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Form Attributes to Measure and Understand Aesthetic Preferences

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ABSTRACT

The aesthetics of a product is critical to its desirability, and can be described in terms of syntactics and semantics. Syntactic aesthetics is an objective description based on the form and configuration of a product, while semantic aesthetics is a subjective interpretation of the form and gestalt of a product. This study seeks to identify a set of syntactic attributes to describe form and understand if an individual's preferences for a form are consistent from one product to another. Form attributes from previous literature were expanded upon to create a consistent vocabulary for syntactic aesthetics that can be used to describe multiple products. Combinations of four selected attributes are utilized to describe a diverse set of designs for two products: vases and canopies. Conjoint analysis is used to quantitatively measure the form preferences of individuals towards different combinations of attribute levels of the objects. Results from conjoint analysis applied to vase and canopy designs indicate a 61.3% consistency of individual form preferences between the products. It is hoped that this methodology can help designers develop aesthetically consistent products that align with users' preferences by quantifying users' aesthetic preferences towards products through a vocabulary for syntactic attributes.

Keywords: aesthetics, form, design

1. INTRODUCTION

The visual appearance of products, often the first component that is noticed in the product, is an important aspect of design valued by designers and users alike [1–3]. The aesthetics of products relates to many characteristics including shape, arrangement, texture, and color. These can influence several aspects of an individual's perceptions of the product, including its emotional and functional qualities [4,5].

Product designers may consider users' aesthetic preferences throughout the design process, which is a subjective process that involves interpretation [6]. Not surprisingly, users and designers may perceive the same product differently and the aesthetic goals of designers may be different than those of users, which may bias the designers' understanding of the user's aesthetic preferences [7,8]. Therefore it can be beneficial to understand and objectively characterize users' aesthetic preferences towards products to allow designers to develop products that align with users' aesthetic preferences [4].

Several different efforts have gone into assessing visual design in a methodological way, in part to come up with a consistent vocabulary for design which could be useful for human designers as well as a way to prompt computational systems for design synthesis [9,10]. In this study, we propose a new method for generating such a vocabulary. This method draws on the syntactics of visual aesthetics which describe a product using form-related words such as *curved, long,* and *symmetric*. This syntactic terminology can be linked directly to the product features, allowing designers to directly apply their understanding of syntactic preferences to the physical design. Two sets of products (vases and walkway canopies) in diverse styles are presented to a sample of online users to elicit their preferences for the designs' visual aesthetics. A conjoint analysis is performed to quantify individuals' preferences to form attributes which can be used to give designers a direction for product form throughout the design process.

Research Questions. This study seeks to develop a collection of syntactic attributes that can be used to describe the form of different products. Combinations of different syntactic attributes can be used to create an aesthetically diverse set of designs. Furthermore, we are interested in understanding whether an individual's preferences to form described by syntactic attributes are consistent between different products. The research questions of this study are as follows:

RQ1 What are the syntactic attribute words that can be used to describe the form of products to understand aesthetic preferences?

Syntactic attributes are objective terms that can be used to describe the form of different designs and can be consistent between different products. Combinations of these syntactic attributes can be utilized to create a diverse set of designs. Conjoint analysis can be used to elicit an individual's aesthetic preferences based on syntactic attributes.

RQ2 Are individuals' aesthetic preferences for form consistent across different products?

Suppose an individual's preferences for syntactic attributes of one type of product can be extracted using conjoint analysis as discussed in RQ1. If we extract preferences from a totally different type of product, will they be the same as for the first type of product? Previous work indicates that products with similar semantic characteristics also share similarities in form features [19]. We are interested in understanding whether an individual's aesthetic preferences defined by syntactic attributes are maintained across different products. This question has ramifications for the way designers might consider preferences when designing for aesthetics.

2. BACKGROUND

2.1 Levels of Aesthetic Attributes

One way of describing the aesthetics of a product is as semantic or syntactic. Semantic attributes relate to the subjective interpretation of the gestalt, or overall configuration of a product, to describe how the shape feels to an individual, such as *cool*, *modern,* and *sleek* [11]. In contrast, syntactic aesthetics relate to the product's form elements and configuration, including shape, composition, and texture [11]. Syntactic aesthetics are more objective and can be determined directly by the designer [12]. Examples of syntactic aesthetics terms can include *curved, long,* and *symmetric.*

Syntactic and semantic aesthetics can be used to derive three different levels of aesthetic attributes: form (level 1), gestalt (level 2), and interpretation (level 3) [13,14]. The form of the product at the first level is described using syntactic attributes for the shapes of the product features. At level two the product gestalt, or overall visual arrangement and composition of the product as a whole, includes rules of symmetry proximity, similarity, continuance, repetition, and closure [11,13]. The interpretation of the form at level three defines the semantic aesthetics of a product, which can be very subjective and can even differ from culture to culture [15].

2.2 Measuring Aesthetic Preferences

Understanding the semantic attributes of products has been the focus of many studies to select and refine the product based on user feedback throughout the design process. Kansei engineering offers one approach to understand and quantify a user's semantic aesthetic preferences using the semantic differential method [16]. This method first develops a list of semantic attributes that are related to a product through user surveys and design expert consultation. The semantic attributes are then used in a questionnaire distributed to users to understand their semantic preferences towards a product. For instance Hsu, et al. used the semantic differential method to describe telephones using images and word pairs. They found that the preferences between designers and users and their interpretations of the image-word pairings differed for the same object [8]. Chuang, et al. used the semantic differential method to understand users' preferences for mobile phones and linked those preferences to the design elements of the mobile phone [17]. Johnson, et al. surveyed design reviews, museum exhibitions and commentary on products to develop a semantic language for aesthetics to describe sensory, symbolic, and stylistic attributes of products [18].

While many studies focus on understanding the semantic attributes of products, some studies also investigated the syntactic aesthetics of products. Breeman, et al. formalized a mapping between the shape of an object and its semantic aesthetic characteristics [19]. Hu, et al. defined several design attributes of cameras, such as body structure and button shape. They varied combinations of the camera attributes to generate several designs with different aesthetics based on the gestalt principles [20]. Similarly, Kobayashi, et al. parametrized the form of a chair using points and curves along the chair back seat. They varied the parametric attributes to generate different forms and then measured the users aesthetic preferences to semantic attributes such as attractive, cool, and stylish [21].

Many studies on product aesthetics and user preferences focus on semantic attributes, which is a subjective metric and can often only be used to describe a single product at a time. Additionally, the literature lacks a consistent vocabulary for syntactic attributes that can be used to objectively describe multiple products based on their form. This study adopts a format similar to the semantic differential method to select syntactic attributes that can be used to describe two objects: vases and canopies.

2.3 Conjoint Analysis

Conjoint analysis is commonly used to quantitatively measure the preferences of a sample of individuals. In conjoint analysis, a product is defined by attributes, each with several levels. Products embodied by different combinations of attribute levels are created and compared through a questionnaire. There are two different commonly used conjoint formats, discrete choice experiments and rating or ranking based conjoint [22]. This study uses rating or ranked based conjoint which allows for individual preferences to be directly quantified. Several products with different attribute levels are presented to users to rate or rank the products. A utility function (EQ.1) can be created through their ranking to provide a model that can predict an individual's preferences towards attributes and levels.

$$U(P) = \alpha + \sum_{i=1}^{m} \sum_{j=1}^{k_i} \beta_{ij} x_{ij} \quad (1)$$

U(P): overall utility of product P
α: intercept of linear regression
β_{ij}: the coefficient of regression associated with the j^{th} level of the i^{th} attribute
x_{ij}: the j^{th} level of the i^{th} attribute

The coefficient of regression β represents both the direction and magnitude of an individual's preference for each attribute (m) and attribute level (k_i). A positive coefficient indicates that the individual prefers that specific attribute level while a negative coefficient indicates that it is not preferred. The magnitude of the coefficient represents the strength of preference for the attribute level. The difference between the most extreme levels of a single attribute provides an indication for how much the individual values that attribute overall compared to the other attributes.

Many studies have used conjoint analysis to understand users' aesthetic preferences. Kelly, et al. defined the form attributes of a water bottle through a parametric model using 5 radii, which were varied to generate the different designs. They used rating based conjoint to understand user preferences towards the bottle shapes and found that users preferred shapes they were familiar with [23]. Similarly, Mata, et al. used a parametric model of a vase to generate 90 vase solutions to see the potential of the tool in generating designs of varying forms that can also result in different aesthetic and emotional responses [7]. Sutono, et al. designed chairs using 6 design parameters, each with 3 levels. They used rating based conjoint analysis to understand the emotions evoked with each design [24]. Lugo, et al. measured user preferences to products with similar gestalt and found that products with similar complexity were equally preferred [16]. Chou, et al. used rating based conjoint analysis to measure the preferences of products among different stakeholder groups. They developed the stakeholder agreement metric to evaluate the level of agreement between the groups to help designers make go no-go decisions [25].

In this study, rating based conjoint is used to create utility functions to quantify individuals' preferences towards syntactic attributes of vases and canopies. The two utility functions of vases and canopies are compared to measure the level of consistency between the individual's preferences towards syntactic form attributes of vases and canopies.

3. METHODS

Overview of approach. Form attributes were collected from the literature and organized by a group of designers and design researchers to collect and structure a vocabulary that can be used as syntactic attributes to describe the form of different products. Four attributes (each with two levels) were selected from the list to design a diverse set of products. The designs were used in a rating based conjoint analysis to understand individual preferences to form attributes.

Vases and walkway canopies were chosen as two case studies that the syntactic attributes could be applied to and evaluate individuals' preferences. Vases were selected due to the broad range of possible visual designs, the importance of their visual design in user preference, and relatively basic functionality which allows individuals to focus on the form of the design when attributing preferences [7,26]. Similarly, canopies were chosen because of their aesthetic range and straightforward functionality. A diverse set of designs were selected for vases and canopies using different combinations of syntactic attributes. The two utility functions, derived from the conjoint analysis of each individual's preferences of vase and canopies, were compared to evaluate the consistency between syntactic preferences.

3.1 Developing Syntactic Attributes

A list of syntactic aesthetic attributes used to describe the form of products including the shape, such as geometry and size, and configuration, or the arrangement of the shapes, were collected from previous literature [11,13,14,17–20,27]. A total of 101 terms were collected. Similar and synonymic terms were combined to condense the list to 48 overall words that can be used to describe product form. This list of form attributes was presented to 9 designers and design researchers with human-centered design, mechanical engineering, and industrial design backgrounds to refine and categorize the words to create a syntactic aesthetic language that can be used to describe different products. The designers were divided into three teams and were given the 48 words written on index cards. The designers were given one hour to expand on the list of words and to generate categories representing the list of attributes to ensure a comprehensive set of attributes that can be used to describe product form. This exercise was intended to create a final list of syntactic attributes that can be used to describe the form of various different objects. Designs of products embodying different combinations of the syntactic attributes can be created to generate a set of designs that are aesthetically diverse. This was applied to the design of two products: vases and canopies.

Four attributes with two levels each were selected from the syntactic attributes (Table 1) based on their ability to describe the form of vases and canopies: width (wide | narrow), length (long | short), curvature (curved | angular), and complexity (complex | simple). These four attributes with two levels can be combined to create sixteen different designs, which is a reasonable amount of combinations for the conjoint analysis. Images of vases and canopies that embodied the different combinations were selected to represent an aesthetically diverse design set. Thousands of 2D images of vase silhouettes were collected from online databases and stock images [28,29]. Vases that exemplified the sixteen syntactic attribute combinations were chosen from this set. The design of a canopy was modified from a study by Mueller et al. (*2016*), which used a parametrized canopy designed in Grasshopper powered by Rhinoceros CAD to generate a diverse set of canopy designs [30]. The Design Space Exploration plug-in was used to output one thousand randomly generated canopy designs [31]. A selection of canopy designs were chosen to embody the sixteen syntactic attribute combinations. Three researchers individually characterized the selected vase and canopy images based on the four attributes and their respective levels. The researchers reached total agreement on the description of sixteen designs each of vases and canopies, which were then used in the conjoint analysis.

3.2 Measuring User Preferences

A ratings-based conjoint analysis was used in a survey to quantify individual preferences to vases and canopies based on form attributes. Survey respondents were presented with 16 vase designs and were asked to sort each image into five groups based on their aesthetic preferences: strongly like, somewhat like, neither like nor dislike, somewhat dislike, strongly dislike, as shown in Figure 1. Respondents were explicitly told to rate their preferences based on visual design and not the functionality of the designs. This entire process was repeated for 16 canopy designs.

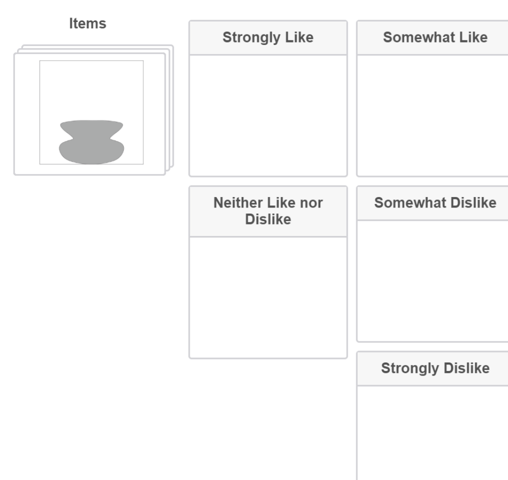

FIGURE 1 Two rating based conjoint analysis questions were presented in the survey, one with 16 vase designs and the other with 16 canopy designs. A user drags vases in the "items" pile to one of the 5 bins that best represent their visual preference.

A control question which asked respondents to specify the criteria for rating (visual, functional, or both) was included to ensure respondents understood the directions before proceeding. The order of designs was randomized for each participant. The survey was piloted with designers and design researchers to test for clarity, ease of comprehension, and length of survey to avoid survey fatigue. The final survey was distributed using Amazon Mechanical Turk, a crowdsourcing platform for survey [32]. To ensure quality of responses, only respondents with 99% approval rating and master status on Amazon Mechanical Turk were allowed to complete the survey. Respondents were compensated $1.25, which was determined based on the predicted time to complete the survey and the federal minimum wage at the time of the study.

The ratings from the survey were used to quantify the syntactic preferences of each respondent for vases and canopies. Linear regression analysis through the conjoint package in R was used to derive two utility functions for each respondent, which represent their form preferences for vases and canopies respectively.

4. RESULTS

4.1 Syntactic Attributes

Many similarities in the categorizations existed between the three groups of designers in the exercise developing syntactic attributes. For instance, one group created the group *Geometry* which consisted of the subgroups *rounded, linear, and pointy* including terms such as angular, circular, geometrical. Another group created the category of *Shape* with the subgroups *rounded, pointy,* and *geometric* and also included the terms wide, narrow, big, and small. After the exercise, a final list of terms was created by comparing the groups, subgroups, and terms created by each team. Groups with similar themes and overlapping terms were combined. A final list of syntactic attributes composed of 67 terms are grouped into these categories: complexity, dimension, cohesion, curvature, texture, strength, and color. The final list of syntactic attributes for each of these categories are listed in Table 1. Some attributes are combined into opposing pairs, which can be used to describe two extreme forms of products. This terminology can be used to objectively describe the syntactic aesthetics of several products based on their form elements and principles of design to create the visual compositions, including aspects of the overall shape and how different aspects of the geometry come together to affect the proportion, and cohesion.

Four attributes with two levels each were selected from the syntactic attributes based on their ability to describe the form of vases and canopies: width (wide | narrow), length (long | short), curvature (curved | angular), and complexity (complex | simple). Two levels from each attribute are selected to create sixteen (2^4) different combinations of the four attributes. Images of vases and canopies that embodied the different combinations were selected to represent an aesthetically diverse design set. Examples of vases and canopies are shown in Figure 2. The characteristics of each design was agreed upon by three researchers.

TABLE1 List of 67 syntactic attributes distributed over seven categories

Complexity / Uniformity	Dimension / Size		Cohesion	Shape / Curvature		Texture	Strength	Color
	Length	Volume		Geometry	Connectedness			
complex- basic/simple/unadorned	long/tall - short	big - small	balance	angular - curved	closure - open	smooth - coarse	fragile - robust	
homogenous/unity - varied	narrow - wide	heavy - light	symmetry	rectangular - circular	connected	soft - rough	light - heavy	
	elongated - squat	deep - shallow	proportion	geometric - organic	continuance	fine - grainy	weak - strong	
	thick - slender	compact	unity	bony - rounded	hollow	dull - sharp	delicate	
	low	large		sharp - straight		fuzzy - smooth	taut	
	fine	fat		squared - flowy		bumpy		
	flat	expansive		flat				
	petite			loose				
				sleek				
				taut				

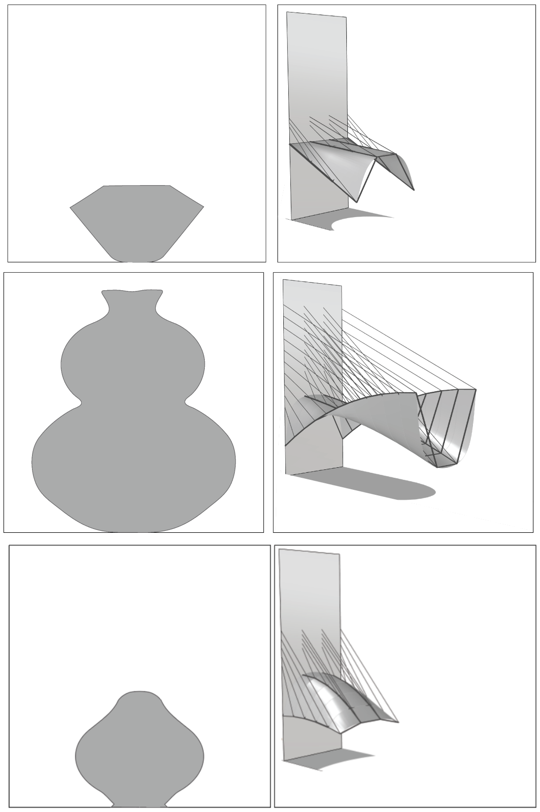

FIGURE 2: Examples of vases and canopies described using syntactic attributes (Top: short, wide, angular, simple. Middle: long, wide, curved complex. Bottom: short, wide, curved, simple).

4.2 Conjoint Analysis

The sixteen vases and canopies embodied different combinations of length, width, curvature, and complexity were included in a conjoint analysis. 120 survey responses were collected through Amazon Mechanical Turk and 118 responses that passed the quality control question were accepted.

Respondents were asked to group their designs based on their aesthetic preferences into five categories: strongly like, somewhat like, neither like nor dislike, somewhat dislike, strongly dislike. These groupings were translated into ratings for each design on a 1-5 scale (strongly dislike - strongly like). The conjoint analysis library in R was used to translate the ratings into utility functions using linear regression models [33]. Two utility functions for each respondent were calculated to quantify their form preferences for vases and canopies based on the four attributes. The coefficients of regression in the utility function represent the direction and magnitude of preference for each level. The linear utility functions of one respondent for vases and canopies is written in EQ.2 and EQ.3 and illustrated in Figure 3.

$$\begin{aligned} U(vase) = 3.125 &+ \\ 0.375(short) &+ -0.375(long) + \\ 0.625(wide) &+ -0.625(narrow) + \\ -0.375(curved) &+ 0.375(angular) + \\ 0.25(complex) &+ -0.25(simple) \end{aligned} \tag{2}$$

$$\begin{aligned} U(canopy) = 3.562 &+ \\ 0.563(short) &+ -0.563(long) + \\ -0.187(wide) &+ 0.187(narrow) + \\ -0.062(curved) &+ 0.062(angular) + \\ 0.313(complex) &+ -0.313(simple) \end{aligned} \tag{3}$$

The sign of each coefficient indicates the direction of preference. This respondent preferred short, wide, angular, and complex vases (EQ.2) and short, narrow, angular, and complex canopies (EQ.3). The magnitude between each attribute level indicates which attribute the respondent prioritized relative to the other attributes. The greater the magnitude, the more important the attribute is. For vases this respondent prioritized width, followed by length and curvature equally, and lastly complexity. For canopies their order of preference was length, complexity, width, and curvature.

As shown in the utility functions graphed in Figure 3, there is a level of consistency between an individual's syntactic preference for vases and canopies. This individual preferred short, angular, and complex vases and canopies, as indicated by the same direction of the coefficients. However, the individual did have varying preferences for width between vases and canopies.

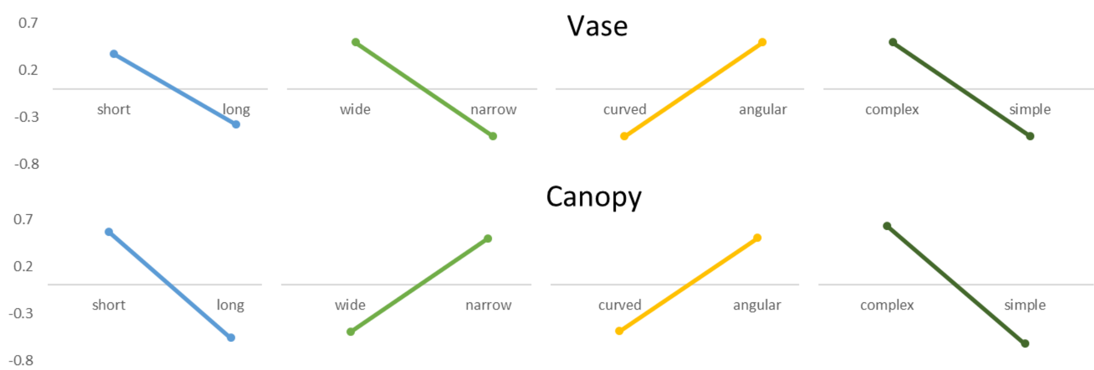

FIGURE 3: Linear utility functions representing syntactic preferences of one respondent for vase and canopy

We were interested in understanding the overall level of consistency of the respondents in their syntactic preferences between vases and canopies. In this case, the direction of the coefficients for each attribute level, represented by the sign of the value, was compared between the two utility functions of vases and canopies for each individual. If the signs of the coefficients in the two utility functions were the same then the individual preferred that attribute level for both vases and canopy. For instance, the preferences shown in Figure 3 show the same direction for the attributes of length, curvature, and complexity for canopies and vases, and opposing signs for width. This indicates a consistency of preference for this individual for 3 out of the 4 attributes for both vases and canopies. The number of times the signs of the coefficients matched for each individual's utility functions were tallied across all of the responses. A one proportion z-test was used to predict the overall proportion of responses that maintained a consistency with their syntactic preferences between vases and canopies. Overall, survey respondents showed consistency with their syntactic preferences 61.3% of the time (p-value=0.048), shown in Table 2. The level of consistency differed for each attribute, with curvature representing the greatest level (70.7%), followed by length (62.9%), complexity (62.1%), and width (60.3%).

TABLE 2: Percentage of responses with consistent syntactic preferences overall (based on a one proportion z test) and for each attribute (observed percentages)

Overall Consistency: 61.3% (p-value =0.048)			
Length	**Width**	**Curvature**	**Complexity**
62.9%	60.3%	70.7%	62.1%

It was observed that more than half of the respondents were consistent with preferences in at least three of the four attributes (55.2%). Most respondents were consistent with their preferences in three of the four attribute levels (38.8%) as shown in Figure 4. Some respondents preferred the same level for all attributes in vases and canopy designs (16.4%). Only a few respondents had very differing preferences between vases and canopies (12.1% agreed with only one attribute) or completely opposing preferences (1.7%).

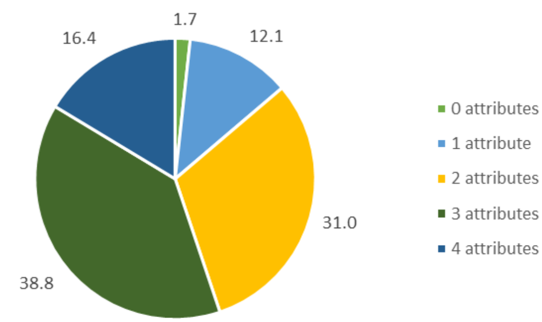

FIGURE 4 Percentage of respondents who were consistent across four possible attributes

5. DISCUSSION

Syntactic aesthetics can be used to objectively describe the form of a product. This study developed a language of syntactic attributes to characterize the form of products. This syntactic language was applied through combinations of four chosen attributes to select an aesthetically diverse set of designs for vases and canopies. A conjoint analysis was used to quantify individuals' form preferences to the two products. The utility functions of each individual were compared to evaluate the potential of using an understanding of syntactic preferences of one product to inform the design of another. The findings from this study address the research questions as follows:

RQ1 What are the syntactic attribute words that can be used to describe the form of products to understand aesthetic preferences?

An expansive language for syntactic aesthetics was established with a group of nine designers and design researchers. The list of 67 form attributes span several categories to define form, including complexity, dimension, cohesion, shape, texture, strength, and color. This terminology for syntactic attributes can be used to objectively define the aesthetics of products. Combinations of these syntactic attributes can be used to generate diverse design sets of products embodying wide-ranging aesthetic descriptions.

Understanding the aesthetic attributes of products is crucial for designers. Designers seek to understand users' aesthetic preferences to products as part of the design process. In early stages of design, designers may use collages or mood boards of various pictures of objects, colors, etc to describe the overall aesthetics of the product to be designed [34,35]. Often these boards use semantic descriptors and images that can be open to subjective interpretation [35]. On the other hand, this study illustrates that syntactic attributes to define the aesthetics of products can be used to generate diverse designs of multiple objects. These form attributes can be used to measure user preferences through conjoint analysis, objectively linking users' preferences to product form.

RQ2 Are individuals' aesthetic preferences for form consistent across different products?

Results from the conjoint analysis of vase and canopy designs indicate that individuals may exhibit a certain level of consistency in their form preferences across different objects. Some respondents even demonstrated perfect or near perfect consistency in their preferences between vases and canopies. This indicates that some individuals may have stronger aesthetic inclinations than others that drive their preferences across diverse products.

However, understanding an individual's syntactic preferences to one object does not always provide a comprehensive indication of their preferences for another object. Nevertheless, since respondents showed an overall consistency rate of 61.3% for their syntactic preferences, with some attribute levels displaying higher levels of consistency than others, comprehending the preferences for one product can provide a potential starting point for designers regarding aesthetic form. Designers can utilize readily available products, such as vases which are simple yet highly aesthetic designs, to gain an initial insight into individuals' aesthetic inclinations based on form attributes. Designers can employ this understanding of form preferences to establish a direction for product form at the onset of the design process.

6. CONCLUSION

By using syntactic attributes to describe product form, designers can develop an aesthetically diverse range of designs for a product. Rating based conjoint analysis is an effective method to understand individuals' preferences towards these attributes. Designers can use this understanding to give a direction for product form in the early stages of the design process.

There are certain limitations to this study. Although survey respondents were asked to rate their preferences based on visual design, the functionality of the products shown may have influenced the ratings. This can be particularly true for canopies which have a higher level of functionality compared to vases. Additionally, the difference between the product types in this study could have affected the level of consistency in form preferences. It is possible that products more similar in functionality may show higher levels of consistency between syntactic attribute preferences. To overcome these limitations, future research can employ the same methodology in this study to investigate the consistency between form attributes of more similar products, such as canopies with other building structures, or vases with other decorative objects, to understand the extent in which the syntactic preferences of one product can be used to inform the design of another. This methodology also holds promise for synthesizing design processes by quantifying individuals' aesthetic preferences in ways that can be optimized through the use of computational tools. For instance, syntactic preferences can be translated directly into the form characteristic of products, which can then be programmed into artificially intelligent design tools to incorporate aesthetics in the design.

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