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THE INTEGRATION OF AFFECTIVE DESIGN INTO QFD

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ABSTRACT

The use of design methodologies in product development has been proven to work for functional and performance requirements. However, when it comes to more abstract requirements – like attractivity – existing, widely accepted design methodologies do not provide guidance. This paper introduces tools commonly used in psychology for determining and quantifying Sensory Requirements and then proceeds to detail a method for collecting and preparing data on sensory attractiveness in a way that it is readily incorporated into the well defined method for product development, Quality Function Deployment.

1 INTRODUCTION

The use of design methodologies in product development has been proven to work for functional and performance requirements, helping engineers understand what customers want, then producing products that fulfill these requirements [1,2]. However, when it comes to affectivity – mood, emotion, feeling, sensibility, or mental state – existing widely accepted methodologies do not provide guidance. The problem with including affectivity is that it is not directly measurable and quantifiable; thus it is difficult to define affectivity in technical terms. This makes it challenging for mechanical designers to understand customers' desires and to respond to them appropriately. Additionally, affectivity is usually a product of the artistic disciplines. These disciplines often work intuitively and without prescribed methodologies, which hinders working closely with method and process-driven engineers. This separation often results in products where functionality and affectivity do not work together.

Another problem is that Affective Requirements are harder to gain from customers than functional and performance requirements. Prospective customers find it difficult to explain what attracts them to a product, whether it's a nice surface, an appealing design or simply a pleasing smell. However, people are able to judge a product for affectivity within seconds.

This paper introduces a tool for determining and quantifying Affective Requirements. It demonstrates a method for finding appropriate design responses to Affective Requirements, and it shows one way to integrate Affective Requirements into the existing Quality Function Deployment (QFD) methodology.

2 PREPARING THE HOUSE OF QUALITY FOR AFFECTIVE SOLUTIONS

QFD consists of an integration of processes through an accumulation of Houses of Quality. Each House transfers qualitative data received from a previous house into quantitative data, preparing for the next house. In a typical product development process, (e.g. cars, machine tools or electrical hardware) there are four houses [1,3]. They are the Functional House of Quality, the House of Quality for Part Design, the House of Quality for Production, and the House of Quality for Quality Control. If the calculated information listed in the Technical Matrix is not meaningful enough for the development team, another House of Quality using the "Hows" as "Whats" can be generated [3]. The interrelation between the four houses is shown in Figure 1.

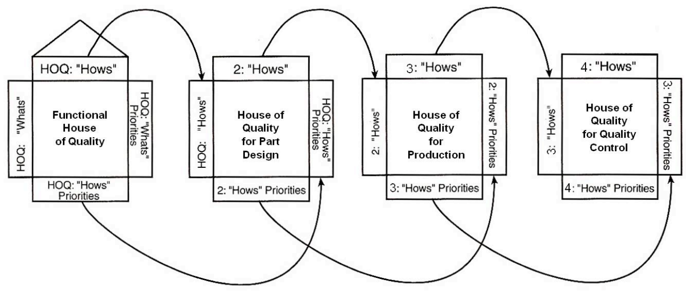

Figure 1: Interrelated Matrices (Adapted from [3])

The data entered into the Customer Requirement Table always consists of a certain level of abstractness. Customer Requirements need to be formulated in sentences that can be answered by product developers. That is usually no problem when customers are asked for technical or performance requirements, such as cost, size, or features. However, asking the customer for requirements regarding how the product would attract them or make them feel good makes it difficult to generate corresponding Technical Requirements, as any answers given would be on a different qualitative level. Technical Requirements are measurable and hence designers can always check whether they fulfilled these requirements. Affective Requirements are not measurable. Because of this, Affective Requirements cannot be added to the Customer Requirements in the first House of Quality of a design process. Similarly, Affective Requirements cannot be integrated into the House of Quality for product characteristics, also known as the Functional House of Quality. The lack of quantitative data requires a separate elaboration of affectivity. The steps of this elaboration are:

1. Determine Affective Requirements
2. Respond to Affective Requirements
3. Determine Solutions for Affective Design

The results of these three conceptual design steps should provide solutions for affective design with no aim at solving functional requirements. The solutions found for affectivity still need to be evaluated with solutions that were found in response to Functional Requirements. Designers must then prove that the functional and affective design solutions work together and that there is no negative impact on functionality. Thus, the solutions for affective design are integrated into the second House of Quality of the design process, the House of Quality for Part Design. The steps of integrating affectivity into the design process are shown in Figure 2.

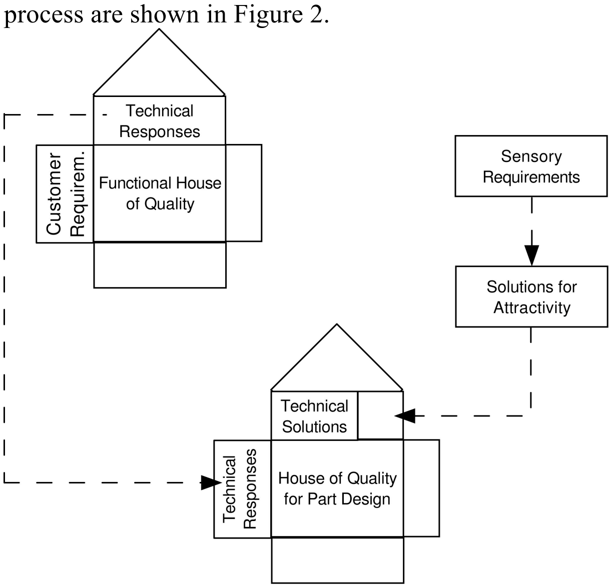

Figure 2: Steps of Affective Design

In the sections that follow, details for each of the steps in this process are presented using a typical classroom desk-chair as an example. The described process begins with preparation of the House of Quality, overviews the determination of affectivity, and ends with interpretation of the completed House of Quality for Part Design.

After functional Customer Requirements are generated following standard QFD methodology, work can begin on starting to organize information into a Functional House of Quality. This can occur in parallel to the elaboration of solutions for Affective Design. The purpose of the Functional House of Quality is to translate customers' demands into Engineering Requirements and to show either positive or negative relationships between them [2]. Engineering Requirements are formulated in such a way that they are measurable, allowing for a benchmark with the company's current product against competitive products. The Functional House of Quality does not provide possible solutions, but strategic goals that help the development team to decide where to focus.

There are three steps to construct the Functional House of Quality. First, the Customer Requirements will be input into a planning matrix to help designers decide where to focus their efforts. The second step is to develop a list of Engineering Requirements which will be put into a Relationship Matrix opposite the Customer Requirements. Using this relationship data, a Technical Matrix is used to find Technical Correlations, which are used to help form precise goals. See Cohen's text for an introduction to using multiple Houses of Quality [3].

3 AFFECTIVITY OF PRODUCTS

Integrating Affective Requirements into the House of Quality requires preparatory work. Tools and methodologies from psychology can be used to gather qualitative information and transform that into something that is quantitative and useful for engineers. Kansei engineering can also be applied [4]. An outline of one way to accomplish the preparation of Affective Requirements for the House of Quality using psychology tools is presented in the paragraphs that follow.

As Affective Requirements are on a different abstract level than more familiar engineering design requirements, the question of how they can be gathered from customers must be addressed. It cannot just be done by surveys or questionnaires. Customers often cannot express what would affect them beyond function. It would be even harder for them to imagine affective features that they have never seen before. But if a company aims to provide features to delight the customer, it needs to be able to evaluate possible new features. Psychologists have dealt with this problem extensively and have developed tools that allow them to measure the meaning of words and expressions. One particularly useful tool that allows the measurement of words is known as the Semantic Differential Method [5].

The Semantic Differential Method is based on the hypothesis that peoples' minds move in certain linear dimensions, where the combination of these dimensions represents the Semantic Space. For the purposes of integrating Affective Requirements into QFD, the Semantic Space is defined by the five human senses: Sight, Touch, Hearing, Smell and Taste. The dimensions of the Semantic Space allow a picture to be drawn of what is in the mind of the customer [5]. It should be noted that a growing body of literature points toward the interrelatedness of the human senses. Specifically, smell and taste are coupled [6, 7]. However, some abilities, such as discerning surface roughness appear to be independently determined from visual and tactile sensory information [8]. At its core, the Semantic Differential Method is a tool that can provide information about what design attributes are responsible for affectivity. It also indicates how strongly certain attributes contribute to affectivity.

For each of the five senses, samples are brainstormed in the form of bipolar adjectives. For example, Quiet, Loud, and Cool, Warm are two sets of bipolar adjectives. Some dictionaries now exist in the field of Kansei engineering which can aid in brainstorming adjectives [9]. The most meaningful samples can then be selected and a Semantic Differential Chart can be built with these samples. This chart is used in a survey with prospective customers. The gained data is then be analyzed statistically and the most important attributes, the Affective Requirements, are determined. These attributes then serve as an initial point for the design process.

In the desk-chair example, a Semantic Differential Survey was conducted with a sample population of 80 engineering students at Oregon State University, which provided sufficient data for an appropriate statistical evaluation. The results are presented in Figure 3. While statistical evaluation provides important data about the attributes that should be considered, the development team needs to interpret the results.

After discarding non-significant attributes and grouping the remaining attributes into higher categories, it becomes obvious that all of the attributes refer to avoiding distraction. It becomes clear that the test persons do not expect a product with an attractive appearance. Rather, they expect a product that is especially attractive to the senses of touch, hearing, and smell. These are the senses that are the most cognitively sensitive to pain and inconvenience. Hence, it can be concluded that the desk-chair is attractive to the test people if the desk-chair does not register any sensory data. This is a manifestation of affectivity that many design engineers would not initially consider, but is nonetheless very important to the process of designing comfort. The design team must now respond to the Affective Requirements with adequate design features.

The next step is to create positive affectivity. Structuring the process of finding affective solutions with some techniques of Systematic Design helps to achieve new affective design solutions. First, as many ideas as is reasonable should be explored for each attribute. Then, these ideas are filtered so that the most effective are left. The ideas are evaluated based on defined criteria such as functionality, cost, or perceived value. However, the criteria for affective design can only be defined and tested by the potential user of the product. Thus an evaluation process that involves the customer is necessary.

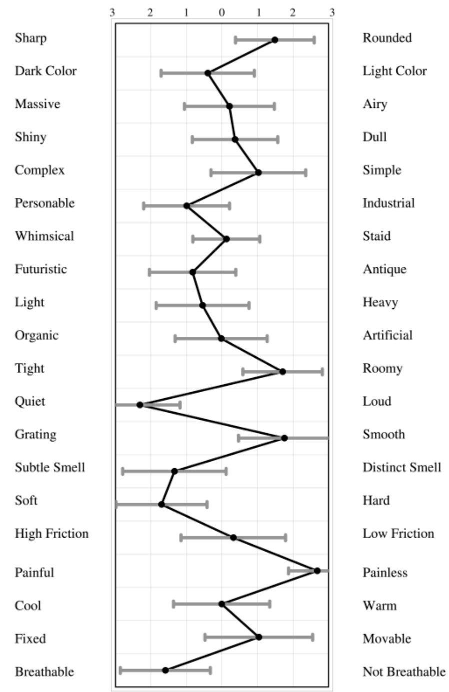

Figure 3: Total average of 80 test persons with standard deviation bars

As the attributes only provide adjectives that describe attributes the product should have in order to be attractive, designers do not know to which design features the particular attributes belong. There is no direct, recognizable relationship. Each attribute could possibly be connected to any of the number of design features leading to a multitude of combinations of design features and attributes. A Morphological Matrix provides the ideal tool for the task of analyzing the design combinations, searching for the most appropriate design solutions.

The process of generating ideas for prospective solutions requires creativity from the development team. Using the Morphological Matrix helps to organize this process but the matrix itself does not provide any solutions. Many different formal creativity techniques are readily available in the literature. For instance, brainstorming [10] is one of the most commonly used methods [11], but there are also many other powerful techniques such as Method 635 [12,13], or the Gallery Method [14] that can be applied in order to find new paths to increasing affectivity.

Figure 4 shows a Morphological Matrix for the desk-chair with some of the ideas that were found for each attribute in combination with each design feature. Building the Morphological Matrix showed that not all attributes have an important relation to all of the design features. In that way, a process of selection had already been initiated. But an incredible number of possible combinations still remain. At this point it is useful to consider the Kano Model and to classify the attributes into Kano's Three Levels: Delighters, Satisfiers, and Dissatisfiers [15]. The goal is to develop Delighters while avoiding Dissatisfiers and fulfilling Satisfiers.

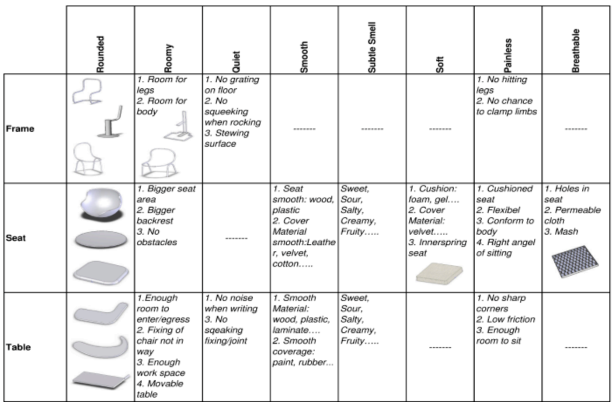

Figure 4: Morphological Matrix for Desk-Chair

Table 1 shows how the attributes were classified in the desk-chair example with help of the Kano Model. As dissatisfies have to be eliminated, the attributes "quiet" and "painless" are documented as demands for the design process. The Morphological Matrix can then be reduced by these two columns. Further reduction can be made by considering the relationship the attributes have among each other by distinguishing between independent and dependent attributes.
The attributes that remain after removing the dissatisifiers from the Morphological Matrix generally allow for different and novel choices of combination. However, some of the attributes are not directly connected to any other attribute and thus are independent attributes. An example of this is the attribute "smell" for the seat or the table. Independent attributes have two big advantages:

1. Independent Attributes can be determined separately. It is easier to conduct an evaluation with test persons when they can focus on only one variable. Thus, finding the right point on a nominal scale for one independent variable should be straight forward.

2. By separating independent attributes from the Morphological Matrix, the possible combinations of features is further reduced.

Finding the right responses to an independent attribute requires test subjects who are asked to rate different responses to attributes in terms of affectivity. However, asking people to rate a series of smells usually does not lead to a clear result, as people tend to have difficulties with absolute judgments [16, 17].

Level	**Attribute**
Delighters	Subtle Smell, Breathable
Satisfiers	Rounded, Roomey, Smooth, Soft
Dissatisfiers	not painless, not quiet

Table 1: Kano Model for Attributes

The development team must then decide which attributes can be determined independently and which can only achieve their validity in combination with other attributes. In the case of the desk-chair, rounded, roomy, smooth, soft, and breathable are related to either some or all of the other attributes and are thus dependant attributes. Clarifying how they are related among each other will help to determine the best combination of attribute solutions. Additionally, the design team can consult a growing body of literature on specific sensory perceptions to gain further insight [18].

One way to understand these relations is to use a Tree Diagram (Figure 5). On the highest level is the overall product. All attributes that refer to the overall product, such as "rounded" and "roomy," are noted on this level. The second level consists of the three design features "Frame," "Seat," and "Table." The attributes that refer to these features are noted with the particular feature. On the third level, the independent attributes are illustrated. The Tree Diagram shows clearly which design features can be evaluated independently. It also shows which design features do not need to be evaluated separately. The process of evaluation then works from bottom up. The independent attributes on the third level, found using Pairwise Comparison [19] are determined first and so on.

Finding the right combination for dependent attributes is not as straightforward as determining independent attributes. For instance, if, for each of the three attributes that are related to "seat," just three possible attribute solutions were found, then there would already be 3 x 3 x 3 = 27 possible combinations.

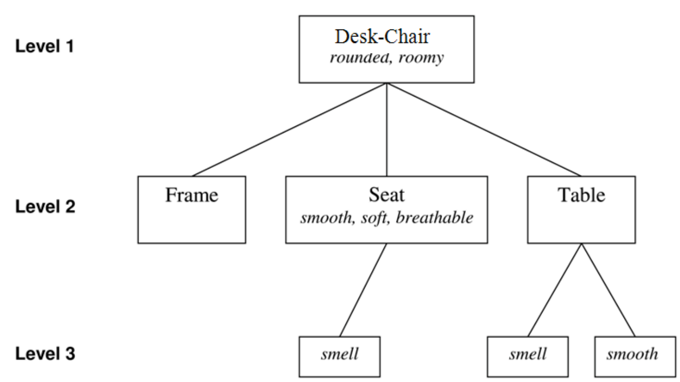

Figure 5: Levels of dependence of Attributes

Thus, in order to find the right combination, 27 prototypes would need to be built and be tested by the prospective customer. By increasing the attributes or attribute solutions, as is the case for complex products, the amount of possible combinations will easily jump into the hundreds or even thousands. It is generally not feasible to conduct such an extensive evaluation process. Thus, a better process that reduces the number of prototypes but still shows appropriate results must be used. Conjoint Analysis, a method that was developed to determine the best fit of combinations in marketing, can be applied to reduce the number of prototypes.

The purpose of Conjoint Analysis [20] is to find a combination of attributes for a product that represents the highest utility for the customers. As affectivity can only be rated on an ordinal scale, nonmetrical Conjoint Analysis is best used in combination with a statistical software model, such as Monotone Analysis of Variance (MONANOVA).

In order to avoid overwhelming the participants and to reduce data, the stimuli should be reduced to a reasonable number. One way to reduce stimuli is by using Fractional Factorial Design [21]. The representative set of prototypes is then created and evaluated by the customer.

The data received from customer evaluations is then computed in a statistical software package using the MONANOVA model. The results of the analysis are relative utility values for each of the attribute levels. By choosing the highest utility of each attribute, designers can build a seat that represents the best balance of smoothness, softness and breathability. The absolute utility of all 27 possible combinations can then be determined by adding up the attribute level utilities of each of the possible combinations. The best combinations are then integrated into QFD.

4 AFFECTIVE SOLUTION INTEGRATION INTO HOUSE OF QUALITY FOR PART DESIGN

The final step of Affective Design is the integration into QFD through the House of Quality for Part Design. In this second main step of the QFD process, Technical Requirements are translated into Technical Solutions. The Technical Requirements come from the Functional House of Quality. Before the development team can begin looking for Technical Solutions, the solutions for affective design are added to the Technical Solutions Table, as are the relationships to Technical Requirements. Figure 2 graphically depicts the flow of this process. In this way, Affective Solutions can be checked for their adaptability to Technical Solutions.

After all technical responses with their required quantities are determined; the process of finding solutions begins. The possible solutions are narrowed down to discrete design features. The design features are of the same quality as the solutions that were found for affective design. Thus, it makes sense to bring both of them together in the House of Quality for Part Design. Before starting to find solutions for functional design, it is advantageous to implement the solutions for affective design first, as can be seen in Figure 6. These solutions are denoted by the letters a_i, b_i, c_i, d_i and e_i, which stand for the particular solution that was chosen by test persons. They may also serve as solutions for some of the functional problems. The Relationships Matrix shows that there are impacts on the Engineering Requirements. Moreover, the solutions for affective design are now assigned with quantitative values.

The combination of qualitative Affective Solutions and quantitative Technical Requirements already leads to some overall design solutions. An example is the seat. The affective design process determined shape, material and smell. With the Functional Requirement of seat area being 240 in^2, a final solution for the seat is already presented.

	seat design a_i	seat material b_i	seat smell c_i	table smell d_i	frame design e_i		
seat area	◉				◉	9	240 in^2
distance between table and seat	△				◉	6	18 in
moves necessary to enter / egress	△				◉	8	2
size of table						6	200 in^2
time to clean	○	◉			○	3	30 sec.
price per item	△	◉	△	△	○	3	80 $

Figure 6: Solutions for Affective Design Integrated into the House of Quality

Once the solutions of affective design are integrated and the relations are determined, the designers can start finding Technical Solutions that were not yet covered by affective design. Figure 7 shows only a few supplemented technical solutions. After this process, all Technical Solutions are unified in the Technical Solutions Table in the House of Quality for Part Design. Thus, any relationship between the requirements and the solutions, both technical and affective, can be recognized. These connections are not as easy to interpret as the relations in the Functional House of Quality. There is not always a direct connection between Affective Solutions and Technical Requirements. However, a strong relation tells designers that affective design solutions have boundary conditions, which are the quantitative values in the Planning Matrix. For instance, the table design was determined by Affective Design, however, it can be seen that the table area has to be 200 in^2, as this is a Functional Requirement.

As in the Functional House of Quality, the Technical Matrix supports the development team to set strategic goals. This time the goals are quality and cost targets. After all of the impacts are determined in the Relationships Matrix, the priorities can be determined again with a matrix calculation. The completed

House of Quality for Part Design for the desk-chair can be seen in Figure 8.

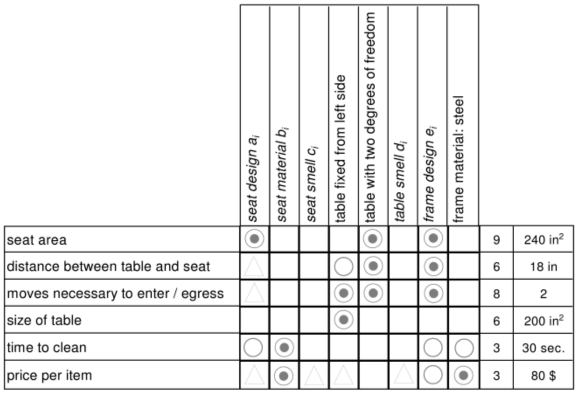

Figure 7: Affective and Functional Solutions in House of Quality

The factors of technical importance show another reason why affective design has to be treated separately from functional design in the first stage of design. Most affective solutions do not show high factors of importance. This is because the House of Quality emphasizes functional design. Although the voice of the customer who also asks for affectivity is translated in the Functional House of Quality, the results of the matrix analysis still show high factors of importance only for Technical Requirements. This is due to the fact that Technical Requirements show more relation to other Functional Requirements. Affective Requirements can occur independently and without any impact on technical demands. Thus they would not show a high priority and engineers would neglect them, even though they could be of great importance for the customer. Treating Affective Design separately and then integrating the solutions into the House of Quality for Part Design ensures that Affective Design is not overlooked in the product development process.

While Technical Correlations have significance in the Functional House of Quality, they are of greater importance in the House of Quality for Part Design. Here is where Affective and Technical Solutions merge and their interactions can be observed. The development team should take enough time to carefully elaborate on the Technical Correlations. By determining the positive (+) or negative (-) relationships, it becomes apparent how affective and functional design work together or hinder each other. This is the last chance to make major design changes without producing extensive costs, because the next step embodies engineering and planning for processes in manufacturing. If the development team recognizes that there are no major changes necessary, these processes can be planned with the next House of Quality. The third House of Quality helps translate design characteristics into process characteristics. The fourth House of Quality is subsequently used to translate process characteristics into production control characteristics, guaranteeing a high quality end product. The product that is finally derived should then be both attractive and functional.

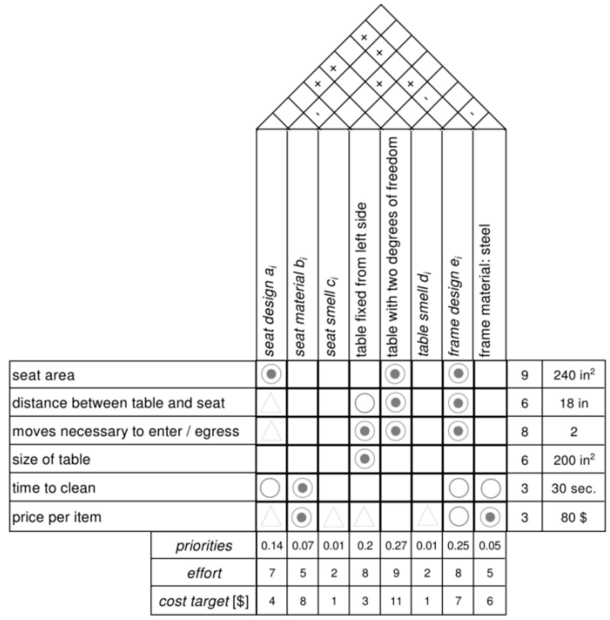

Figure 8: House of Quality for Part Design

5 CONCLUSION

This research presents a way to integrate affectivity into product development. It is done by supplementing Quality Function Deployment with some methodological tools that help designers determine Affective Requirements, find appropriate responses, and evaluate them. The solutions that are found are integrated into the House of Quality for Part Design. Here the relationships between Technical Requirements and Affective Solutions, as well as the impact of affective design solutions on solutions for functional design, can be determined.

The use of this methodology is beneficial in guiding the development team towards finding solutions for Affective Design. The most important aspect is that this methodology enables an interdisciplinary team of engineers and artistic designers to work together and create a product that unifies functionality and affectivity. The generation of attributes for the survey, the analysis of the survey data, as well as the process of finding ideas for affective design, gives the development team opportunities to understand what affectivity means in relation to the product under development. This results in an extensive number of ideas that can possibly serve as solutions for affective design.

One potential avenue of continued research would be to elaborate further on the process of evaluating Affective Requirements and Solutions. More specifically, expanding research into maximizing a product's Kansei [22] quality could prove beneficial.

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