuristics that got $R > 0$ were considered as increasing the aesthetic pleasure, and therefore, these were selected, while heuristics that got $R \leq 0$ were discarded, as there was no consensus between the experts on whether those really increased the aesthetic pleasure.

Table 7. Section Conditions

	Conditions
1	If: H>M AND H>L AND H>60 THEN r=1
2	If: M>H AND M>L AND M>60 THEN r=0
3	If: L>M AND L>H AND L >60 THEN r= -1
4	If: H>M AND H>L AND H<60 THEN r=0
5	If: M>H AND M>L AND M<60 THEN r=0
6	If: L>M AND L>H AND L<60 THEN r=-1
7	If: L=M AND L>H AND L<60 THEN r=-1
8	If: L=M AND M>H AND M<60 THEN r=-1
9	If: L=H AND M>L AND M<60 THEN r=0
10	If: L=H AND L>M AND M<60 THEN r=-1
11	If: H=M AND M>L AND M<60 THEN r=0
12	If: H=M AND L>M AND M<60 THEN r=1

H: High, M: Moderate, L: Low.
Source: authors.

Results of the validation of aesthetic design heuristics through an expert survey

We found 18 heuristics considered as increasing the aesthetic pleasure, (evaluated score R > 0). Conversely, 28 heuristics were discarded ($R \leq 0$, 11 with negative score): there was no consensus between the experts. *Table 8* indicates the selected aesthetic design heuristics that obtained a positive or negative score according to the validation process.

Table 8. Results of the validation process. R: Score. Heuristics with codes (HName) refer to table 7.

Heuristics with a positive score				**Heuristics with a negative score**			
T	Heuristic	R	Variable	T	Heuristic	R	Variable
1	Use parallel lines for grouping and orienting the product's elements.	15	Parallelism	1	Take a product component and exaggerate its size	-12	Peak shift
	Create harmony on the product balancing its color, shapes, and textures.	15	Harmony	2	Use asymmetry on the product to attract the user's attention.	-10	Symmetry
	Create a product easy to remind using symmetric, simple, and balanced shapes.	15	Symmetry	3	Use diversity and variety of design components to produce contrast and differences in form.	-8	Variety
2	Use shapes with curved contour lines to produce a security impression for the user.	12	Dynamization	4	To obtain naturalness replace the formal language of technical elements with natural forms. For instance: mimic a waterfall on a bathroom's sink faucet	-7	Naturalness
3	Distribute the product's elements along continuity lines to create a sense of order and unity.	10	Good continuation		Use a variety of colors to create an interesting product.	-7	Variety
	Maximize the simplicity and balance of the product.	10	Prägnanz		Design the product, like a puzzle game to stimulate curiosity.	-7	Solving puzzle

Heuristics with a positive score				Heuristics with a negative score			
4	Use Symmetry on the product to create a unity effect.	9	Symmetry	5	Take the product's elements with similar characteristics and move them closer to form groups.	-5	Similarity
5	Use common movements characteristics (same time, velocity, and direction, or flicking time, frequency, and intensity) on the product's elements to create a motion impression.	7	Common fate	5	Adjust the proportion of the product according to the golden ratio (1.618) to create a much eye-catching product.	-5	Golden section proportion
5	Apply fluidity and smoothness to the surfaces to give a feeling of lightness and elegance.	7	Elegance	5	Use color combinations that are similar in saturation.	-5	Saturation
5	Apply low brightness colors to express the feeling of simplicity, determination, and mystery in the product.	7	Brightness	6	Use an unclosed product's shape to call for the user's attention.	-3	Closure
5	Apply contrast to create a desirable tension and reinforce the unity of individual components.	7	Contrast	6	Use unfamiliar colors for the product category and simple shapes to create, at the same time, unity and variety on the product.	-3	Unity and variety
				6	Create a product that can be visually interpreted in several ways the interpretation should be compatible and effective to...	-3	Conjunctive Ambiguity

Heuristics with a positive score				Heuristics with a negative score
6	Use saturated colors to call attention to your design.	5	Saturation	
	Harmonize using contiguous colors in the chromatic scale.	5	Harmony	
7	HParallel2	3	Parallelism	
	Use the same colors on product's elements with similar characteristics to…	3	Similarity	
	Mimic the way of functioning of an inspiration source on the product to…	3	Metaphor	
	Use elegant shapes, high- quality materials, and stylish colors to create a sophisticated product.	3	Elegance	
8	HIsolation	2	Isolation	

Source: authors.

Heuristics with the higher positive score (R=15) are those in which the great majority of experts, from all the experience categories, agreed on a high level of contribution of heuristic to increase aesthetic pleasure. For the medium positive score heuristics (R=7), the agreement level was not as large, but it still has an important level of consensus. In these cases, there can be a minor variation

among the experts' opinions that belong to different categories. Finally, for the lower positive score heuristics (R=2), only experts from the two categories with higher experience levels (6 to 10 years and 11 years and more) agreed that heuristics contribute to a high level. In this case, most of the experts that belong to the rest of the categories agreed that such heuristics contributed to increasing the aesthetic pleasure too, but at a moderated level.

Concerning heuristics with higher negative score (R=-12), the great majority of experts, all the experience categories confounded, agreed that these heuristics do not contribute to increasing the aesthetic pleasure while the medium negative score (R=-5) contributed at a moderate level. For the lower negative score (R=-3) and heuristics with R=0 there is not a clear agreement among the experts.

The highest positive scores heuristics are eight heuristics (45%) about Gestalt laws, three (16%) about color, and seven (39%) that instruct to keep the unity in the product and create a visual balance using harmony, metaphor, elegance, and contrast.

Discussion

From the analyzed heuristics, those with the highest score are Gestalt laws: the most common aesthetic determinants present in design textbooks. For instance, for R=15 and 10 (parallel lines, continuity lines, symmetry/unity, and so on). They are the least novel maybe. One exception is “shapes with curved contour for security” (R=12, “dynamization variable”). Understandably, a harmony heuristic appears ranked here: harmony is an important standard of beauty. Conversely, if we analyze the highest negative scored, the first position (R=-12) was: “exaggerate component size.” This heuristic is related to the “peak shift” variable. The second position (R= -10) was: “use asymmetry for attention”,

asymmetry variable. Finally, third, the heuristics “Replace with natural forms”, and “Design like a puzzle” correspond to the naturalness, and solving puzzle determinants, respectively. These two corresponded to less known aesthetic design determinants, not commonly presented in design textbooks, such as peak shift, asymmetry, naturalness, and solving puzzles. The highest negative (R=-12) heuristic rankings were assigned, maybe because they are known but are difficult to apply, for instance, it is known that asymmetry is difficult to handle in design, or because they are very unfamiliar to the respondents (such as peak-shift). For low negative rankings (R=-3), for instance, “unfamiliar colors for product category”, we believe it was because, even if perceived as powerful, this heuristic is difficult to handle. Concerning the “product interpreted in different ways” heuristic, its effect could be deemed difficult to control. Elsewhere we have noted that ugly cars are perceived as such because of their similarity with certain objects (for instance, a fish tank) (Cadavid et al., 2016), so metaphorical elements should be used carefully. Medium rankings (R=7), “fluidity-smoothness lightness for lightness and elegance” was maybe considered new.

Conclusions

The heuristics set proposed in this article is unique because it is related only to product aesthetics. It differs from other general Sets as Yilmaz' (2010) who only presents five aesthetic design heuristics out of 77.

Concerning the heuristics extraction, we reviewed 156 publications; we think this contributed to obtaining a very heterogeneous aesthetic heuristics set. We constructed an applicable set of 169 aesthetic design heuristics extracted from the literature; 121 of them were verified twice: first, through a visual analysis of 50 design-awarded products, from different categories, at least three heuristics were recognized in each analyzed product; second, from

a sample of 48 heuristics, 18 were found highly apt to generate aesthetic pleasure in the users. These results assure that heuristics already have practical application in product design and may be useful for design practitioners. However, we are aware that for the heuristics set to be properly applied it needs to be supported by visual elements, for instance, cards with examples of products that have heuristics.

Importantly, using the set, some poorly known aesthetic determinants could be consciously implemented during the design. Rather than being limited by the most common aesthetic design determinants, the proposed heuristics set could expand the design space. We believe that such exploration could enhance aesthetic design by, first, exploring design space zones rarely visited using intuition, and second, providing more novel but, at the same time, typical results that are more unified, but varied. Importantly, this exploration is not random, it is well-focused.

The heuristics here presented, especially the validated ones, are readily applicable to support the designer's intuition, they do not replace it, though. Moreover, heuristics can enrich existing aesthetic design methods and eventually, also be a basis to support the development of computerized aesthetic design tools.

We believe that the heuristics set is important per se because, unlike design textbooks, heuristics support the application of theoretical aesthetic determinants to design with them: they explicit how to apply them to get some desired result, what the textbooks do not do often. Some heuristics might appear orally, as designers' or teachers' utterances, in aesthetic design workshop corrections, but they are not common in design textbooks.

As further work, it is important to develop the structure of the heuristics set and complement it by a choice strategy, for instance, using a decision tree model to indicate to the designer the appropriated heuristics according to their design needs.

The results obtained can be used as a basis for creating a methodological toolbox that, using visual examples of products presenting heuristics, appeals to designers and supports the aesthetic design process of these determinants.

Finally, first, a sensitivity analysis of the considered threshold and the assigned weights should be done; second, the validation process using a broader expert panel until higher statistical validity is reached should continue. Using physical products could yield more robust data for this. The type of products designed by the experts should be considered too.

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