The Form of Emotive Design

by
Philippa Mothersill

Submitted to the Program in Media Arts and Sciences, School of Architecture and Planning,
in partial fulfillment of the requirements for the degree of
Master of Science in Media Arts and Sciences at the Massachusetts Institute of Technology

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Abstract

We have an unconscious understanding of the meaning of different physical objects through our extensive interactions with them. Designers can extend and adapt pre-existing symbolic meanings through the design of these objects, adding a layer of emotive expression by manipulating their forms. Novice designers can express the 'character' of the objects they want to design using familiar vocabulary, but may not be able to draw on expert design skills to transform this meaning into the medium of form. This thesis explores the physical design language encoded into objects and asks: can a CAD tool that uses descriptive adjectives as an input aid designers in creating objects that can communicate emotive character? In this thesis I explore the underlying emotive design 'grammar' of the form of objects, and through this present an emotive semantically-driven a Computer-Aided Design (CAD) tool that uses expressive words to design forms with emotive character. A quantitative framework for emotive form design is proposed and integrated into the EmotiveModeler CAD tool. Using this CAD tool, I investigated the variables of this emotive form design framework and tested the resulting designs and the software itself with both novice and experienced designers to evaluate if the tool can help these users more easily create inspirational and emotive forms using the expressive vocabulary we are all familiar with.

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Chapter 1
Introduction

> *"We live our lives in the middle of things. Material culture carries emotions and ideas of startling intensity. Yet only recently have objects begun to receive the attention they deserve." - Sherry Turkle [55]*

We have an unconscious understanding of the meaning of different physical objects through our extensive interactions with them, be it through their cultural symbolism, our learned experiences, or our intuitive reactions to them [31]. Objects can express this meaning through their physical embodiments; their functional design indicates how we may use them, their colour and materials express the aesthetic qualities of the culture, and their forms convey a combination of both logical and expressive meaning [2].

The form of objects is one of the first aspects of a design we perceive, and is often one of the first features expressed by designers [32]. We can readily perceive information and emotive expressions through the form of objects, both in nature and in man-made objects. We can intuitively understand the meaning of an apple transforming from smooth and healthy to wrinkled and rotten. Equally we can comprehend the twisting and bending of a simple sack of flour (Figure 1) as Disney animators imbue it with almost as wide a range of emotional expressions as humans have [53].

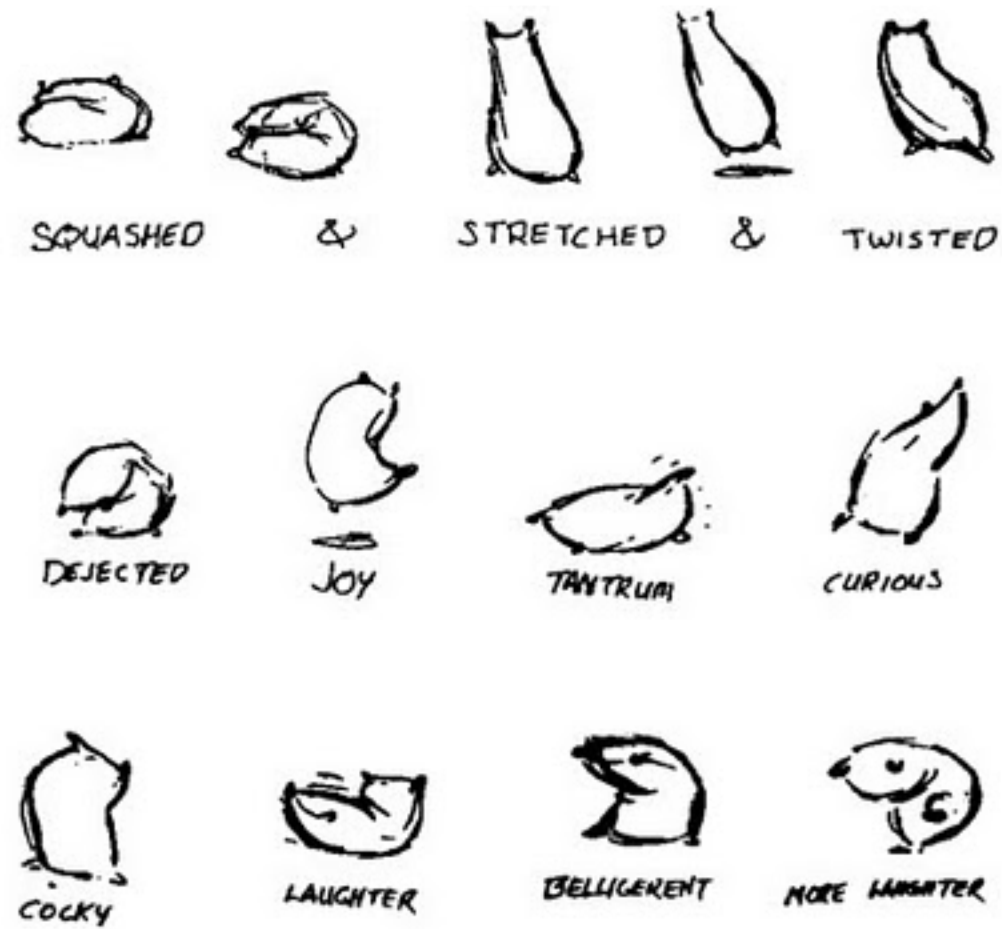

Figure 1. The animated flour sack conveying a range of emotions
from *"The Illusion of Life: Disney Animation"* by Johnston & Thomas, 1995 [53]

Though objects may have existing symbolic significance that we recognize through their overall structure, the details of the form of the object can extend these underlying meanings to convey a more individual character [33]. It is the job of product designers to take advantage of our intuitive perception of forms and use this 'product language' to manipulate the meanings objects communicate [18]. Designers endeavor to capture the emotionality of some information or experience, and to embody that emotionality in physical sensorial attributes such as form, so that our expectations of the object are extended past pure functionality [13].

Whether or not we are experts in this semantic language of objects, we can often communicate the 'character' we perceive to be embodied in objects using the higher-level expressive vocabulary and adjectives that we are all familiar with [27]. Through a greater natural intuition and a development of knowledge through experience, designers have a more sensitive perception of the meaning conveyed in forms. The patterns of design in these forms, be they presented in two-dimensions or three, more readily coordinate with the internal models of understanding in an experienced designer's head [21]. This may not be the case with inexperienced designers – we may have an instinctive reaction to the emotive meaning of objects, but we may not always be able to consciously decode the distinct suggestions of detailed design attributes, or translate their meaning between different modes of sensory perception.

Most of us also do not have the requisite ability to embody this character through the medium of form – translating the abstract meanings of ideas into the physical geometry of objects are the skills that artists and designers take many years to hone. Recent cultural movements in accessible creating, making and personalization are showing that people want to make and design objects themselves [17]. However, creating designs that express the rich meanings that we perceive in objects is still very hard for novice designers. Whilst Computer-Aided Design (CAD) tools that make 3D form design more accessible do exist, simple tools to aid this more abstract part of the expressive form design process do not. What is required is a means to easily create designs of 3D forms that can express the emotive details that expert designers comprehend, but which uses a vocabulary that we all understand.

To explore this point in question, this thesis asks: can a CAD tool that uses descriptive adjectives as an input aid designers in creating objects that can communicate emotive character?

1.1. Thesis Overview

My research looks to investigate how a quantitative taxonomy for emotive form design can be created and integrated into a CAD tool, to enable people with a range of design skills to express emotive meanings through the very form of objects.

I will start by providing a background into how objects can convey meaning through their design, and the methods and tools that designers can use to embody these abstract concepts into the more concrete physical design properties in their creations (Chapter 2). I will then present a summary of established research into both emotion theory and shape-perception theory, and propose a quantitative emotive form design taxonomy that draws these areas of research together (Chapter 3).

Using this taxonomy as an underlying computational framework, I developed the EmotiveModeler CAD tool – an emotive semantically-driven CAD tool that can generate emotive forms from words and emotions, enabling novice designers to create expressive designs using only high-level vocabulary as the input (Chapter 4).

The accuracy and effectiveness of both the emotive design taxonomy and the EmotiveModeler CAD tool itself were evaluated through the analysis of user studies, and modifications to improve the combination as a system are suggested (Chapter 5).

The thesis will close with reflections on the findings from these evaluations and suggestions for future work to expand this concept of communicating emotive meaning through the design attributes of objects (Chapter 6).

Additional support material and references referred to throughout this thesis are included at the end of this document (Chapter 7).

Chapter 2
Background

> *"Humans display the intriguing characteristic of making and using objects. The things with which people interact are not simply tools for survival, or for making survival easier and more comfortable. Things embody goals, make skills manifest, and shape the identities of their users."*
>
> *- Mihaly Csikszentmihalyi [14]*

Designing objects that serve more than just a utilitarian function - things that express a certain character - has been a part of the creative arts for hundreds of years [14]. Our perception of the objects in our world is shaped by our past experiences, intuitive reactions and extrinsic goals. Artists and designers are sensitive to these aspects of perception and use them to evoke meaning in their creations. The following section gives an introduction to how the design attributes of an object can become a communicative medium, and the methods by which designers can embed these emotive meanings in their creations.

2.1. The Emotive Meaning in Objects

> *"The designer could be cast in the role of a communicator whose messages to the user concern the symbolic qualities of products. Just as a journalist creates informative messages from a vocabulary of terms, so could a designer be thought of as having a repertoire of forms at his disposal with which he creates arrangements that can be understood as a whole in their essential parts and that are usable by a receiver because of this communicated understanding"*
> *- Klaus Krippendorf [31]*

Product semantics is the study of the symbolic qualities of man-made forms and the meaning that can be conveyed through them. These symbols can be of any information-bearing representational external medium that is perceptible to the human interacting with the object [21] and, when combined, act to engage our cognition and emotions. As Van Breemen details: "The principal medium of communication is the shape of an object, but the colour, texture, material and other visual properties play also important role. Actually the totality of these object properties makes impression on us and exerts emotion" [56].

Designers employ these symbols by way of "a nonverbal product language as the vehicle for communication" [31]. Through their experience and aesthetic intuitions, designers can devise a “transformation procedure” through which their intended meaning for the product can be embodied in the geometric shapes and physical material properties of the object [21]. Metaphor, anthropomorphism, and conventional associations all form part of this transformation of the more abstract concepts of meaning into the concrete physical details of an object.

The intent of these processes is to allow the designer to communicate their intended meaning to the users of the product. Collecting the information from the products we experience around us, we both consciously and intuitively compare these sensory patterns to our internal ‘schemata’ developed from years of experience and past responses to stimuli [20, 5]. While internally evaluating these sensory stimuli, Desmet describes how "through cognitive processes, like interpretation, memory retrieval, and associations, we are able to recognize metaphors, assign personality or other expressive characteristics, and assess the personal or symbolic significance of products" [15].

It is the embodiment of this ‘expressive character’ in objects that I am particularly interested in researching in this thesis. Whilst the communication of function in a product is indeed one of the most important meanings to convey, I will not focus on the design of functionally communicative objects in the traditional sense, as there is much existing research on this topic in the area of ergonomics [48].

2.2. Designing Emotive Shapes

"Form lays the foundation for our most primary response to objects... [it] extends, adapts, and sharpens those meanings elicited by symbolic shapes"
- Stephen Luecking [33]

Form is one of the key contributors to the meaning an object can convey. Building on the contextual associations related to the function of an object, form influences the aesthetic characteristics that we often first perceive – its visual shape – and plays an important role in our physical interactions with objects [56]. The following section describes how these meaningful forms can be constructed – from their mathematical beginnings, to the designer's process to mold these details into meaning, to the software tools that can begin to automate this transformation.

2.2.1. The DNA of a Design

"A design could be said to be a pattern created by man… It is a recursive thing, a hierarchical thing. Any pattern in general is built from other, lesser, patterns, each having a relationship with each other…

The final judgment [on] the distinction between a meaningless set of marks and a pattern is the prerogative of man, so evidently the relationships in the structure of a pattern are in some ways an analogue of human thought processes. Hence one passes from design to pattern, and from pattern to thought processes." - A. D. Newman [39]

Forms are constructed from points, lines, planes, surfaces and volumes, that are made richer by texture, colour and material [33]. In combination, these elements of form create a design, and similarly all of these elements contribute to our perception of its meaning. A three-dimensional form is made from many two-dimensional shapes. These shapes are revealed step-by-step as a form is rotated, and create the "total visual appearance of a design [with] shape is its main identifying factor" [57].

As Thompson writes in his seminal publication on the physical laws and mechanics underlying all natural organisms, *On Growth and Form*: "The study of form may be descriptive merely, or it may become analytical. We begin by describing the shape of an object in the simple words of common speech: we end by defining it in the precise language of mathematics" [54]. The non-verbal product language described earlier may indeed be explained in both descriptive and analytical means. Stiny, in particular, breaks down this language of design into a set of rules: rules that compose the spatial elements in the design i.e. the geometry of the shapes and form, and rules that describe the design in terms of it's meaning and function [50]. Mapping these geometric spatial design rules – what Stiny terms 'shape grammars' – to their associated descriptions creates a language from which many resulting designs may be created [49]. For example, the shape grammar that we describe a square as can be broken down into four equal-length lines, where each line is orthogonally connected to another line at each end.

Once these initial set of rules for shape grammars and descriptions are created, design algorithms can then combine them to "produce an object as a work of art in response to some initial conditions" [51]. Under the right conditions, we can imagine that these algorithms could start to map the rich and abstract meaning that designers wish to embody in objects onto the very shape parameters that create the forms that we perceive [56].

2.2.2. A Designer's Process

> *'It is the designer's job to decode the common values and opinions that exist in the culture, and reproduce them into forms that embody the appropriate symbolic meaning" - Nathan Crilly [13]*

Whether conscious or unconscious, this transformation of abstract meaning and ideas into concrete shape parameters and forms is the process carried out by designers to create the objects with which we interact [19]. Designers carry out an almost synesthetic synthesis of a wide range of cognitive, emotional and sensory inspirations to create an object whose design attributes symbolize these very experiences. Often, the designer will use analogies to "penetrate to the essence of special meaning which he attaches to the problem" [5]. These can be in the form of personal anthropomorphic analogies, or direct scientific associations, or penetrating the meaning of words or concepts using commonly associated symbols.

Designers build up this library of analogies associated to the design language of objects through their experience of intuitive human reactions to objects. They draw upon this library early in the design process, when unformed ideas are being molded into the beginnings of solid objects. The translation of idea to object, or of word to form, is often an intangible process existing inside the designer's head. As Gregory writes, it is "only the products which appear in material form come to the eyes of the man in the street" [19]. Other than the intuitive emotional reactions that the viewer has on the designer's creation, there is little way that the richness of the designer's process can be shared with other people. What if the initial stage of this creation process – the stage in which ideas are broken down into analogies or words and then transformed into shapes and forms – could be understood and systematized, so that novice designers too could convert their concepts into physical forms?

2.2.3. CAD Tools for Creating Three-Dimensional Designs

Once a designer has imagined the object they wish to create – embedded with the symbolic shapes and forms to convey the meanings they desire – they must realize it in the physical world. The physical design of objects today relies heavily on 3D computer-aided design (CAD) tools. These computational design tools provide designers with the ability to model complex forms with great detail. However, the interfaces provided by these CAD tools require very concrete inputs about design elements such as geometry and curvature. In the early phase of a design process, the information that designers are trying to embody in a meaningful form can often be very abstract, dealing with emotive metaphors and semantic descriptions as opposed to millimeters and angles. Part of the skill of the designer is in mapping these qualitative inspirations to the more quantitative units from which a 3D form can be created [32]. If these abstract qualitative design inspirations could be mapped onto more concrete quantitative design elements and integrated into CAD tools, novice designers could be able to create objects which do not just serve a function but express meaning too.

There are many professional CAD tools available commercially such as SolidWorks, AutoCAD and Rhinoceros. These tools are feature-rich, enabling experienced users to create 3D models to their exact detailed specifications. However, these tools have complex interfaces and hundreds of commands, which make them very hard for novice designers to use [52]. This limitation has been recognized by developers, and more accessible CAD tools have been made available for novice designers to use, e.g. TinkerCad, kidCad, and SketchUp [26]. Whilst these beginners CAD tools do allow novice designers to easily and quickly create 3D models, the limited feature set of the software can result in the created 3D models often being fairly simple. The operational affordances of many of these CAD tools also only speak in the language of geometric transformations, not the more abstract, verbal way in which people generally think about describing the character of form, i.e. if we want to create a 'sad' object, we may want it to look 'droopy'. Such tools do not solve the fundamental problem noted above that novice designers may not have the skills possessed by experts in understanding what quantitative design features are required to create forms that express certain meanings.

2.2.4. Semantically-driven and Generative CAD tools

> *"A paradox exists in all man-machine interactions and is epitomized in the interactions between the architect and the computer. The paradox is as follows: Architects are concerned with issues generally considered to be unmanageable by computers. These issues draw upon human experiences, senses, attitudes, even idiosyncrasies, none of which are enjoyed by machines at this point in time. So the standard procedure is to partition the design task: the man is given what he is good at doing (which is usually what he enjoys), and the machine is given only those tasks it can handle efficiently."*
>
> *- Nicholas Negroponte [38]*

Research has been carried out in the development of CAD tools that start to solve this problem that novice designers face by using computational systems to modify certain design elements of a 3D model using the language we all understand. CAD tools have been created which allow users to input descriptive words to generate certain features of the design of a 3D model so that the form evokes the feeling of the word. These CAD tools use research in semantic transformation [56], shape grammar [49], affective (or Kansei) engineering [3], fuzzy theory [24], evolutionary modeling [46], computer vision [7] and machine learning [29] to create underlying frameworks that map descriptive words onto specific design elements, often derived through semantic image analysis of existing products.

However, this semantic image analysis of existing products to define the relationships between design attributes and the descriptive adjectives leaves these CAD systems open to contextual or cultural bias. The CAD tools also build on a set of existing models rather than regenerating the forms completely, limiting the uniqueness of the generated models. This existing work also does not enable more abstract emotive information to be mapped onto the new medium of a form; information that would not normally be conveyed through either pure functional or aesthetic design choices. For example, the design of a perfume bottle can express the character of the perfume within, but the description of the scent itself, e.g. musk, may not easily map to a meaningful semantically designed form. Designers have the ability to convey this non-obvious information in a form, often creating the required semantic connections through our underlying emotional reactions to sensory stimuli [45].

By creating design language frameworks that include the theory about our natural emotional reactions to sensory stimuli such as shapes, tools like this could create more intuitively emotive forms relating to a range of sensory experiences and descriptions. This tool could enable novice designers to design objects that can express emotional as well as functional information through their form, creating an additional kinesthetic functional value to the objects as well as an aesthetic style. By connecting the natural verbal language we intuitively use to describe the meaning of our designs to the emotive shapes that we subconsciously associate with them, these CAD tools can begin to visualize the otherwise hidden transformations present in the early stage of the design process.

Chapter 3
A Language for Emotive Design

> *"Generally speaking, cross-modal correspondences can be defined as a tendency for an individual to match (or associate) a feature, or attribute, in one sensory modality with a sensory feature, or attribute, in another sensory modality, no matter whether physically present or merely imagined… Shape symbolism refers to the idea that people associate certain attributes [with] specific shapes, typically varying in their size and or angularity/degree of curvature [and] can therefore be seen as specific forms of cross-modal correspondence" - Charles Spence [47]*

Much research has been carried out to understand our perception of different sensory stimuli, and how their interpretation can be related across the senses through synesthesia. It has been shown that simple perceptual stimuli such as colours, shapes, sounds and scents can reliably convey certain emotional responses, unconnected from contextual, cultural or personal idiosyncratic biases [8, 9, 11]. In this thesis, I am most interested in the connections we make between meaning, i.e. words, and shapes. In the following section I discuss existing research into theories of emotion, our association of words to emotions, and our perception of different shapes and forms. Bringing this research together, the last section of this chapter presents my hypothesis for how words can be mapped to emotions and then shapes – the quantitative emotive design taxonomy that provides the bedrock on which the EmotiveModeler CAD tool rests.

3.1. Mapping Words to Emotions

> *"Words are associated with emotions. For example, delightful and yummy indicate the emotion of joy, gloomy and cry are indicative of sadness, shout and boiling are indicative of anger, and so on." - Saif Mohammad [37]*

Words often form the initial representation of the emotive experiences designers wish to embody in their creations [39]. Words are also the common language that both experts and novices in product semantics can use to describe the 'character' that we perceive to be embodied in objects [27].

Similar to a grammar for design relying on a small selection of rules that can be combined together to create unique forms [49], the words that we use to express the character of objects can also be simplified into their related emotions. In the following pages, I present some of the research on emotion theories and show how words can be connected to certain emotions and emotion scales.

3.1.1. Defining Emotions: Introduction to Dimensional and Categorical Emotion Models

Two prominent theories of emotion break emotions down into a dimensional emotion model and a categorical one [6]. Both theories have their merits when endeavouring to quantify emotions and their relationship to other variables in the perception of a design [15], and I will call on both frameworks in this thesis.

A categorical emotion model defines a discrete set of basic or primary emotions that are especially fundamental in the construction of all other emotions. There are several categorical framework theories that have been proposed that define anywhere from 2 to 18 basic emotions, derived from research that includes facial expression analysis, biological and neurological reactions, and psychological instincts [40]. In this research, I have chosen to use Plutchik's theory of primary emotions: acceptance (or trust), joy, surprise, anger, fear, disgust, sadness and anticipation [41]. Plutchik's theory is based on a notion that these primary emotions are 'biologically primative' – emotions that we feel based on our subconscious instincts such as reproduction, protection, flight, repulsion possession etc [40, 41]. Our perception of the character of an object is also often based on an instinctive, subconscious feeling – what Desmet describes as a "change in core affect" [15]. Hence, Plutchik's theory and the associated set of primary emotions provide a similar rationale on which to base this research.

Using the colour wheel as an analogy for the gradation of these primary emotions between each other, Plutchik also defines a structural model for the "mixtures or combinations of these primary emotions in various proportions [that] will produce all of the emotions which are know and described in life" [41]. These mixtures of primary emotions are called dyads, e.g. joy + anticipation = optimism. Discounting the dyads which contain emotions of opposing affect (e.g. joy and sadness), there are a total of 24 Plutchik dyads. The primary emotions and how they can be combined to create dyads is shown below in Figure 2.

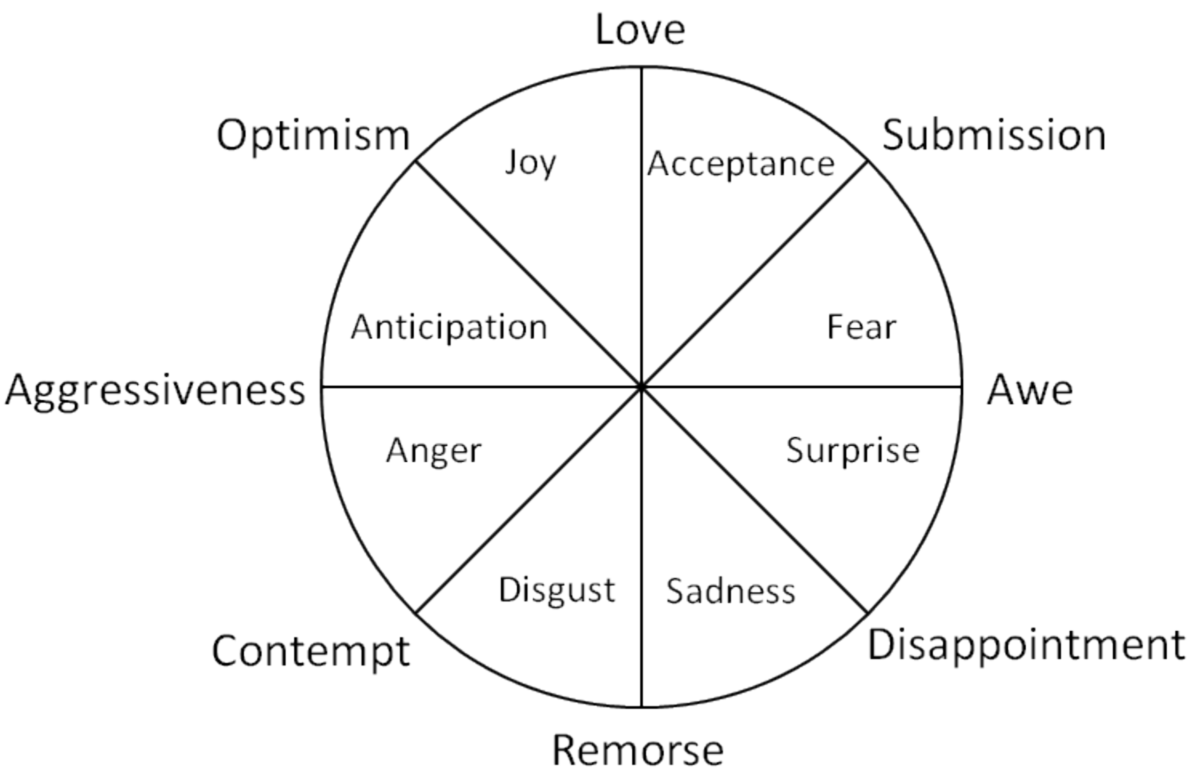

Figure 2. Plutchik's emotion wheel showing the primary emotions (inside the circle) and list of dyads (edge of circle) [41]

This categorical model of emotions provides a simple set of primary emotions and strategy for combining them suitable for the foundations of an emotive design grammar. However, a wide variety of emotions can still be associated to each discrete category [6], and it is not sufficient alone to provide a quantified method to create and evaluate an emotive design framework with very wide range of applicable emotions.

In comparison to the discrete nature of emotion definition in the categorical emotion model, dimensional emotion models define emotions based on a set of continuous scales. Common dimensions in theories proposed in this area include valence – indicating the positivity or negativity of the emotion – and arousal – indicating the excited or calm emotional state. Russell's circumplex model of affect [44] creates a two-dimensional bipolar valence-arousal space, onto which words with different emotional meaning can be mapped (Figure 3).

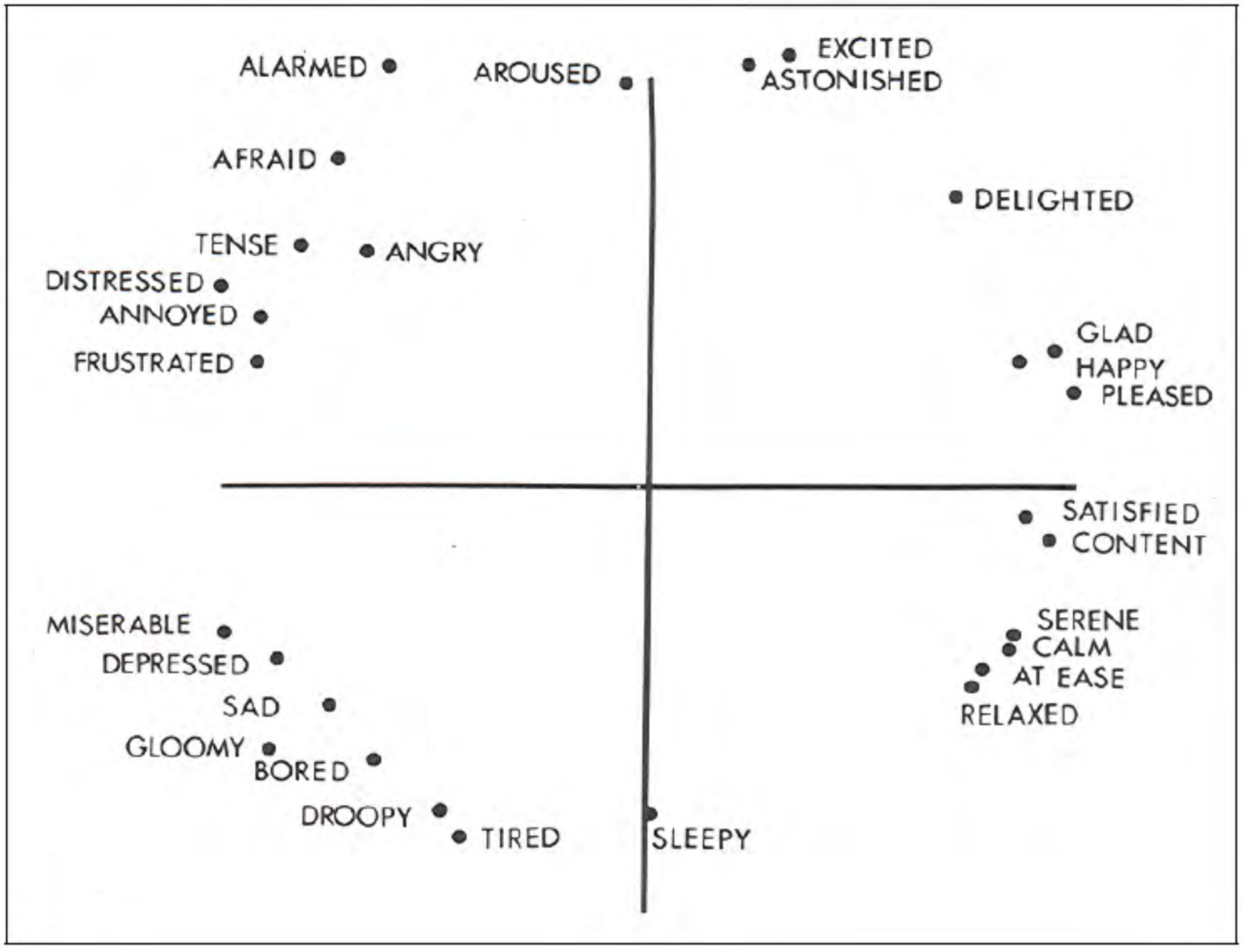

Figure 3. Russell's circumplex model of affect (0° axis representing valence, 90° axis representing arousal) [44]

The simple two-dimensional scales of valence and arousal enables a broader conceptual definition of emotions in terms of physical dynamics of an emotion, which is useful when applied to a physical design language. The gradual nature of Russell's dimensional model also enables a more precise definition of complex or subtle emotions and words, making it easier to compare the emotional states of words, and hopefully designs.

This research uses both the categorical and dimensional emotion models in the design and analysis of forms with emotive meaning. Plutchik's categorical model defines a discrete set of primary emotions and strategy for combining them (dyads) that provides a useful basis on which an emotive design grammar can be created. Russell's dimensional circumplex allows these emotions to be analysed in the more quantitative two-dimensional space of valence and arousal, which will also provide a useful terminology related to the design of forms as well as the overall analysis of this work.

3.1.2. Mapping Words to the Categorical and Dimensional Emotion Models

Many of the words we use in our everyday lexicon have emotional associations to them. When we associate these words to other things, such as shapes, we are then instinctively associating these emotions to them as well [37]. Therefore in order to create a semantically-driven CAD tool that uses an emotive design grammar, dictionaries which relate words to the categorical and dimensional emotion models described above are required.

The NRC Emotion Lexicon created by Mohammad [37] is a dictionary of over 14,000 words sourced from Roget's Thesaurus that associates the words to Plutchik's eight primary emotions. For each word in the database, associated primary emotions are indicated by assigning a 1 to that primary emotion (primary emotions that are not associated are assigned a 0). The overall valence of the word is also indicated with a 1 or 0 (representing positive or negative respectively). Below is an example of the information contained in the NRC Lexicon (in the .json text format [28]):

```
…},
alarm {
        positive:0,
        negative:1,
        anger:0,
        anticipation:0,
        disgust:0,
        fear:1,
        joy:0,
        sadness:0,
        surprise:1,
        trust:0
}…
```

As I am mainly concerned with the association of Plutchik's primary emotions to words and not the overall valence, I have modified this lexicon to only contain the eight primary emotions and their associated values for each word. This dictionary forms the basis for discretely mapping the emotive design grammar for Plutchik's eight primary emotions to a much wider selection of words.

In addition to mapping words discretely to the eight primary emotions, it is useful in this research to be able to map words and emotions to the dimensional scales of valence and arousal. Psychological construction theories propose that these primary emotions are a combination of emotional dimensions, and can therefore be represented on a dimensional model [22].

Normative emotional ratings for a large range of words (including ratings for Russell's Valance and Arousal dimensions) have also been collected in the Affective Norms for English Words database [4]. Using this existing research, the positions of Plutchik's primary emotions and dyads on the Valance-Arousal dimensions can be found (Figure 4, with detailed breakdown included in Appendix 7.2.1).

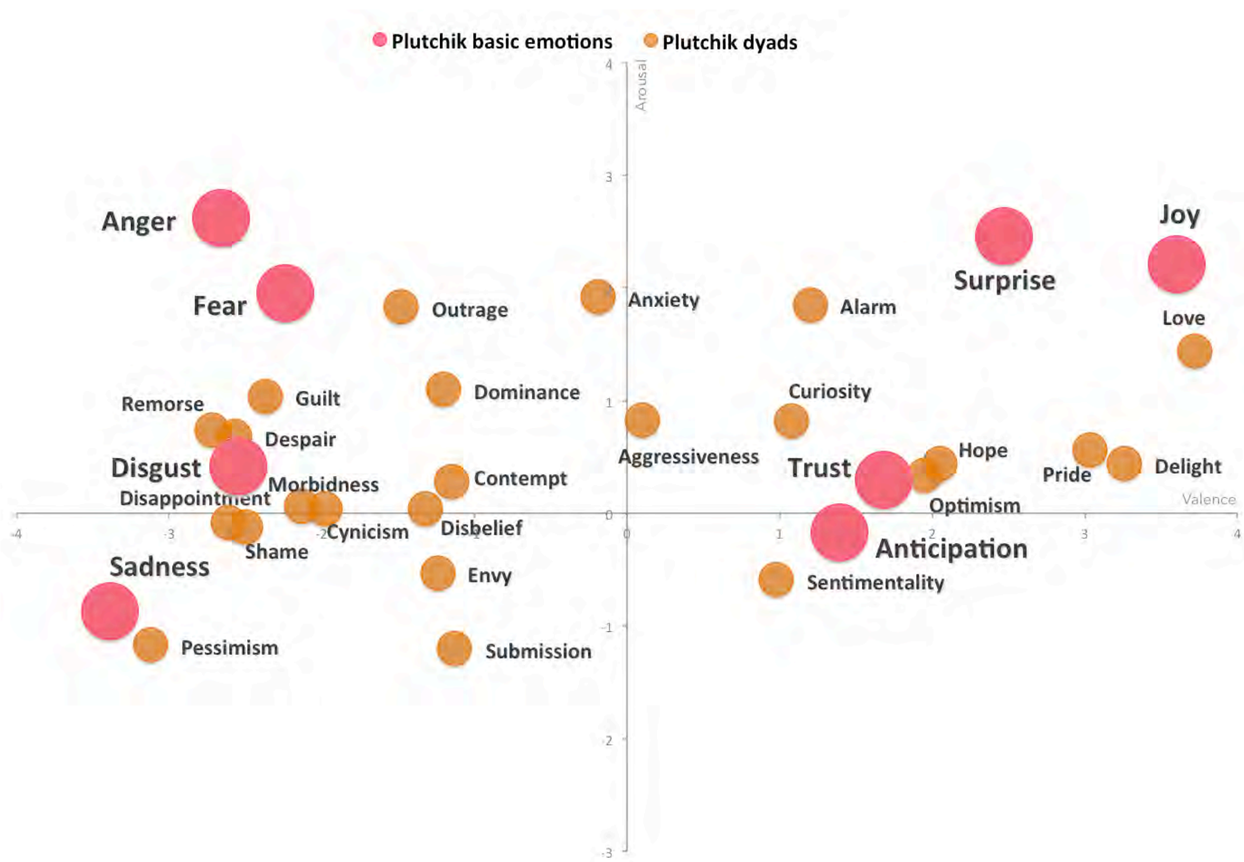

Figure 4. Plutchik's primary emotions and dyads plotted on Valence-Arousal dimensions (based on ANEW ratings)

This dictionary provides a useful quantitative method of comparing my emotive design grammar hypothesis to any responses from studies carried out to test this research.

3.2. Mapping Shapes to Emotions

"…characters of lines may be the result of association, or they may have some deeper reason, but they are there, in the lines themselves, without regard to what the lines may be used to represent, and are among the most valuable means of artistic expression…

…some lines do this gently and flowingly and the easy movement of the eye which they induce is pleasurable. There are others which deviate suddenly, which jar and shock, and such lines may be stimulating and exciting or even painful to follow. There are arrangements of line which are restless and uneasy; there are others that are intolerable.

There is almost no emotion or state of mind, from tranquility to horror, that may not be suggested by the character and arrangement of pure lines.
- Kenyon Cox [12]

Among the factors affecting our perception of objects, embedded within the product semantics of design discussed earlier, is our intuitive reaction to line and form. In the following pages, I present some of the research on emotive shape theories and show how a quantitative emotive design framework can be generated that connects emotions to specific three-dimensional shapes.

3.2.1. Background of the Emotive Perception of Shapes

Beyond those meanings elicited by conventional associations, certain shapes have been shown to evoke similar emotional perceptions. Kohler's 'maluma' and 'takete' experiment - where he showed that the majority of people matched the nonsense word 'malumba' to a drawing of a smooth rounded shape and the word 'takete' to a spiky angular shape (Figure 5) – show that even simple line drawings can evoke almost universally similar perceptions [30].

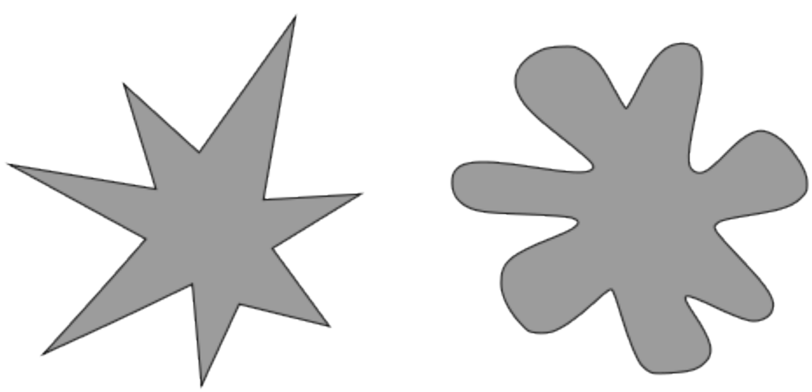

Figure 5. Kohler's 'takete' (spiky shape) and 'malumba' (rounded shape) experiment

Recent studies in the developing field of neuroesthetics have further endorsed this notion of the existence of a universal perception of shapes. Experiments in which abstract forms were manipulated to have spikier or more rounded shapes (Figure 6) showed that even the neural signals in our brains consistently corresponded more positively to the rounded shapes [1].

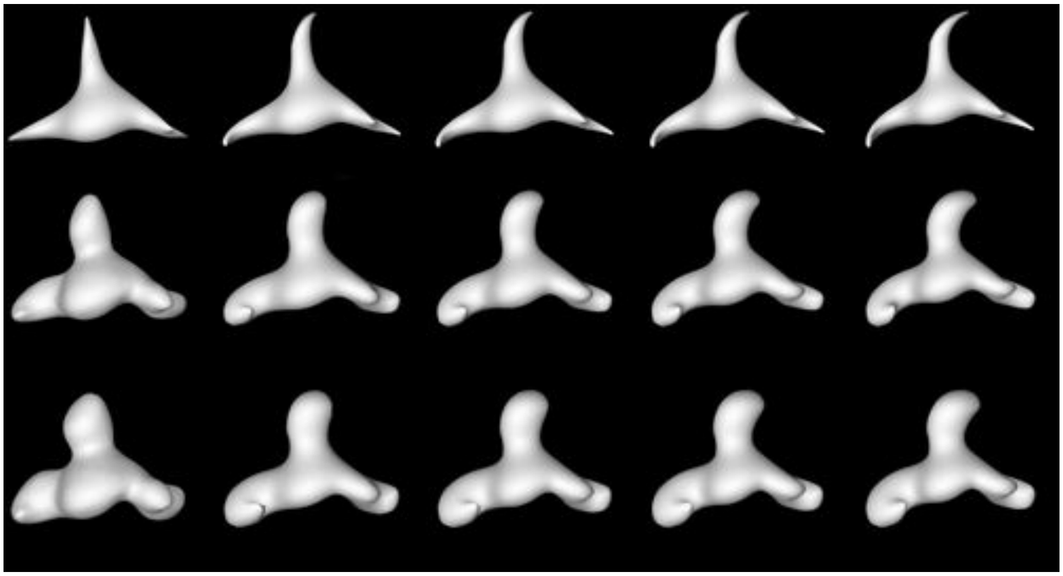

Figure 6. Spiky to rounded variants of a similar shape used to evaluate our neurological response to emotive forms [1]

Extending this simple evaluation of shapes, research has been carried out to qualitatively formalise our perception of emotive forms by mapping various elements of shape to different expressive adjectives.

Two key studies in evaluating the emotive perception of shapes that I will draw upon in this research were carried out by psychologists Poffenberger [42] and Collier [11]. I will particularly refer to the three construction elements that Poffenberger used to break the character of simple lines - form, rhythm and direction – as a structure on which to build the emotive design framework:

> *"…the curved or angular character of the line will be called its 'form', the size of the waves or angles will be called 'rhythm' and the direction will be referred to simply as 'direction'…" - A. T. Poffenburger [42]*

In these studies, lines are broken down into sub-sections of the construction elements; forms can be straight or angular, rhythm can be small, medium or big, and direction can up, horizontal or down (Figure 7). These various lines are then associated to expressive adjectives such as 'sad', 'merry' and 'furious'. As described above, these adjectives can be linked to our descriptions of different emotions. Hence by analyzing the design elements of the lines used in these studies, these lines can be mapped onto the valence-arousal affective circumplex (Figure 8).

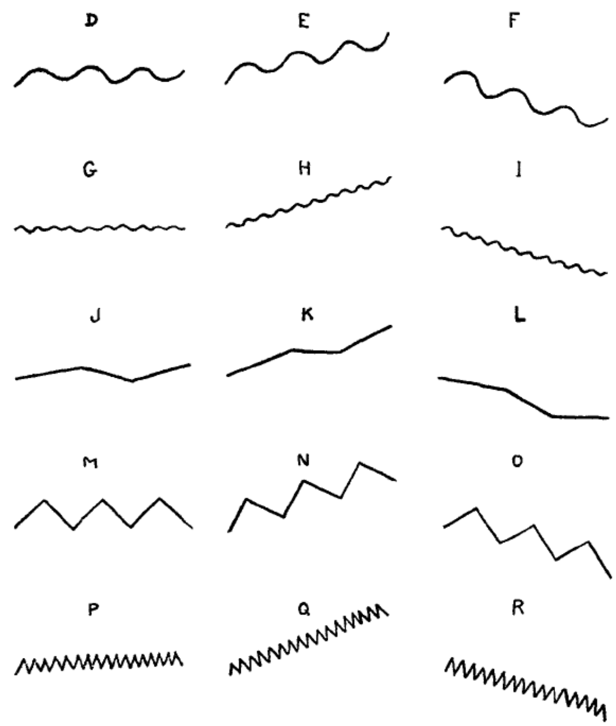

Figure 7. Poffenberger's selection of line drawings used in his shape-emotion experiments [42]

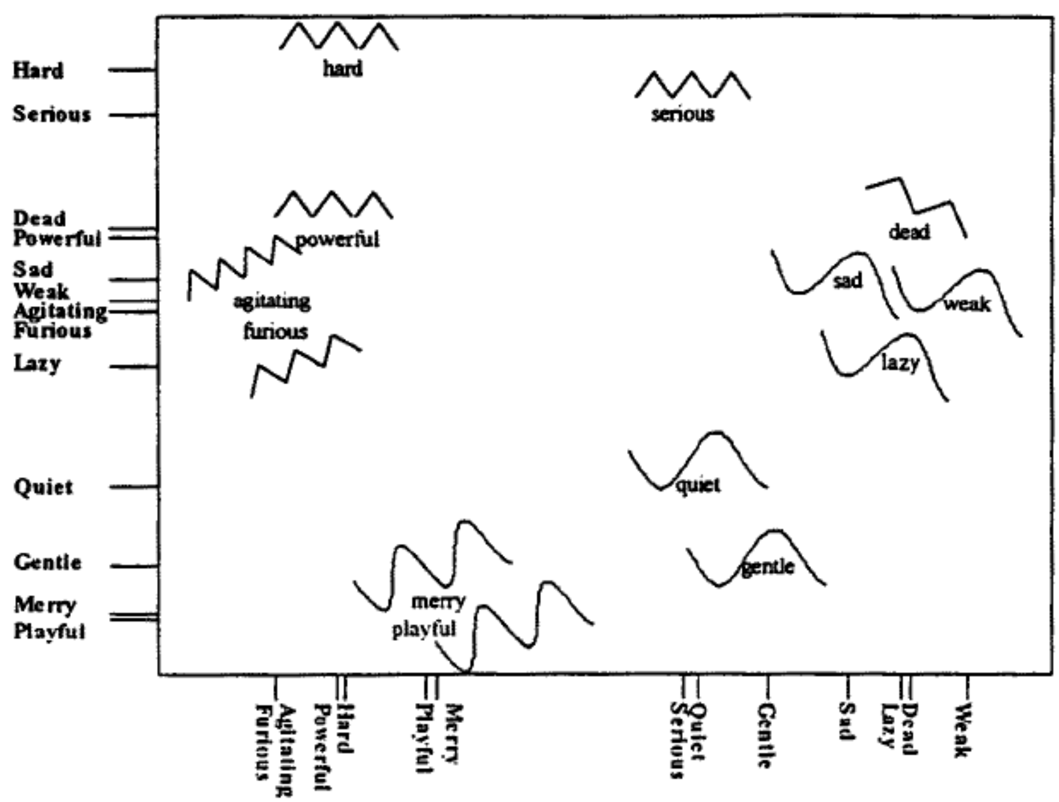

Figure 8. Collier's diagram mapping Poffenberger's shapes onto the valence-arousal dimensions [11] (horizontal axis represents high to low arousal, vertical axis represents positive to negative valence)

In both of these studies, it is suggested that our perception of the affective character of the lines is related to the type of movements we use when expressing the related emotions. Downwards facing lines represent relaxed low-energy emotions such as sadness and trust, while upwards-facing lines express more powerful and uplifting emotions such as anger and joy. Curves with a higher rhythm, i.e. more inflections, show more movement and, therefore, higher energy. Angular curves express a rigidity associated with negative emotions, while the softness of smooth curves are associated to more positive emotive movements. Combinations of these design elements can modify the perceived arousal or valance of the simple lines, creating a more complex perception of the emotion of the shape:

> "*An infusion of straightness into a curve will give it stiffness and vigor, and the most lively and elastic curves are those approaching straightness at one end and curving more and more rapidly toward the other." - Kenyon Cox [12]*

In order to more easily visualize the distribution of the various form, rhythm and direction design elements found in these studies, diagrams mapping them onto their associated areas on the valence-arousal circumplex - and through this their relation to Plutchik's primary emotions and dyads - are shown in Figures 9 and 10. These diagrams were constructed by using the ANEW ratings to plot the emotive adjectives used in the studies discussed above, and overlay the associated design elements (see Appendix 7.2.2. for the design element diagrams constructed for the individual studies).

In general, the design elements for the four quadrants of the valence-arousal circumplex consist of:

- ***Positive, low-energy emotions*** are represented by smooth big and medium curves facing down or horizontal
- ***Positive, high-energy emotions*** are represented by smooth or angular medium and small curves facing horizontal or upwards
- ***Negative, high-energy emotions*** are represented by angular small and medium curves facing up or down
- ***Negative, low-energy emotions*** are represented by smooth or angular big curves facing down

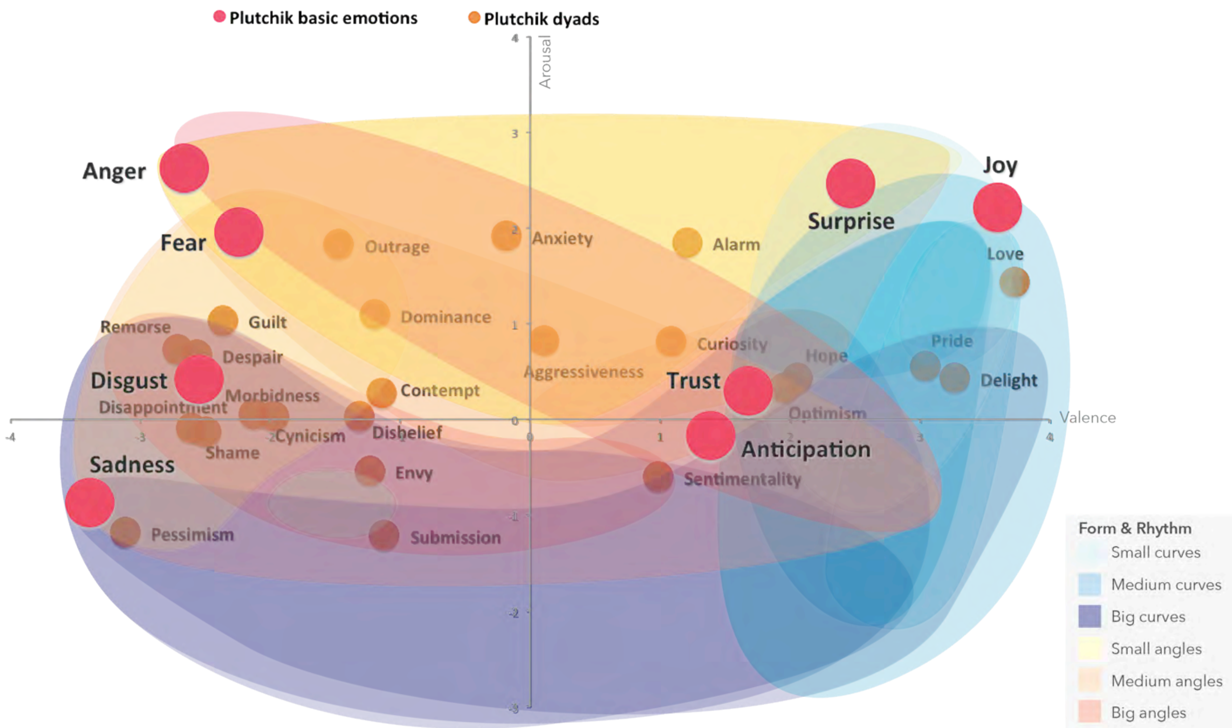

Figure 9. Summary of the form and rhythm elements of the 2D design language defined by Lundholm, Poffenburger, and Collier

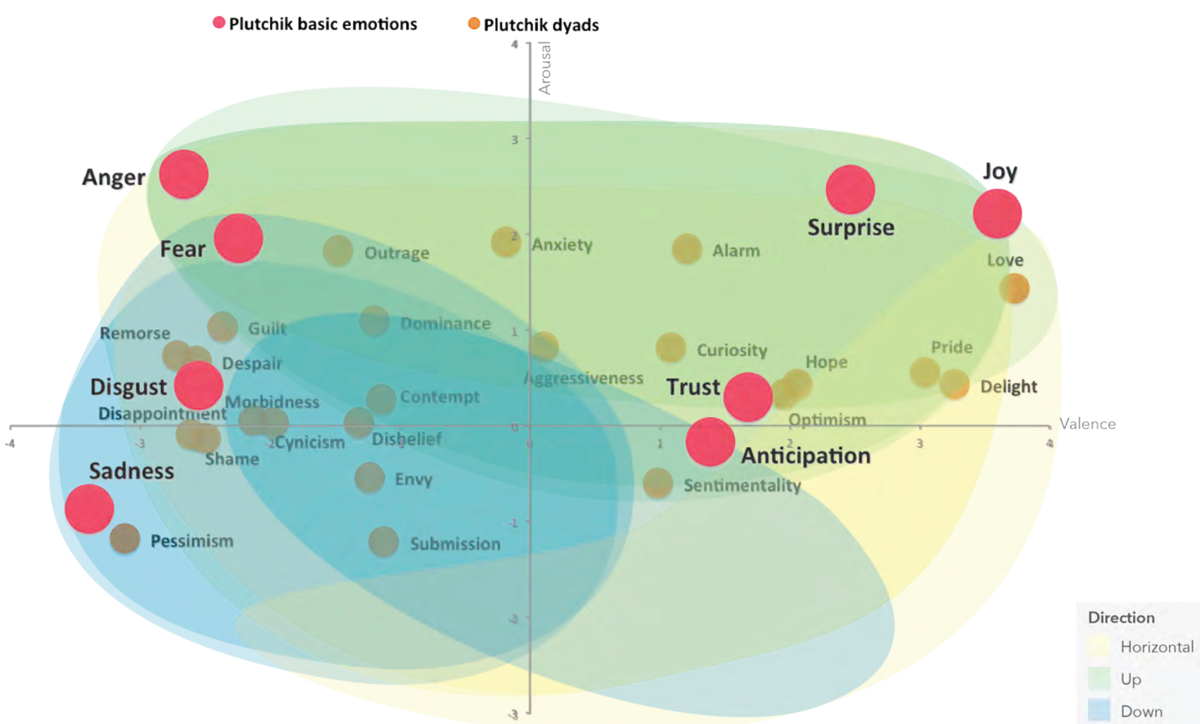

Figure 10. Summary of the directional element of the 2D design language defined by Lundholm, Poffenburger, and Collier

Similarly inspired by a biomorphic expression of emotion in objects, Isbister et al carried out experiments to classify three-dimensional forms with varying emotive design elements (shown in Figure 11) onto corresponding affective dimensions [25]. The design elements considered in this study included similar elements to the two-dimensional studies described above: 'rounded' and 'spiky' were found to be related to the form design element, 'smooth' and 'bubbly' to the rhythm element, and 'droopiness' to the direction element.

Figure 11. Three-dimensional shape stimuli used by Isbister et al in their shape-emotion experiements [25]

Similarly, Figures 12 and 13 show the distribution of the form, rhythm and direction design elements suggested by Isbister mapped onto the valence-arousal circumplex to more easily visualize the relationships between them.

Trends for these three-dimensional design elements for the four quadrants of the valence-arousal circumplex appear similar to those found in the two-dimensional shape studies:

- ***Positive, low-energy emotions*** are represented by smooth big and medium curves facing down or horizontal
- ***Positive, high-energy emotions*** are represented by smooth medium and small curves facing horizontal or upwards
- ***Negative, high-energy emotions*** are represented by angular small and medium curves facing up or down
- ***Negative, low-energy emotions*** are represented by angular medium and big curves facing down

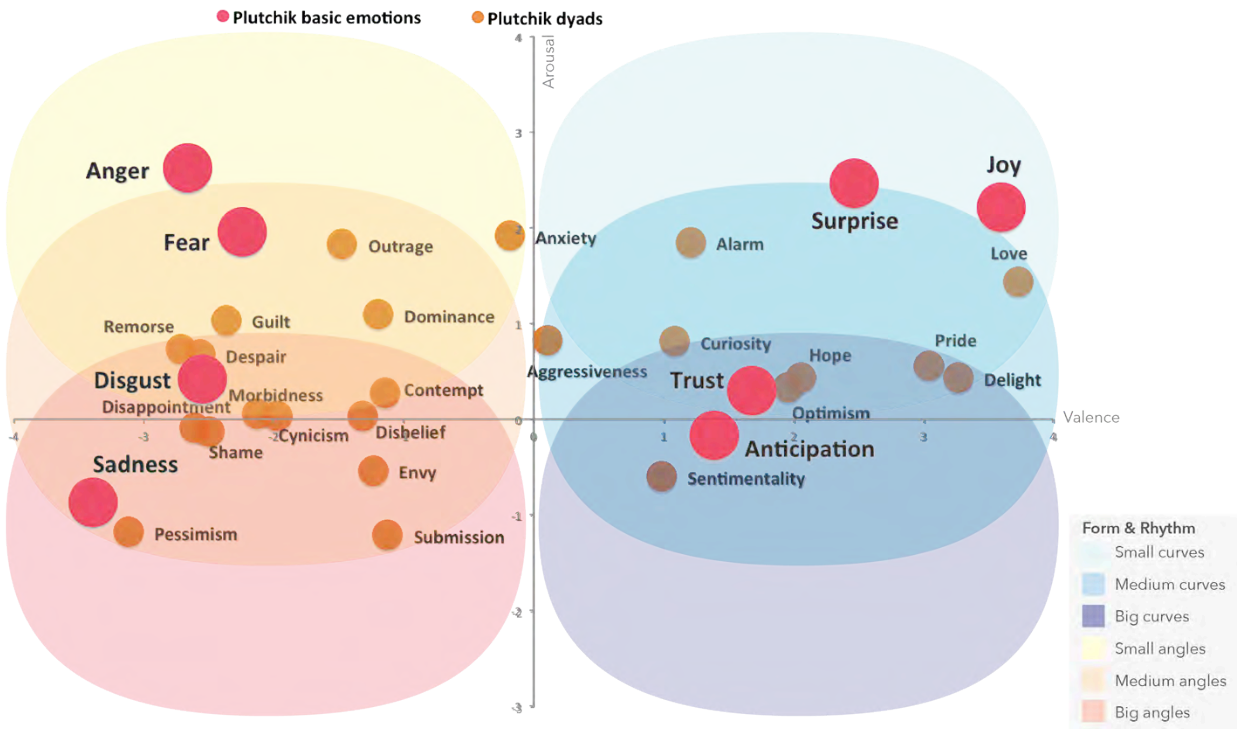

Figure 12. Summary of the form and rhythm elements of the 3D design language defined by Isbister

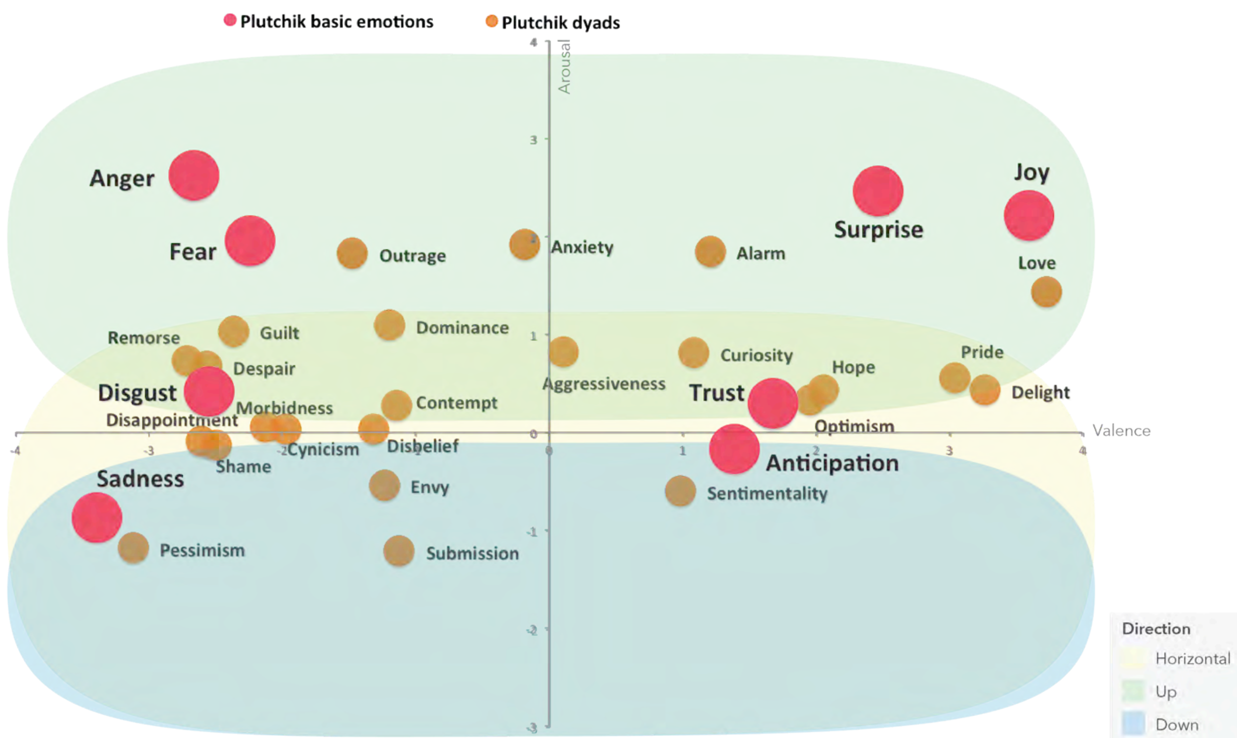

Figure 13. Summary of the directional element of the 3D design language defined by Isbister

3.2.2. Qualitative Taxonomy of Emotive Shapes

In order to transform this existing emotive shape research into a quantitative taxonomy suitable to be integrated into an emotive semantically-driven CAD tool, I first propose a qualitative taxonomy of emotive shapes. In the following section, I will discuss how these more descriptive design attributes can be transformed into the specific design variables that will contribute to my proposed quantitative emotive design taxonomy.

To combine and build on the existing emotive shape research described earlier, the form, rhythm and direction diagrams shown above were layered together, enabling a more detailed breakdown of these design elements to be created. For example, for areas on the circumplex where the existing research suggests that there are only angular or smooth curves, these design elements are translated to the new taxonomy directly. Smooth but slightly edged curves represent those areas where angularity or smoothness overlap. Where areas of big curves overlap with small curves, these are represented as medium curves, etc. For areas on the circumplex where the direction is leaning downwards and straight, the resulting direction on the taxonomy is leaning slightly backwards. Similarly for areas where the direction design element indicated by all of the existing research suggests downwards, this is enhanced to heavily leaning downwards in the combined qualitative taxonomy of emotive shapes.

Diagrams summarizing the various form, rhythm and direction design elements associated to different areas on the valence-arousal circumplex, and their relation to Plutchik's primary emotions, and dyads, are shown in Figures 14 and 15. As the designs are now three-dimensional and hence able to be considered from many angles, the direction design element for downwards facing is referred to as leaning backwards from a central axis, and leaning forward for upwards facing, i.e. when viewed from the side, when 'leaning backwards' the design will appear to lean to the left and vice versa.

In addition to the design elements of form, rhythm and direction discussed above, the center of mass and balance also play an important part in how we perceive three-dimensional objects [33]. These attributes are embodied in a design through the aspect ratio, e.g. width/height of the shape, and distribution of volume, e.g. bottom heavy, in the design respectively. I have included these design elements in this qualitative taxonomy to expand the previous research so that it is more relevant for the design of three-dimensional objects.

Relating these design elements back to Poffenberger's three original design elements, aspect ratio can be considered to be a combination of form and direction. For example, for an area of the circumplex where the form is smooth and the direction is straight or slightly leaning forwards or backwards, a more rounded aspect ratio is expected. Looking more closely at the objects used in Isbister's research described earlier, and building on my own experience as a designer, I also propose that designs with a taller, i.e. lower, aspect ratio generally convey more energy, and vice versa.

The distribution of the volume design element can be considered to be a combination of rhythm and direction. For example, for an area of the circumplex where there are medium size (i.e. rhythm) curves and the direction is straight or slightly leaning forwards or backwards, more balanced middle-heavy forms are expected. Where the direction design element suggests a greater level of leaning, a more unbalanced form is expected. In this hypothesis, I suggest that forms leaning such as this with a more top-heavy distribution of volume convey a sense of low arousal, as the forms take on an almost anthropomorphic shape of a lethargic person slumping. The opposite is expected to be true for high-energy forms, i.e. bottom-heavy forms with smaller upper sections almost 'reaching' upwards energetically.

Diagrams summarizing the aspect ratio and distribution of volume design elements are shown in Figures 16 and 17.

A summary of the design elements I propose for this qualitative taxonomy of emotive shapes (broken down into the four quadrants of the valence-arousal circumplex) is below:

- ***Positive, low-energy emotions*** are represented by top-heavy forms with smooth big and medium curves leaning slightly back or horizontal, and with round, flat and wide aspect ratios
- ***Positive, high-energy emotions*** are represented by middle or bottom-heavy forms with smooth or angular medium and small curves leaning forwards or horizontally, and with tall, round and slender aspect ratios
- ***Negative, high-energy emotions*** are represented by middle or bottom-heavy forms with angular small and medium curves leaning heavily forwards or backwards, and with tall, round and slender aspect ratios
- ***Negative, low-energy emotions*** are represented by top-heavy forms with smooth or slightly angular medium and big curves leaning heavily backwards, and with round, flat and wide aspect ratios

From this qualitative taxonomy, it can be summarized that the valence is generally represented by the form design element (positive valence = smooth; negative valence = angular), and the arousal is represented by the rhythm, direction, distribution of volume and aspect ratio design elements (low arousal = leaning forwards, big curves, top-heavy, wide/flat; high arousal = leaning backwards, small medium curves, bottom-heavy, tall/slender).

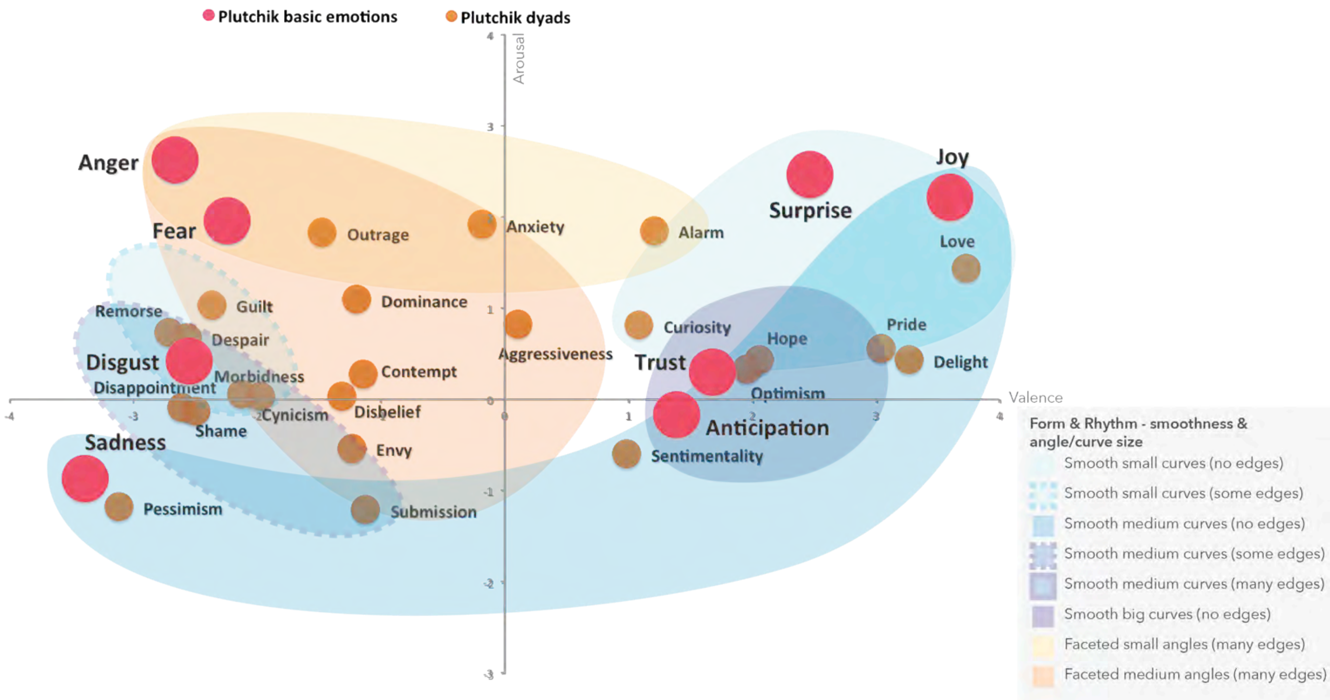

Figure 14. Qualitative emotive design taxonomy: hypothesis for the form and rhythm design elements

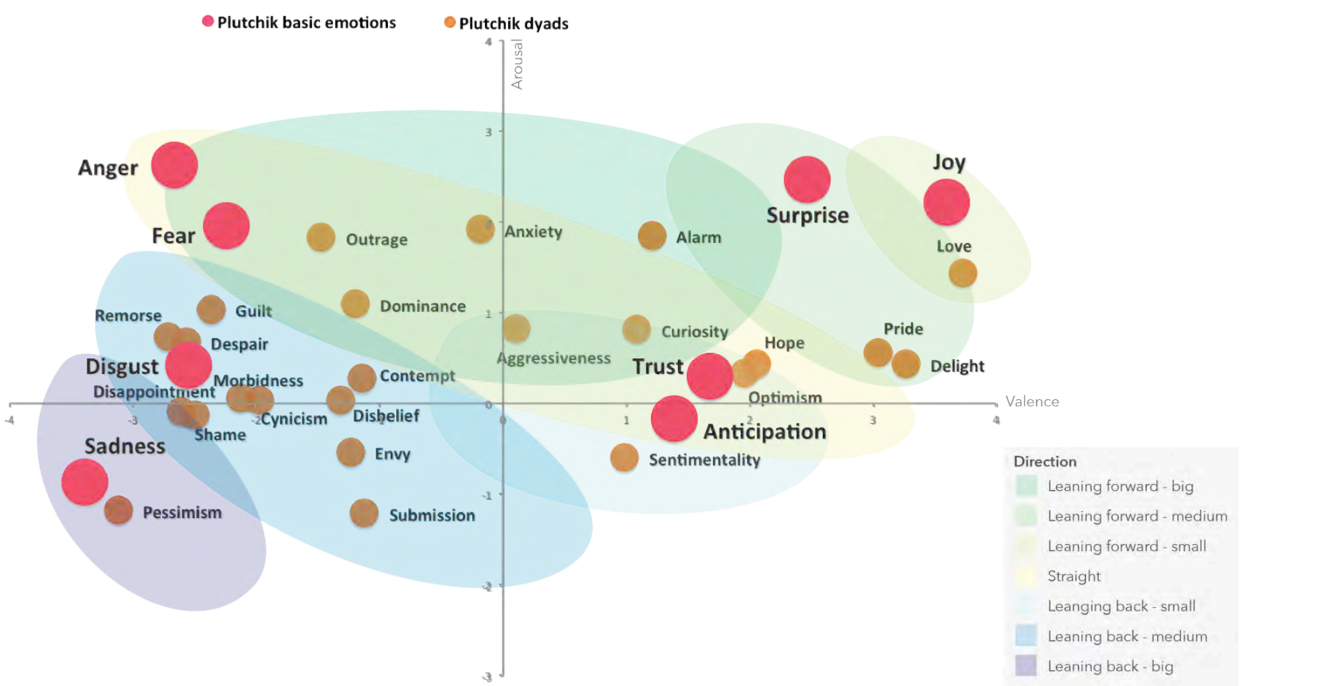

Figure 15. Qualitative emotive design taxonomy: hypothesis for the directional design elements

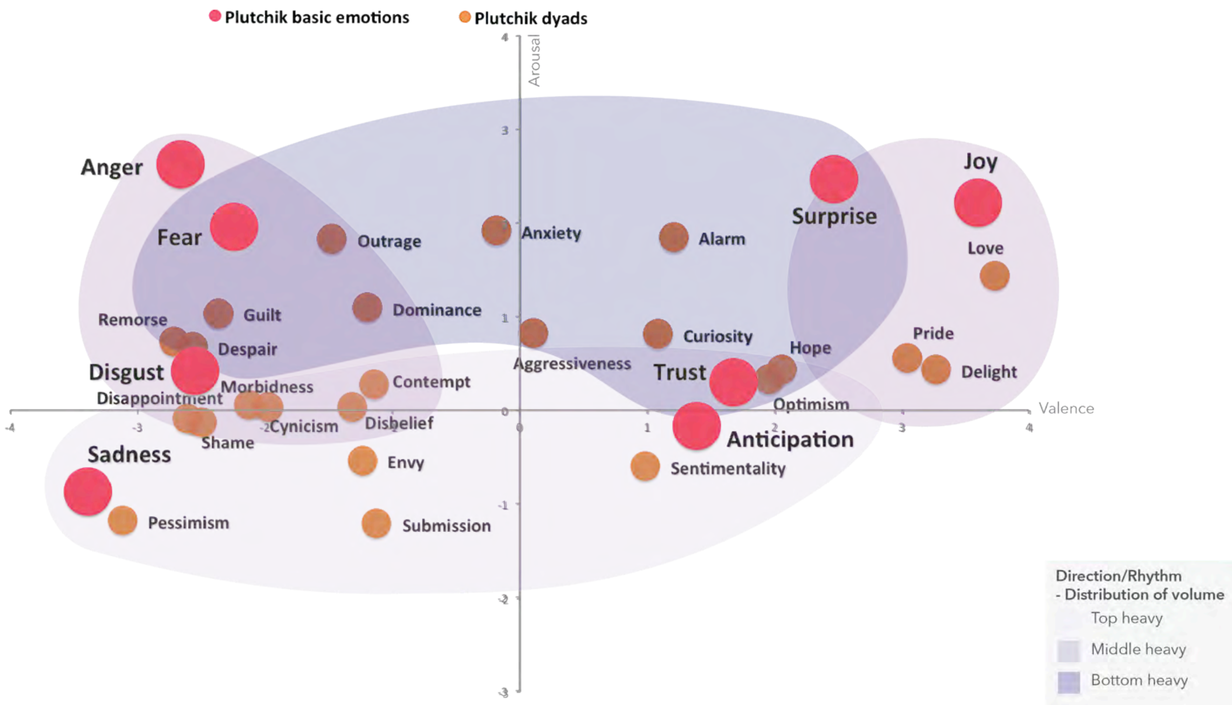

Figure 16. Qualitative emotive design taxonomy: hypothesis for the direction-based rhythm design elements (i.e. the distribution of volume)

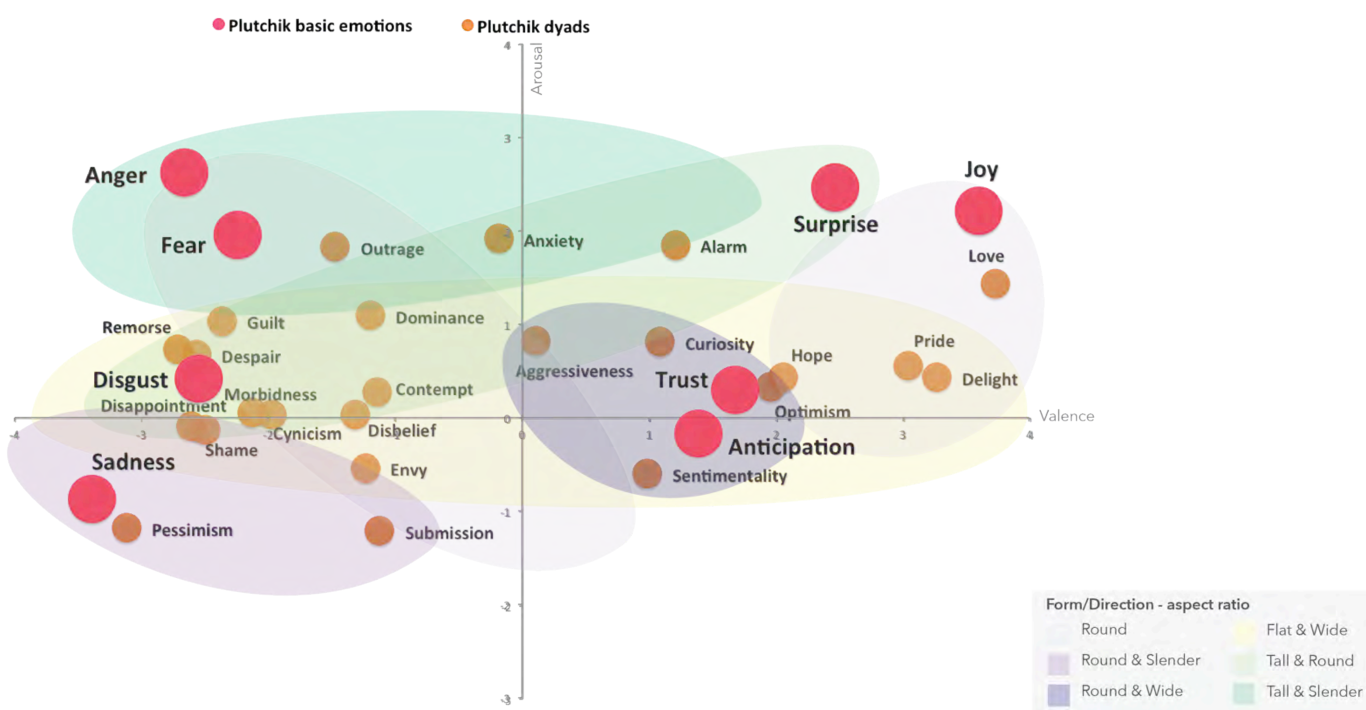

Figure 17. Qualitative emotive design taxonomy: hypothesis for the direction-based form design elements (i.e. the aspect ratio)

To further distill this taxonomy into a useable design grammar based on Plutchik's primary emotions, Figures 14-17 summarizing the distribution of the design elements for the qualitative taxonomy have been used to derive a suggestion of the design elements associated with each primary emotion. The valence and arousal positions of the primary emotions were overlaid onto these diagrams, from which a hypothesis for the form, rhythm, direction, distribution of volume, and aspect ratio design elements could be found. The breakdown of these design elements for each of the primary emotions is listed in Table 1 below (the breakdown of the design elements relating to Plutchik's primary emotions for the existing research is included in Appendix 7.2.3.):

Primary emotions	Form	Rhythm	Direction	Form & Direction: Aspect ratio	Rhythm & Direction: Distribution of volume
Anticipation	Smooth	Big curves	Leaning slightly backwards	Flat and wide	Top-heavy
Trust	Smooth	Big curves	Leaning straight	Flat and wide	Bottom-heavy
Joy	Smooth	Medium curves	Leaning slightly forwards	Round	Middle-heavy
Surprise	Smooth	Small curves	Leaning forwards	Tall and round	Bottom-heavy
Fear	Angular	Small curves	Leaning heavily forwards	Tall and slender	Bottom-heavy
Anger	Angular	Medium curves	Leaning straight	Tall and round	Top-heavy
Disgust	Angular	Medium curves	Leaning slightly backwards	Round	Middle-heavy
Sadness	Smooth	Big curves	Leaning heavily backwards	Round and slender	Top-heavy

Table 1. Breakdown of design elements in the qualitative taxonomy for each primary emotion

But what could the design elements of these forms look like? To help visualize this qualitative emotive design taxonomy, Figure 18 below suggests visual representations of each of the qualitative design elements related to the primary emotions described in Table 1:

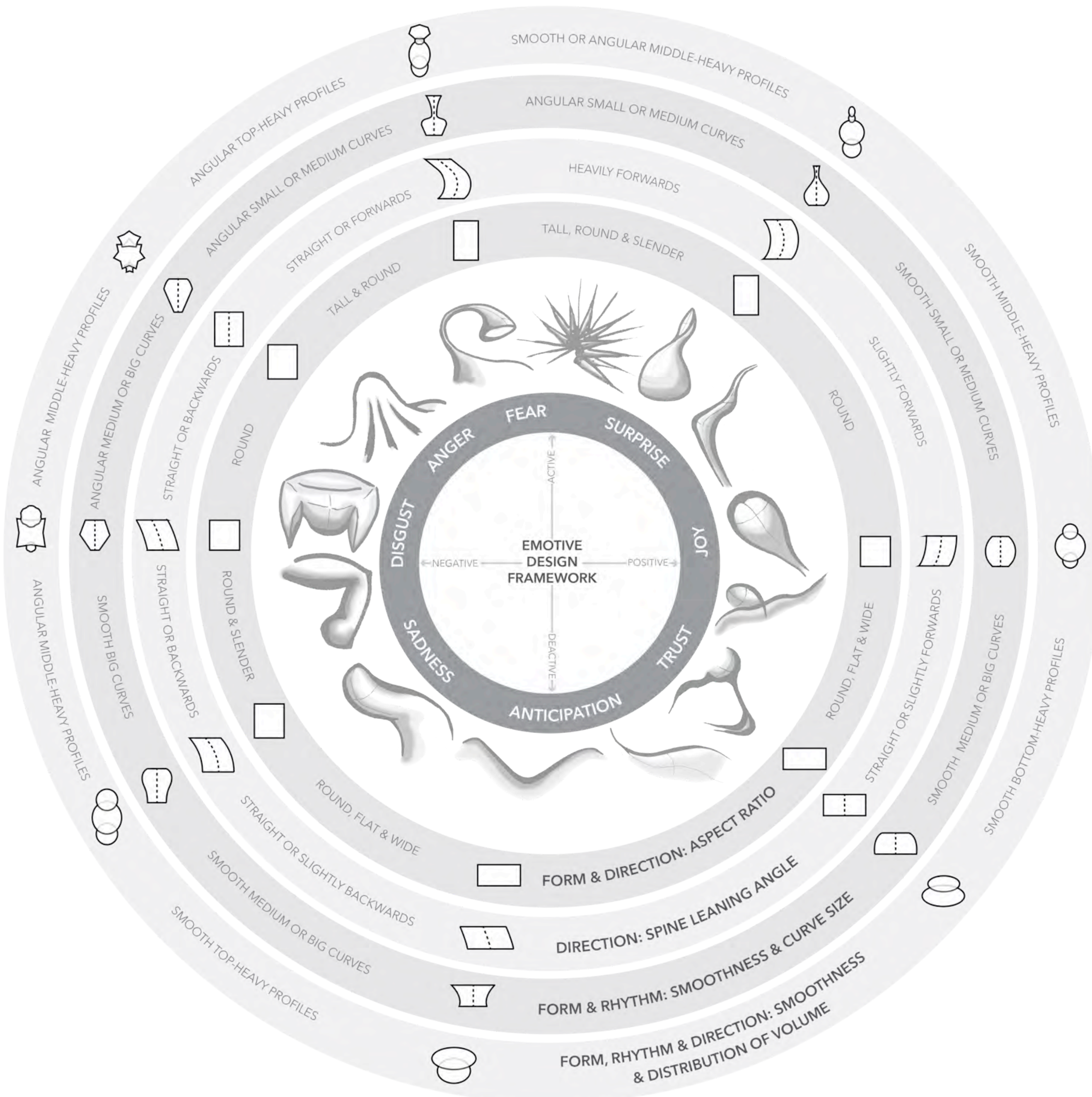

Figure 18. Qualitative emotive design taxonomy: visualization of design elements for primary emotions

3.2.3. *Quantitative Taxonomy of Emotive Shapes*

The existing work into the development of taxonomies for emotive form described above demonstrates the existence of a somewhat universal perception of forms to emotive meaning. However, much of the categorization of the design elements is qualitative, using adjectives such as round or spiky. For taxonomies such as these to be integrated into emotive semantically-driven CAD tools, a more quantified, and therefore computational, version of this taxonomy is required.

In order to describe how the qualitative taxonomy of emotive shapes can be transformed into quantitative variables, a short explanation of the construction of a form in CAD is first required. The underlying CAD tool for the research in this thesis is the Rhinoceros (Rhino) 3-D modeling software developed by Robert McNeel & Associates [43].

One of the simplest ways to create a 3D object of varying shapes in Rhino is by creating a lofted surface from several profile curves. Curves are formed of varying numbers of control points in a certain geometric distribution, with either straight or curved lines joining the control points (determined by a line curvature degree). By distributing the central origins and planes of these curves away from each other, a smooth or faceted surface can be created which blends the shapes of the two lofted curves (determined by a loft curvature degree). Figures 19 and 20 show examples of the different curves and lofts that can be created in Rhino.

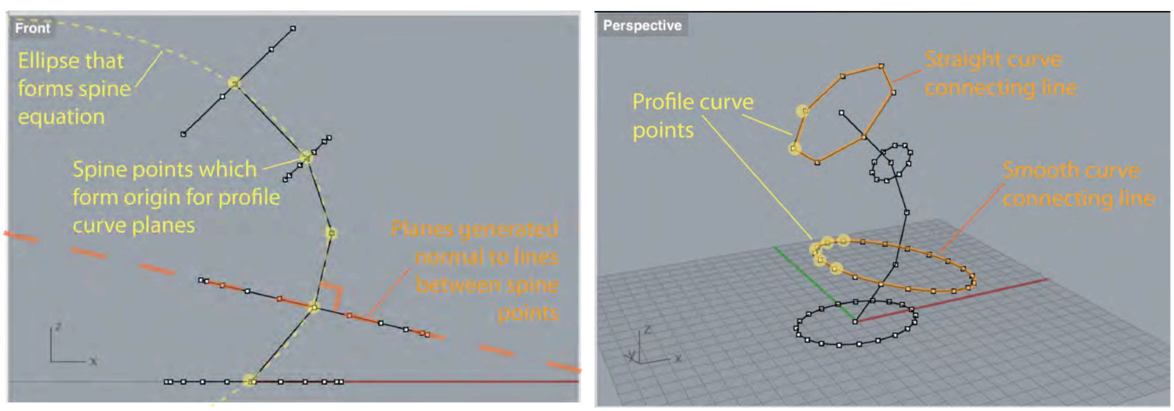

Figure 19. Selection of curves showing different origin positions and planes, number of control points, and straight and curved connecting lines

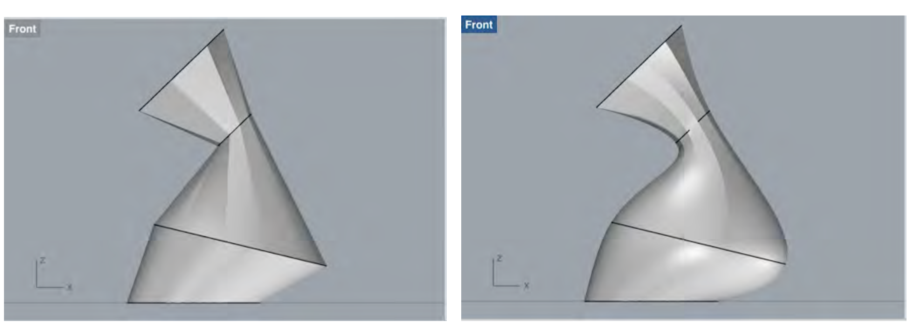

Figure 20. Lofted surface connecting the curves with straight (left) and curved lofted sections (right)

The computational strategy I use in the emotive semantically-driven CAD tool created in this research builds on this fundamental method of creating solid objects in Rhino described above. The various functionalities in creating a form described above – such as the number of points in the profile curves, or the loft curvature degree – can be related to the design elements in both the existing research and the qualitative taxonomy of emotive shapes discussed above. A simple example is the direct contribution of the loft curvature degree to the form design element: in Rhino a loft curvature degree of 2 results in an faceted surface connecting the profile curves, i.e. an angular form, and 3 results in a more blended surface, i.e. a smoother form (left and right images in Figure 20 respectively).

The variables required to generate a three-dimensional design using the process described above were experimented with using the Rhino software. The resulting designs were evaluated and iterated in order to define ranges for the values required to generate designs for the eight primary emotions conveying the design elements as described above. The resulting selection of Rhino 3D modeling tools that I use to translate the design elements described in the qualitative taxonomy described above into 3D objects include:

- ***Form:*** the smoothness of the object can be determined by changing the number of points and degree of curvature in the lines of the profile curves (smooth lines > 20 points and degree = 2, faceted lines <15 points and degree = 1), and the degree of curvature of the surface lofting function (smooth surfaces = 3, faceted surfaces = 2)
- ***Rhythm:*** the size of the curves in the object are determined by how many inflections there are in the shape of the surface, i.e. a smooth conical shape has no inflections, a more spherical shape has one inflection, and a shape with 'S' type curves has two or more. This is dependent on the size of the curves compared to each other along the lofted surface, and is calculated by a ratio applied to the individual level profile curves
- ***Direction:*** the leaning angle of the object will depend on the position of the curve origins and planes in comparison to each other, which can be varied by varying the shape of the central 'spine' of the object. In this taxonomy, this spine will be generated using the equation of an ellipse with varying width, height and origin coordinates (similar to Figure 19).
- ***Form & Direction:*** the aspect ratio of the object will depend on the overall vertical aspect ratio (height/width) applied to the calculation of the spine to determine if the shape is flat or tall, and the individual horizontal aspect ratio (width/depth) applied to the calculation of each of the profile curves to determine if it is wide or slender
- ***Rhythm & Direction:*** the distribution of volume in the object will depend on the position of the largest profile curve along the spine, i.e. if the position of curve with the largest individual level ratio (1) is near the base of the spine then the object will likely be bottom-heavy

The CAD functionalities discussed above provide a general shape and ratio-based geometry to the resulting design of the object, which should enable a wide variety of objects to be designed. Using these functions, my proposed computational construction of emotive objects in the Rhino 3D modeling software (using the Python programming plug-in to execute the computational program) is:

1. Each object consists of 5 curves, whose origins and planes are distributed along a central spine.
2. The height and width of the spine are calculated from the global vertical aspect ratio related to each emotion.
3. The angle of the spine is related to the amount of leaning and an elliptical equation of various radii and origins is used to generate 5 points from the base plane up to the height prescribed by (2) with a connecting line in-between them.
4. Planes perpendicular to the spine line are generated at each of the 5 points, creating 5 levels on which the profile curves can be created.
5. At each level, profile curves are generated with dimensions calculated from the individual level ratio values determined from how many inflections are required and the position of maximum volume, and with the number of points and degree of line curvature for the required smoothness.
6. The profile curves are lofted together into a single surface with the degree of curvature determined by the required smoothness.

The order of transformations in this construction strategy is important in the correct generation of the predicted emotive forms. Some functions will not execute if attempted before others, e.g. a surface cannot be lofted without profile curves. Other functions may generate forms of unexpected shapes if not performed in the specified order, e.g. if profiles are drawn before the planes are generated perpendicular to the spine, they will all be constructed on top of each other on the base plane of the 3D model. This order is a hierarchy of rules that builds upon a selection of base variables to construct an emotive form – together with the following quantified design elements this becomes my emotive form 'shape grammar'.

Using this 3D modeling strategy, the qualitative emotive design taxonomy described in Table 1 above can be transformed into a quantitative taxonomy applicable for use in a computational CAD tool such as Rhino. By analyzing the shapes used in previous studies, appropriate values for the spine equations and aspect ratios for the various qualitative design element descriptions could be determined. For example, various ellipses were compared to the angles of the lines used in Poffenberger's study to determine the appropriate elliptical equation for each of the direction design elements (e.g. leaning forwards – small, leaning backwards – medium, etc). The variables in these equations – the horizontal radii, a, and vertical radii, b, terms in this case – then provide quantitative benchmarks for defining the qualitative design elements for other computationally generated shapes. Similar experimentation helped to determine suitable values for the other design elements.

My hypothesis for these quantitative design elements for use in an emotive form generating CAD tool using the Rhino 3D modeling software is shown in Table 2 below. To help visualize this quantitative emotive design taxonomy, Figure 21 below suggests examples of forms for each of the design elements related to the primary emotions, including a simple base design labelled 'neutral'. (A detailed breakdown of this taxonomy applied to Plutchik's primary emotions is shown in Appendix 7.2.4.)

Qualitative Design Elements	**Quantitative Design Elements**	
Form: Smoothness	No. points in curve, line curvature degree, and loft curvature degree	Smooth surfaces: Loft curvature degree = 3
		Faceted surfaces: Loft curvature degree = 2
		No edges: No. points > 15; Line curvature degree = 2
		Some edges: No. points < 7; Line curvature degree = 1
		Many edges: No. points = 7-15; Line curvature degree = 1
Rhythm: Size of curves	No. inflections	Big curves: 0 inflections
		Medium curves: 1 inflections
		Small curves: 2 inflections
Direction: Lean angle	Equation of spine: elliptical radii (a = ½ width, b = ½ height)	Leaning forward (small): b >= 2.619
		Leaning forward (medium): 1.322 < b <= 2.619
		Leaning forward (big): b <= 1.008
		Straight: a = b = 0
		Leaning backward (small): a <= 0.65
		Leaning backward (medium): a >= 2.619
		Leaning backward (big): 0.65 < a <= 2.619
Form & Direction: Aspect ratio	Global vertical AR (= height/width) or global horizontal AR (=width/depth)	Flat: Global vertical AR >= 2
		Round: Global vertical AR ≈ 1
		Tall: Global vertical AR >= 0.625
		Wide: Global horizontal AR >= 2
		Round: Global horizontal AR ≈ 1
		Slender: Global horizontal AR >= 0.875
Rhythm & Direction: Distribution of volume	Position of largest curve on spine	Bottom-heavy: largest curve at 1st or 2nd spine level
		Bottom-heavy: largest curve at 3rd spine level
		Top-heavy: largest curve at 4th or 5th spine level

Table 2. Breakdown of design elements in the qualitative taxonomy for each primary emotion

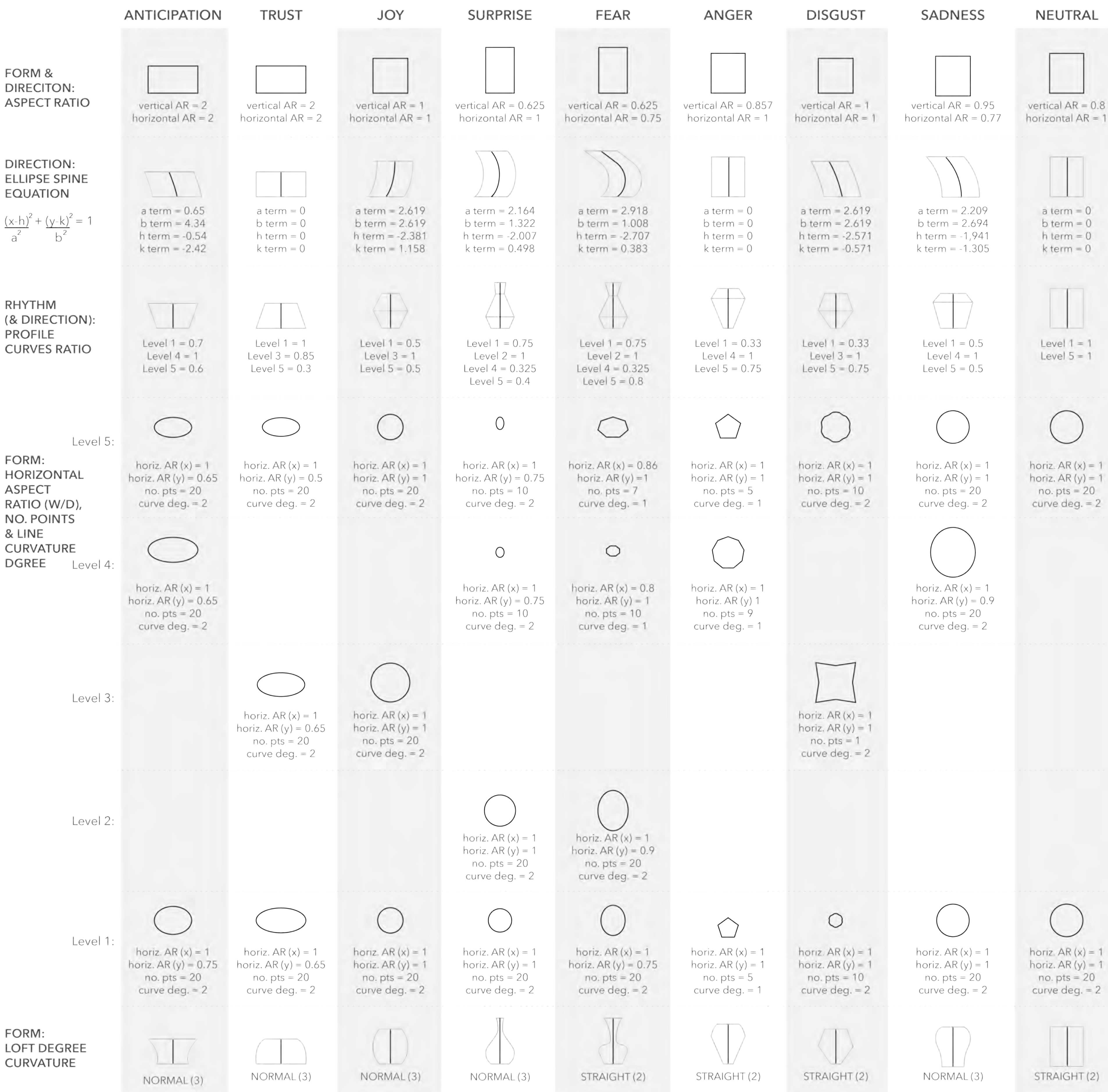

Figure 21. Quantitative emotive design taxonomy: visualization of design elements for primary emotions

3.3. Mapping Words to Forms: An Emotive Design Language Taxonomy

"Every natural phenomenon, however simple, is really composite, and every visible action and effect is a summation of countless subordinate actions… the equation to a curve, the description of a froth or cellular tissue, all come from within the scope of mathematics for no other reason than that they are summations of more elementary principles or phenomena."

- D'Arcy Thompson [54]

In the last two sections, I have shown how words can map to emotions and how emotions can map to forms. This section will bring these two areas together to show how words can be mapped to forms, and hence how an emotive semantically-driven CAD tool can be created.

Since there are thousands of words which could be used in creating an emotively expressive object, it is impractical for an emotive semantically-driven CAD tool to define a grammar of design elements for each word individually. As with the design grammar theory described earlier, defining a small set of rules and a method for combining them can create an almost unlimited number of resulting outputs. In this research, I use a strategy similar to Plutchik's dyad theory for creating many emotions from a set of primary emotions, i.e. combining two or more primary emotions from even opposing areas of the valence-arousal spectrum to create a more complex emotion. Using the quantified emotion design grammar for Plutchik's primary emotions outlined above and the relationship of words to the eight primary emotions defined in the NRC Lexicon described earlier, these design elements can be combined to create forms related to other, more complex emotions.

For example, according to Plutchik's dyad theory, the word 'alarm' contains the emotions fear and surprise. Simply combining the qualitative design elements for both fear and surprise, alarm would be a combination of both of these shapes (see Table 4 below):

Primary emotions	**Form**	**Rhythm**	**Direction**	**Form & Direction: Aspect ratio**	**Rhythm & Direction: Distribution of volume**
Surprise	Smooth	Small or medium curves	Leaning forwards	Tall and round	Bottom-heavy
Fear	Angular	Small or medium curves	Leaning straight or heavily forwards	Tall, round and slender	Bottom-heavy
Alarm (Fear + Surprise)	Smooth and angular	Small or medium curves	Leaning slightly forwards	Tall, round and slender	Bottom-heavy

Table 3. Combination of primary emotion design elements to create a more complex emotion

This combination of 'fear' and 'surprise' in the creation of an emotive form to represent 'alarm' brings together primary emotions from either side of the valence-arousal spectrum, i.e. fear is negative valence and surprise is positive. This creates an almost 'chimeric' combination of the very different underlying primary emotion forms. Building on the existing research described above, I expect that the diverse design elements of both fear and surprise are required to convey the overall meaning of alarm. Therefore, simply averaging the quantified design variables for the two emotions might create a form with an inappropriately neutral emotive shape. A key issue in creating this emotive design language taxonomy is to design the rules for combining the design elements of these very different primary emotions so that the ambiguity of the emotional meaning is sustained in the resultant forms.

In this thesis, I attempt to address this 'chimeric' emotive forms issue by exploring the varying importance of the different design elements in conveying emotive meaning across the valence-arousal circumplex. Poffenberger explores the relative importance of these design elements to each other, and identifies the design elements with the greatest influence for each of the emotions in his study [42]. Figure 22 summarizes this relative importance of the form, rhythm and direction design elements associated to different areas on the valence-arousal circumplex, and their relation to Plutchik's primary emotions and dyads. (See Appendix 7.2.5. for the scaling factor diagram constructed for the Poffenberger study).

In this case it can be seen that for fear the form (orange) and direction (green) design elements are the most important, and for surprise the direction (green) element is most important. Therefore the combination of these emotions - 'alarm' – must incorporate more of the fear design element (angular) and surprise direction element (leaning forwards). Thus scaling factors for these design elements must be higher in fear and surprise.

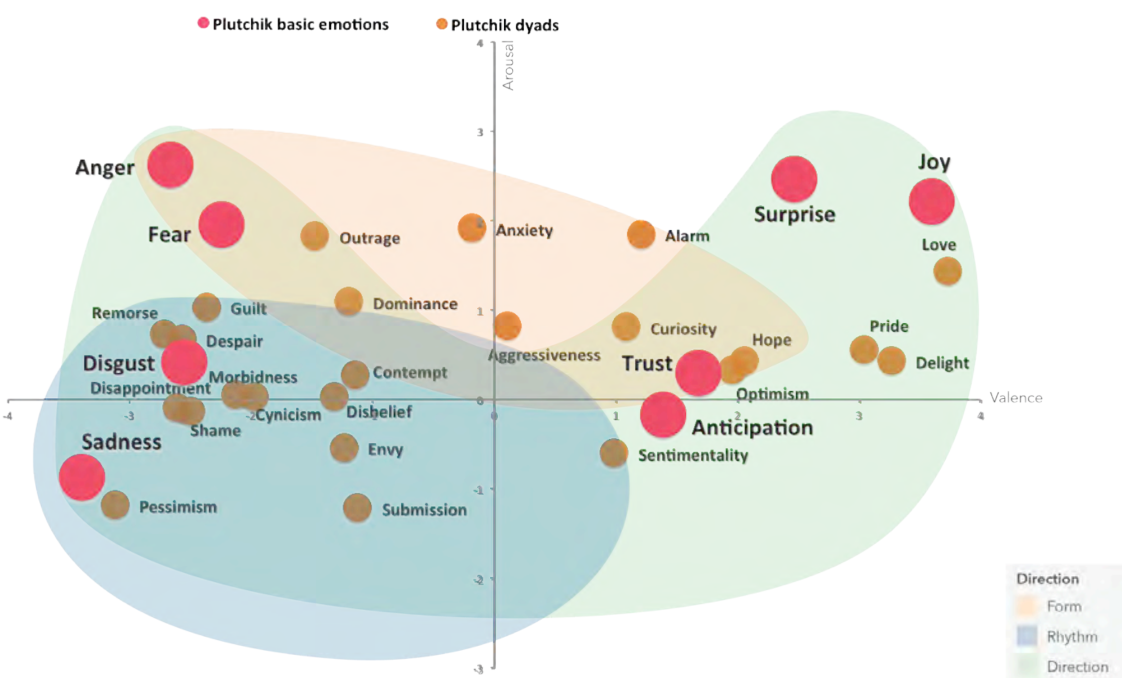

Figure 22. Summary of the relative importance of the form, rhythm and direction design elements

Moving to consider the quantitative design elements contained in the emotive form design taxonomy, my hypothesis for creating a quantified version of these combined designs is to calculate a weighted average of the quantitative emotive design taxonomy values of the primary emotions related to that word. Scaling factors related to the importance of that design element to the primary emotion are included in this average calculation to ensure the attributes important in conveying the associated primary emotions are prominent in the resulting form. I propose values for these scaling factors to be between 0 and 1, where values of 0.7 and above define the design element as very important in conveying that emotion, around 0.5 as somewhat important, and below 0.2 as unimportant.

To continue the example discussed above, the distributions of the hypothesized quantified scaling factors for the varying importance of the different design variables for fear and surprise are shown in Figures 23 and 24 below. These diagrams show how the qualitative findings of which design elements are most important for which primary emotion discussed earlier have been translated into quantitative scaling factors, i.e. for surprise the design variables related to direction have higher scaling factors (0.9) than those for the form design elements (less than 0.7), and for fear most of the direction and form design elements have high (0.9) scaling factors. (Scaling factor diagrams for the other six primary emotions are included in Appendix 7.2.6.)

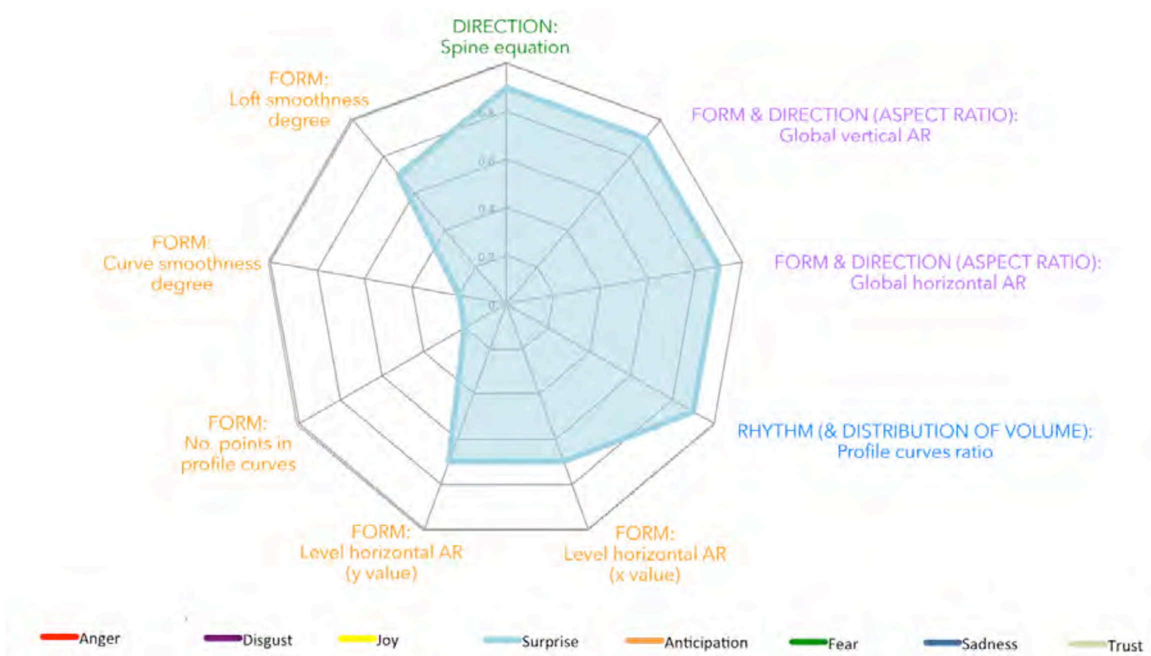

Figure 23. Detailed breakdown of scaling factors for the design elements in surprise

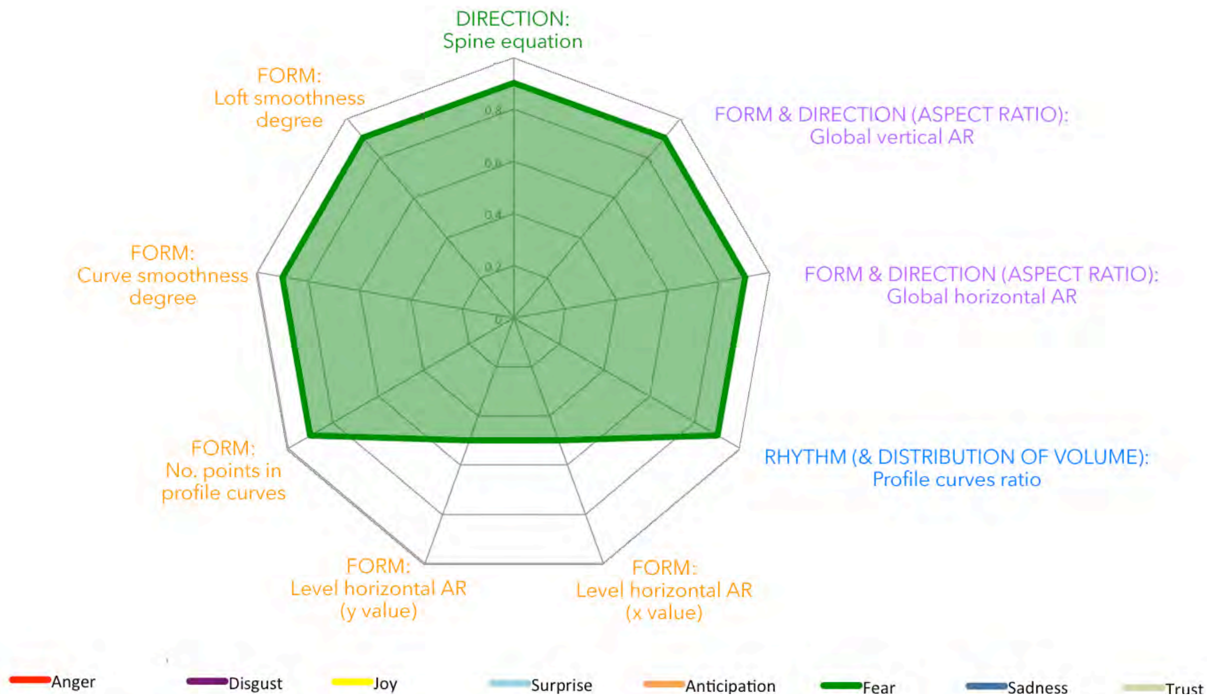

Figure 24. Detailed breakdown of scaling factors for the design elements in the primary emotion fear

Using these scaling factors with the quantitative emotive design variables defined above, the calculation to find the combined average of these design elements is shown below:

$$\textit{Combined emotion design element} = \left[\left(\textit{Primary emotion design element 1} \times \textit{Primary emotion design element 1 scaling factor} \times \textit{Ratio of primary emotion 1 present} \right) + \left(\textit{Primary emotion design element 2} \times \textit{Primary emotion design element 2 scaling factor} \times \textit{Ratio of primary emotion 2 present} \right) + \ldots \right] \Big/ \textit{Sum of design element scaling factors}$$

Continuing the same example of combining the design elements of fear and surprise to create an design representing 'alarm', Table 4 below demonstrates how this equation can be used to calculate scaled combinations of design elements such as the number of points in a profile curve, or the curve smoothness degree.

Primary emotions	**Form design elements**			
	No. points in curve	**No. points in curve scaling factor**	**Curve smoothness degree**	**Curve smoothness degree scaling factor**
Surprise	10	0.2	2	0.2
Fear	7	0.9	1	0.9
Alarm (= Fear + Surprise)	**No. points in curve (combined)** = [(10 x 0.2) + (7 x 0.9)] / (0.2 + 0.9) **= 8** (rounded to whole no.)		**Curve smoothness degree (combined)** = [(2 x 0.2) + (1 x 0.9)] / (0.2 + 0.9) **= 1** (rounded to whole no.)	

Table 4. Example of calculation to find scaled average of combine primary emotion design elements

Using Poffenberger's studies as a starting set of scaling factors (using the values associated to high, medium and low design element importance described above), experiments were carried out using the quantitative design element taxonomy to create forms that represented combinations of emotions based on Plutchik's dyads. The scaling factors for each of the design elements for the primary emotions were modified until the combined design elements, and resulting forms, suitably matched the qualitative emotive design taxonomy diagrams shown earlier. A detailed breakdown of my final hypothesis for the scaling factors for the quantitative design element variable for each of the primary emotions is shown in Appendix 7.2.6.

Bringing all of the above research and experimentation together, designs for any emotive word can be created. Using this hypothesis for a quantified emotive design taxonomy, scaling factors combination strategy, and Rhino Python 3D modeling computational construction approach, I created 32 designs for Plutchik's eight primary emotions and 24 dyads for further evaluation (to be discussed in the next chapters). These are shown plotted onto their associated values on the valence-arousal circumplex in Figure 25. These forms provide a testable output for my hypothesis, and will be evaluated in user studies discussed later in this thesis.

The various form, rhythm and direction design elements associated to these 32 initial designs (initially applied to the design of a bottle, discussed further in the following chapter) were evaluated to ensure that their distribution over the valence-arousal circumplex did indeed resemble the original qualitative emotive design taxonomy discussed earlier. These diagrams and a summary of the distribution of design elements are included in Appendix 7.2.7.

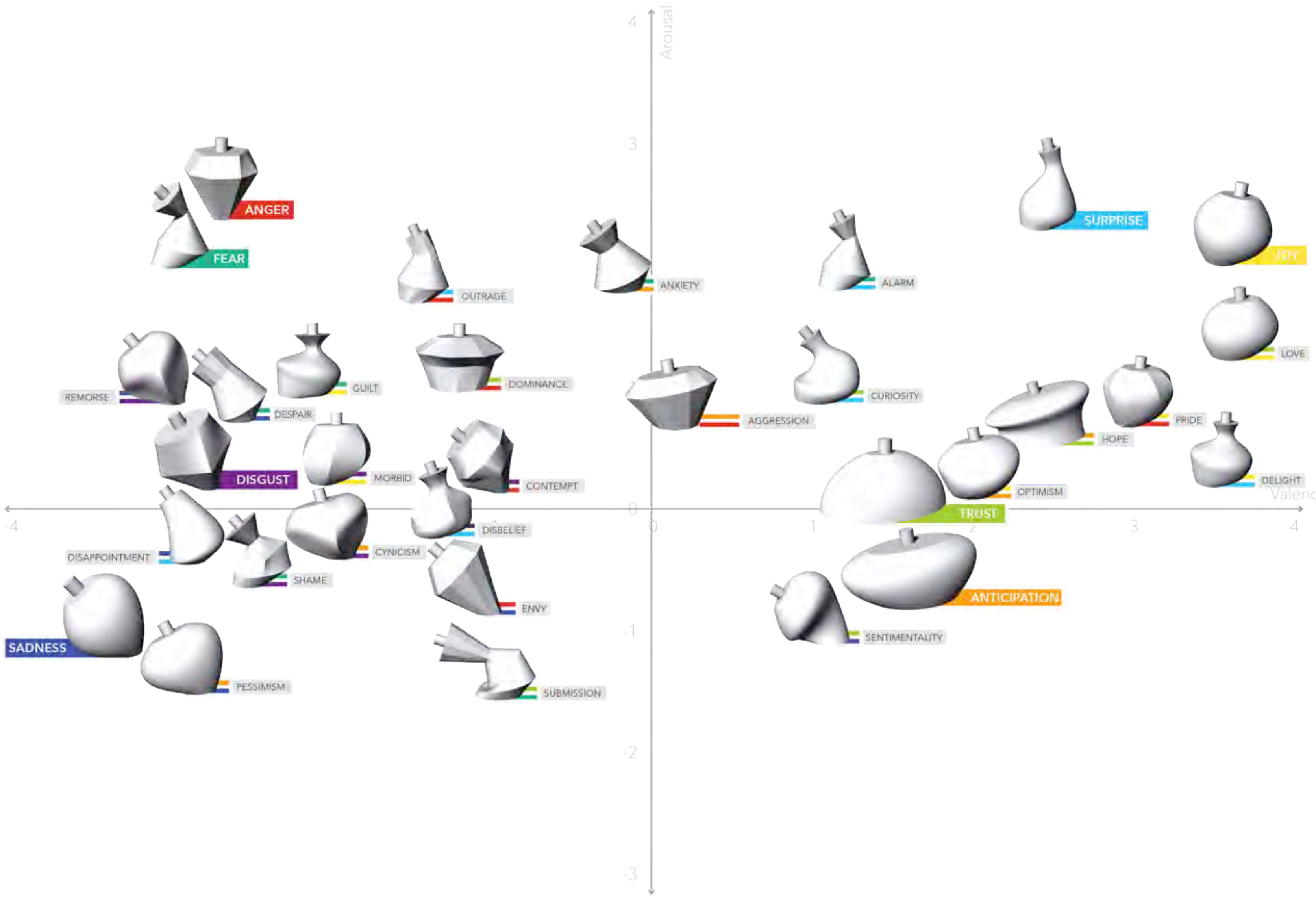

Figure 25. Final forms for Plutchik's primary emotions and dyads plotted on the valence-arousal circumplex (hypothetical positions)

Chapter 4
A CAD Tool for Emotive Design

This quantified emotive design taxonomy and strategy for how the primary emotion design elements can be combined to create shapes representative of many different emotional adjectives can form the basis of an emotive semantically-driven CAD tool. In the following pages, I present the integration of this taxonomy into the Rhino 3D modeling software to create this emotive design CAD tool – the EmotiveModeler.

4.1. The EmotiveModeler

The EmotiveModeler CAD tool uses the Rhino Python plugin to integrate the emotive design taxonomy into computational procedures to create three-dimensional designs with emotive forms related to a word input by the user. This plugin enables custom user-interfaces (UIs) to be generated allowing users to simply interact with the software, while in the background there is much computation carried out to execute the more complex functions required to create the complex 3D forms in Rhino.

The quantitative emotive design taxonomy is a generalizable rule set which can be applied to any shapes to transform them into various designs. The commonality of these design rules allow the taxonomy to be applied to many different underlying forms, therefore enabling many different objects to be transformed within the EmotiveModeler CAD tool. Initially, these underlying objects will be simple forms that can also be referred to in the Python program that can be selected by the users of the CAD tool. These simple objects must allow the emotive shape grammars that the EmotiveModeler CAD tool can apply to the original shape to add extra meaning - the aforementioned 'functional kinesthetic value' - and not just modify the aesthetic style of the object. Therefore, the initial base objects that are included in the EmotiveModeler CAD tool were selected from classes of objects that have a relatively simple functionality and wide range of design possibilities for expressive meaning. These objects were also chosen to have specific existing symbolic meanings to encourage a certain type of emotive information to be expressed through their forms. The three classes of objects that can be designed in this first iteration of the EmotiveModeler are:

- Evocative containers - the somewhat simple functional design of bottles and dining ware can allow the synesthetic relationships between form, flavor and scent to express the character of the object's contents.
- Abstract jewelry - the more aesthetic non-functional nature of jewelry makes it appropriate for representation of very abstract emotional experiences, e.g. dreams, poems or stories.
- Depictive mementos - the often publicly displayable design of commemorative objects for the completion of a certain event, e.g. a trophy, can afford the actionable display of more concrete data relating to our behavior over a certain period, e.g. quantified self data relating to our fitness

A database that defines the underlying features of the selected object – such as overall geometry, contextual features e.g. lids, and ergonomic considerations - refers to the 'neutral' design elements defined above to generate a simple base design of the object from which users can start to modify with words of their choice. The program then uses the quantitative emotive design taxonomy and emotion combination strategy defined above to calculate the design elements related to the input word, and generate the appropriate form in the Rhino 3D modeling software.

In this thesis, the bottle design will be focused on to test the perception of emotive versions of this object created using the quantitative emotive design taxonomy. An example of the neutral base design for the bottle object is shown in Figure 26 below.

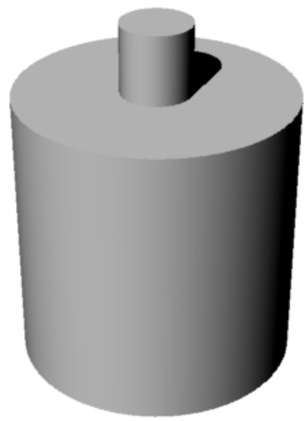

Figure 26. Example of base model for bottle object

4.1.1. Architecture

Users interact with the program through a UI that interacts with the underlying Python program, and through this, the Rhino 3D modeling functions. First, users select a new base object to design - in this first prototype of the software the objects available for the users to choose are a bottle, jewelry or a totem. This loads the neutral object form into the Rhino 3D modeling space. Users are then able to enter words (one or many) into the UI, transforming the shape of the object to that with design elements representative of the emotions related to the input word.

The NRC Lexicon provides only a guideline for the relationship of words to Plutchik's primary emotions, however. Despite part of the aim of this thesis being to create a 'shortcut' for designers – novice and expert – in translating early abstract ideas into more concrete designs, the EmotiveModeler does not intent to replace the precious creativity instilled in the human designer [34]. Yes this thesis is looking to find possible universals in our perception to the meaning of forms, but I also want to embrace the variability and unreliability in the design process that often results in unexpected outcomes. A computer is good at quick rational processes like iterating form design, but the human brain is better at abstract associations. I agree with Broadbent in that "the most effective design process will utilize the brain and the computer, working together in a symbiotic relationship, each acting in ways which are not accessible to the other" [5].

To create this 'creative conversation' between the designer and the EmotiveModeler, a feedback loop is integrated into the system. This enables the users to adjust the emotive design elements related to specific words to match their individual perceptions. Once the user is happy with the design they have created, they are able to render an animation of it and save it as a Rhino 3D model for further manipulation if they desire.

A diagram of the EmotiveModeler program architecture is shown in Figure 27, and a description of some of the key aspects are listed below:

Word-emotion dictionaries:

- *Word_emotion_dictionary.json* – a system dictionary that related adjectives to carrying proportions of the 8 primary emotions (based on the NRC Lexicon [37]).
- *User_emotion_dictionary.json* – a user dictionary that records user modifications or combinations of words and their related proportions of the eight primary emotions.
- The user dictionary is searched for a matching word (and related primary emotions) when a user inputs a word into the UI before the system dictionary so as to find the most up-to-date emotion relationships.

Design element dictionaries and programs:

- *Object_features.json* – a dictionary that defines the global geometry and other features of the base objects.
- *Emotion_taxonomy.json* – a system dictionary containing the primary emotion taxonomy that details the design elements for each of the eight primary emotions (see Table 3).
- *Emotion_taxonomy_scaling_factors.json* – a system dictionary containing the primary emotion scaling factors for each of the 8 primary emotions, needed for when the primary emotion design elements are combined together.
- *Emotion_class.py* - a Python program that reads in the breakdown of primary emotions in the adjective input by the user in the UI from the system and user dictionaries, and then calculates and returns the design elements of the combined emotions from the primary emotion taxonomy and scaling factor dictionaries (using the combining equation described earlier).

UI programs:

- *Emotive_script_ui.py* – a Python program which draws the UI controls and executes the functions in the rest of program when the UI controls are manipulated (uses Meier_UI_utility.py library [35])

Rhino drawing programs:

- *Construction_functions.py* – a Python program which calculates the geometry of the form from the geometric representation calculated in the Emotion_class program, and then draws the spine, curves, surfaces and finishing features of the object in the Rhino 3D modeling space

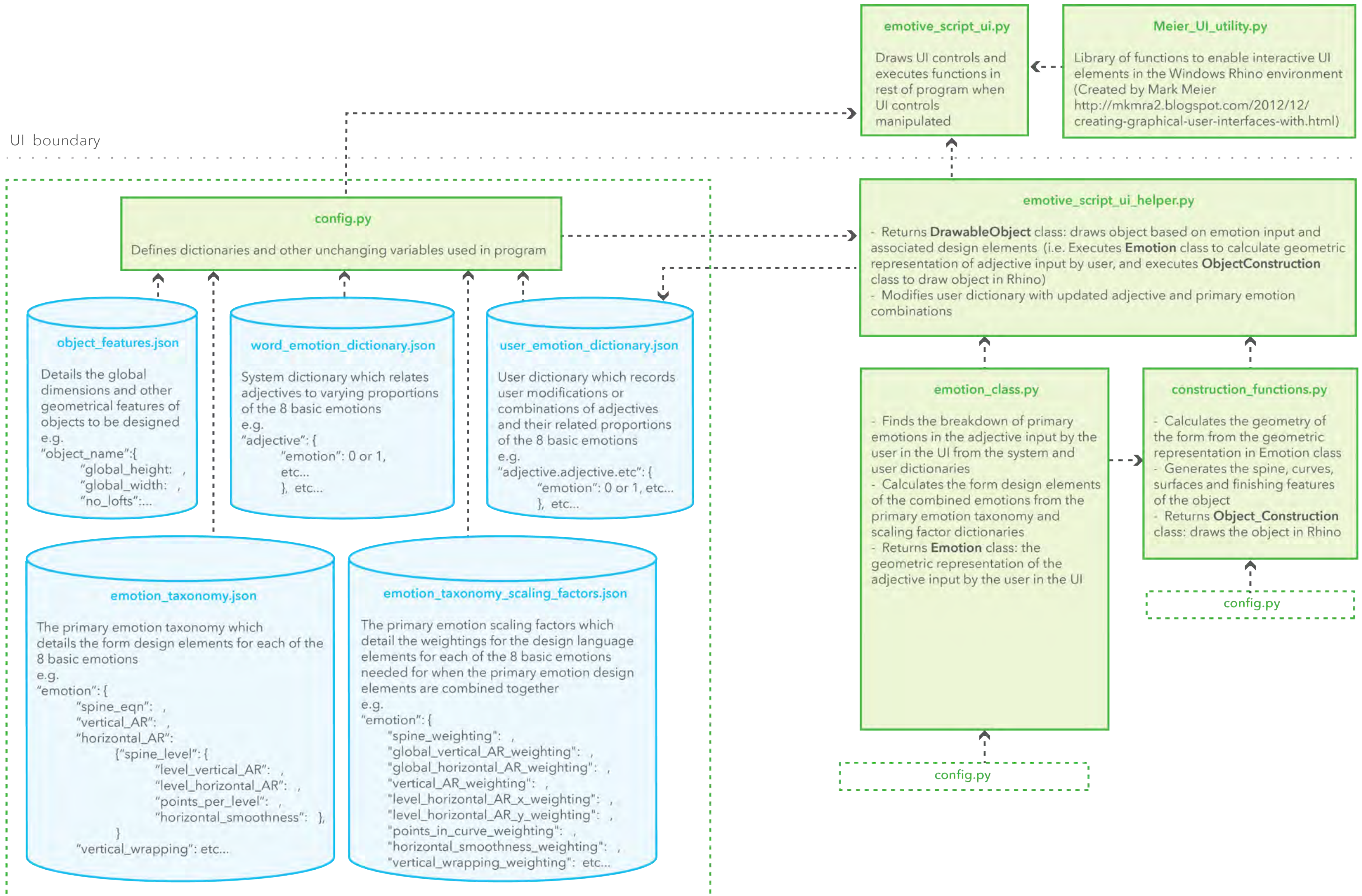

Figure 27. Program architecture for the EmotiveModeler CAD tool

4.1.2. UI

Figure 28 below shows the UI for the EmotiveModeler CAD tool.

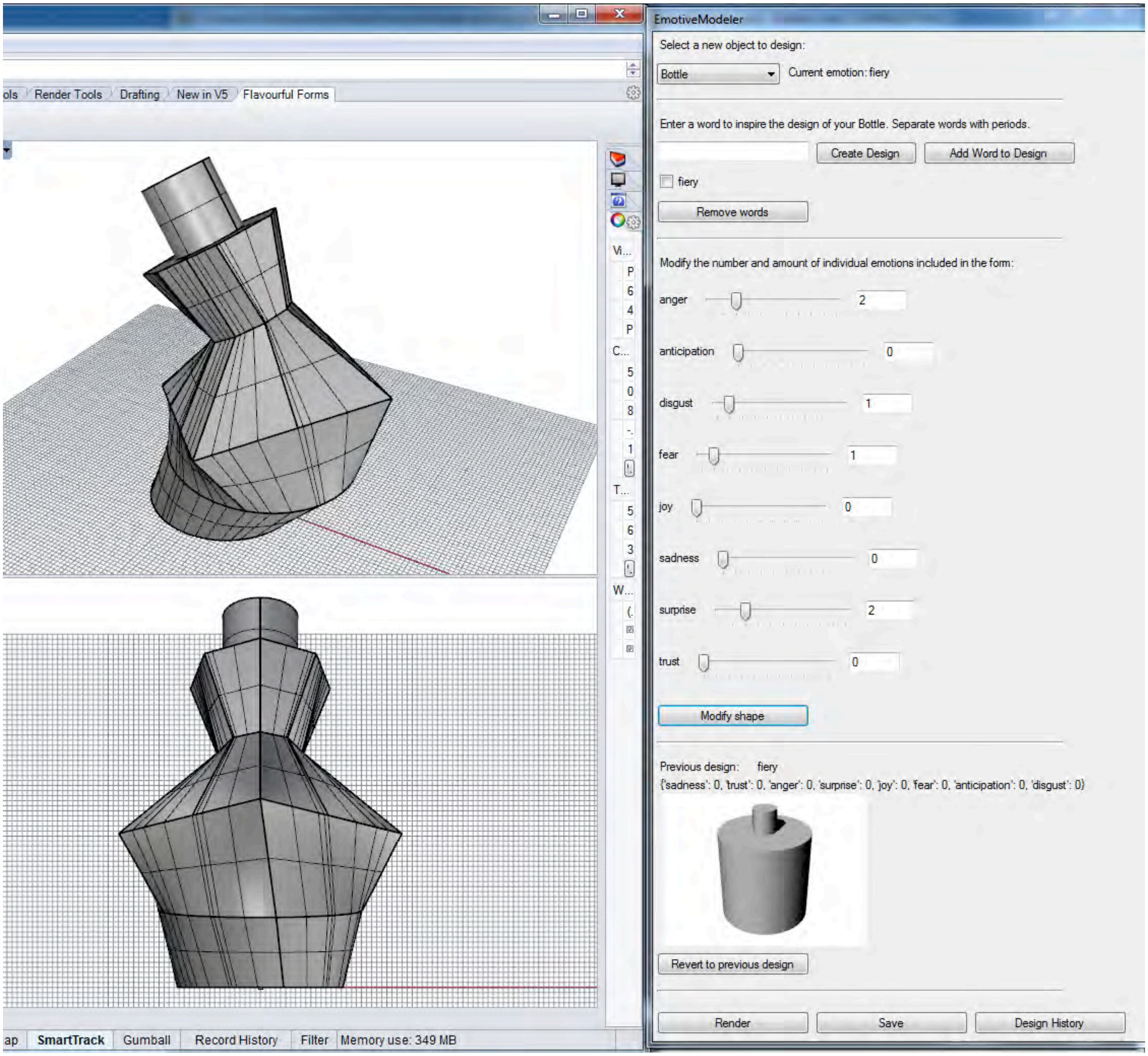

Figure 28. User interface for the EmotiveModeler CAD tool

The features that users can employ in creating emotive designs include:

- Choosing a base object to design from a selection of three objects (the chosen object with neutral design elements is then drawn in the Rhino 3D modeling space)
- **Entering a word to inspire the design of the object selected:**
    - A totally new design based on the entered word can be created by clicking ***'Create Design'***.
    - Words can be added to an existing design by clicking ***'Add Word to Design'*** – this function adds the emotions related to the additional word to the existing breakdown of primary emotions, and recalculates the design elements of this combination of words
    - A ***string of words*** can be entered by separating them with a period (a similar calculation is carried out as above to find the breakdown of primary emotions for the string of combined words)
    - Any words that are currently related to the drawn object are shown in check boxes under the text entry field. Any of these words can be disassociated from the object design by checking the words to be removed and clicking ***'Remove words'***.
    - There are over 14000 possible words in the dictionary, but if a word is not found – through it not being in the dictionary or mistyped – an error message is given and the neutral object form drawn
- **Modifying the number and amount of primary emotions related to the words associated to the form:**
    - The breakdown of primary emotions related to the words entered by the user are shown by the position of sliders for each of the primary emotions.
    - Users can include, remove, increase or decrease the amount of a certain primary emotion related to a specific word or combination of words by ***manipulating these sliders***, and redesign the object to reflect these modified associated emotions by clicking ***'Modify shape'***. (These modified emotion breakdown values are re-entered into the emotion_class program and the associated design elements recalculated.)
    - This modified breakdown of primary emotions is then entered into the user_emotion_dictionary dictionary as a new entry for that specific word or combination of words.
- **Undo-ing, rendering and saving the designs:**
    - The user can revert to the word and emotion breakdown of their previous design shown in the small image by clicking on the ***'Revert to previous design'*** button
    - The user can also render an animation of their design and save the model as a Rhino 3D file for further modification by using the ***'Render'*** and ***'Save'*** buttons

Chapter 5
Evaluating the EmotiveModeler

In order to evaluate if my hypothesis for a quantified emotive design taxonomy is correct and to assess the effectiveness of the EmotiveModeler CAD tool in the design process, three sets of user studies were carried out.

The first user study – the taxonomy study – used a computer-based survey and in-person interview to gain an understanding of the participants emotive perception of the 32 Plutchik primary emotion and dyad designs generated by the EmotiveModeler (shown in Figure 25). The results from this study will enable the quantified emotive design taxonomy to be modified to create a more accurate representation of the emotive perception of forms.

The second user study – the design study – allowed participants to use the EmotiveModeler CAD tool to create emotive bottle designs. Evaluating the resulting designs and overall reaction to the CAD tool will enable adjustments to the user interface to be made, and the overall design experience improved.

The third user study – the feedback study – used a similar procedure to the initial taxonomy study (a computer-based survey and in-person interview), but this time tested the resulting designs from the design study. The results from this study will enable me to assess how accurately the emotive meaning of the forms designed by the participants in the design study could be communicated to others.

In the following pages, I describe these three user studies, and discuss the results and any modifications to the taxonomy and CAD tool.

5.1. Evaluating the Emotive Design Language Taxonomy

To test the validity of the quantified emotive design framework, 33 test objects representing Plutchik's primary emotions and dyads (and an additional form representing the neutral base object) were generated using the EmotiveModeler. The base object of a bottle was chosen as the object to initially test the taxonomy (Figure 25 shows the forms used in this study). Animated representations of these test objects were also created so that they could be viewed on a screen.

Using an in-person computer based survey, 30 participants of ranging design abilities were asked to evaluate the animations of these test forms for their perceived valence, arousal, and emotional associations. Following this, participants were then asked to similarly evaluate 3D printed versions of the test objects, so that any difference in their perception could be evaluated. A more detailed description of the study procedure is included in Appendix 7.2.8.

The aim of this study was to see how close participants' perception of the emotive shapes was to the quantified emotive design taxonomy hypothesis, and improve the taxonomy based on the results.

5.1.1. Taxonomy Study Results and Discussion

As described above, the data collected in this study included 30 responses (n = 30) for the valence and arousal values for both the animated representations and 3D printed bottle designs. It is these values that are used in this analysis section to evaluate how effective the quantitative emotive design taxonomy and scaling factors are at creating shapes that communicate the emotive meaning of words through form. The aim of this analysis is to discover what modifications need to be made to the taxonomy and scaling factors so that the forms generated from the EmotiveModeler more closely represent the perception of the general public.

Averages of the valence and arousal responses for each bottle design for both the animations and 3D printed bottle designs were calculated in order to compare these to the hypothetical valence and arousal values. Despite the majority of participants commenting that viewing the 3D printed forms made a difference in their perceptions, statistical power calculations [10] show that 31 out of the 33 total designs have averages for the 2D animations and 3D printed design datasets with significant similarities (i.e. greater than or equal to 80% statistical power). Participants therefore rated both the 2D animated and 3D printed versions of the bottle designs similarly in terms of valence and arousal.

Due to this similarity in responses, the data set collected for the animated test objects will be focused on for analysis in this thesis. This allows for a more direct comparison to the two-dimensional emotive shape research that the quantitative emotive taxonomy is built from, and also to the digital representations of the 3D models that users see on the computer screen when interacting with in the EmotiveModeler CAD tool itself.

There also appeared to be little difference between the perception of these forms for the experts and non-experts (29 out of the 33 emotive forms tested were perceived to have significantly similar valence and arousal values for the expert and non-expert design participants). There was a slightly bigger difference in the valence and arousal perceptions between the male or female participants - only 22 out of the 33 emotive forms tested were perceived to have significantly similar valence and arousal values for the male and female participants. The forms for envy, remorse, sadness, hope and pessimism were perceived to have higher energy by the female participants, and those for optimism and disappointment to be more positive. Despite these slight differences there do not appear to be any groups that show extreme anomalies in the data, so the data set for all 30 participants will be considered as a whole in this evaluation.

In this analysis, I will first look in detail at the positioning of the individual emotive bottle forms on the valence-arousal circumplex compared to their hypothesized valence and arousal values. The overall distribution of design elements on the valence-arousal circumplex will then be evaluated, and any differences from the hypothesis analysed.

As a simple first comparison of the animated test object responses to the hypothesis, the valence and arousal values for the primary emotion forms is shown in Figure 29. Statistical power calculations were also carried out to compare the average valence and arousal responses for the animated test objects to the hypothetical values. Figures 30 to 32 shows these valence and arousal values for the complete set of test objects evaluated in the study. The forms with valence and arousal values that are significantly similar to the hypothesis are highlighted in purple and orange respectively (the positions of the other 14 designs are also faintly shown). A detailed breakdown of the test objects which are significantly similar is shown in Table 5 below. A summary of the valence and arousal values and emotion words most commonly associated to each form by the participants are also shown in Appendices 7.2.9 and 7.2.10.

Test objects with significantly similar valence	**Test objects with significantly similar arousal**
Positive valence hypothesis: Trust, surprise, anticipation, aggression, optimism, pride, hope, curiosity, (neutral)	*High arousal hypothesis:* Trust, fear, aggression, remorse, hope, despair, guilt, dominance, anxiety, outrage, delight, (neutral)
Negative valence hypothesis: Fear, disgust, contempt, submission, envy, disbelief, dominance, anxiety, shame, outrage	*Low arousal hypothesis:* Sadness, anticipation, optimism, disappointment, cynic, disbelief, sentimentality
Test objects with significantly similar valence & arousal	
Negative valence, high arousal hypothesis: Fear, outrage	*Positive valence, high arousal hypothesis:* Anxiety, dominance, disbelief, aggression
Negative valence, low arousal hypothesis: (Neutral)	*Positive valence, low arousal hypothesis:* Anticipation, Trust, optimism, hope

Table 5. Breakdown of the test objects showing significantly similar valence and arousal values

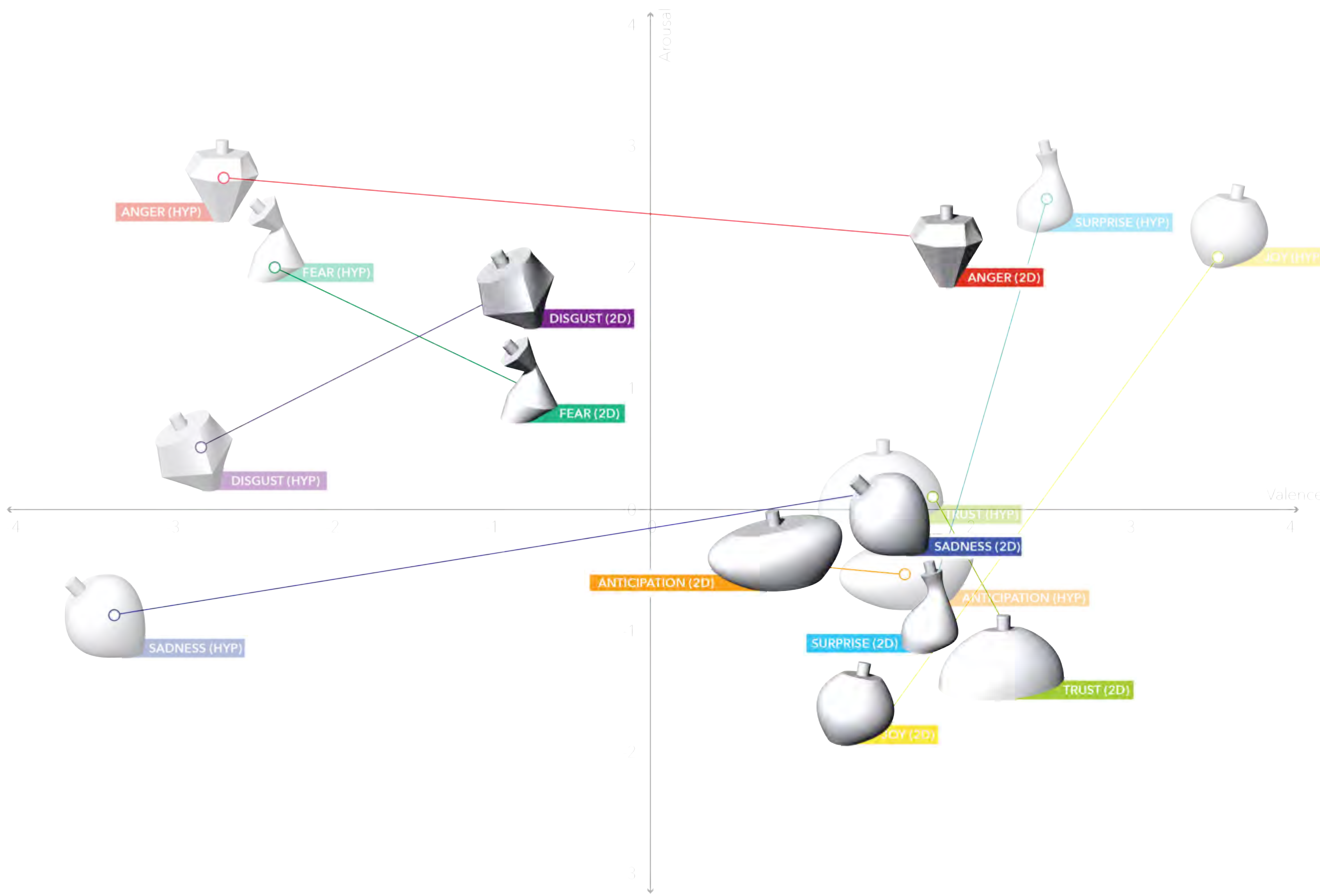

Figure 29. Primary emotion designs plotted on valence-arousal circumplex (hypothesis – faded - and animated test object responses – not faded; lines connect similar primary emotion shapes between hypothetical and animated test object response values)

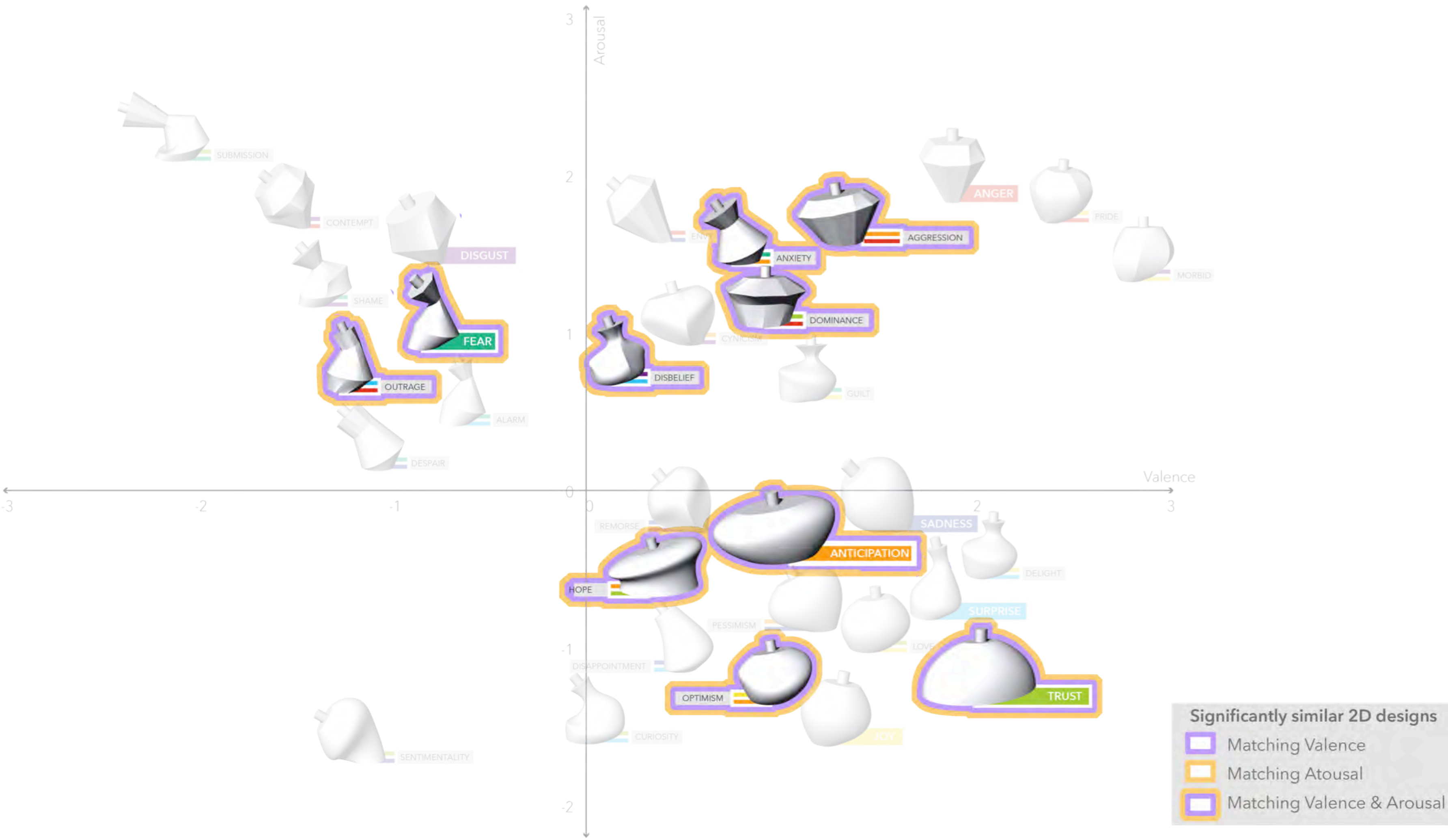

Figure 30. Plutchik primary emotions and dyads forms tested in taxonomy study plotted on the valence-arousal circumplex (animated test object response values) with forms with both valence and arousal values significantly similar to the hypothesis highlighted in purple and orange (forms with neither valence or arousal significantly similar are shown faintly)

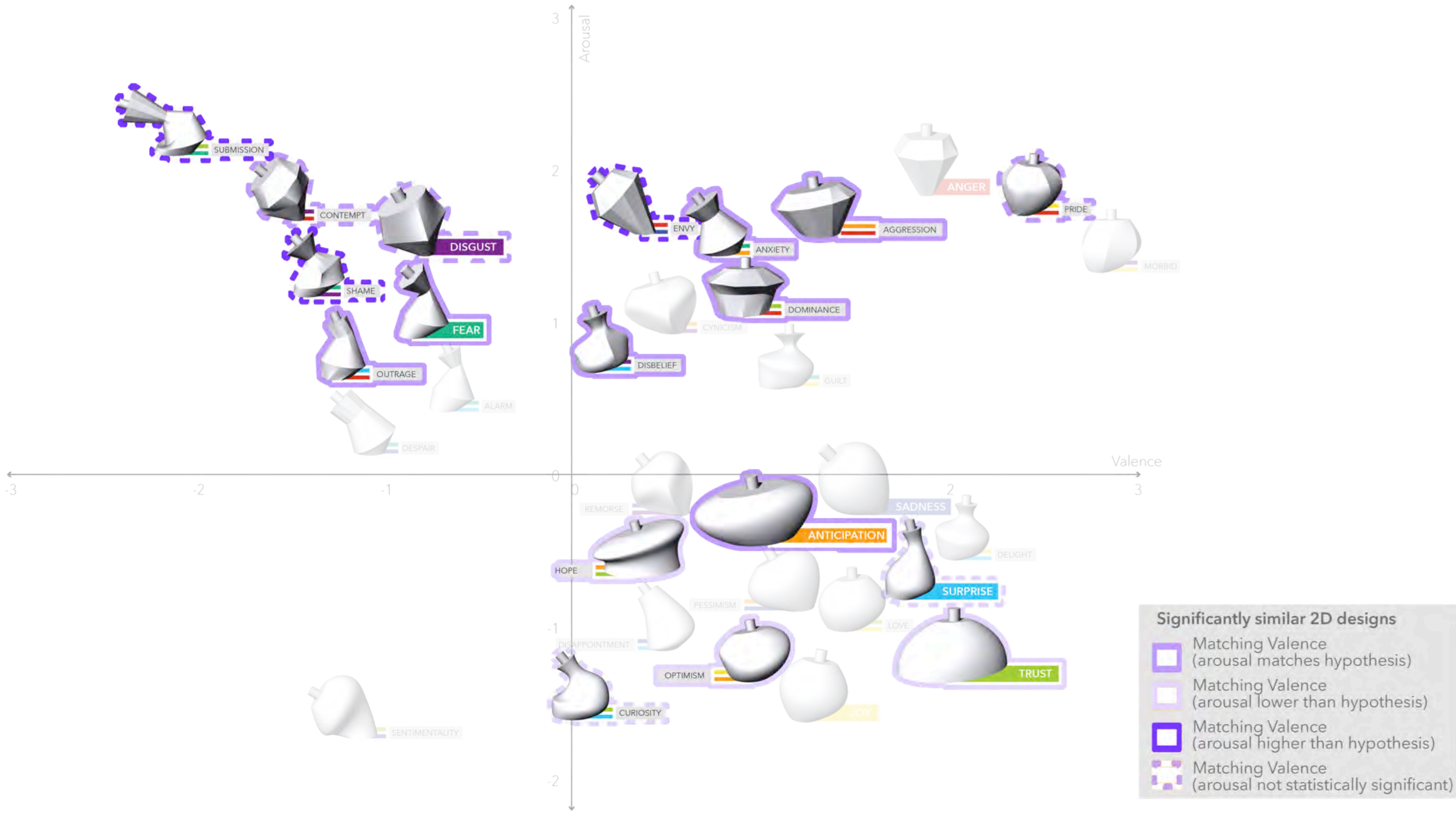

Figure 31. Plutchik primary emotions and dyads forms tested in taxonomy study plotted on the valence-arousal circumplex (animated test object response values) with forms with only valence values significantly similar to the hypothesis highlighted in:
light purple for lower arousal than hypothesis, medium purple for matching arousal, dark purple for higher arousal,
and dotted line indicating that the arousal data collected was not statistically significant
(forms with neither valence or arousal significantly similar are shown faintly)

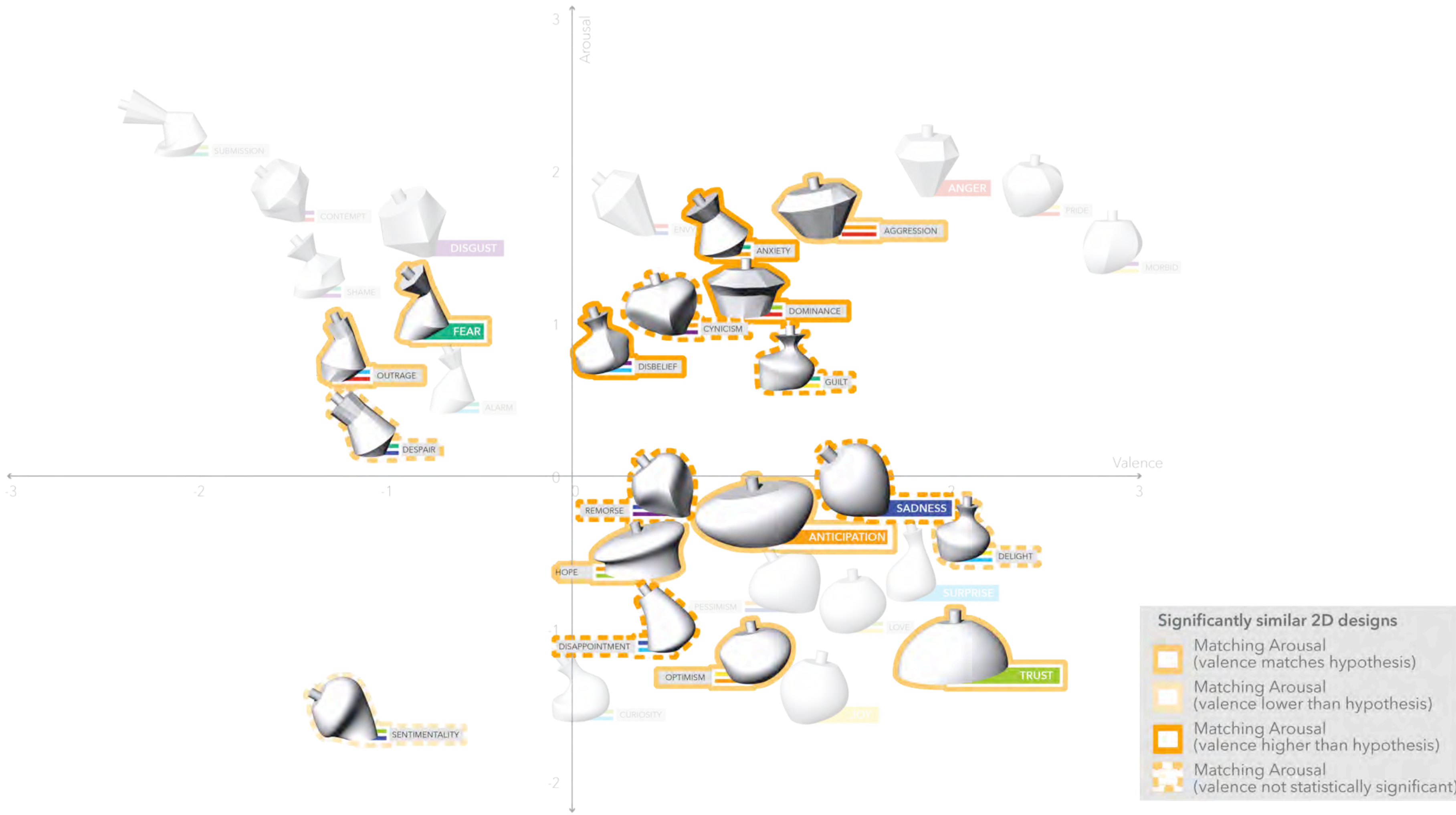

Figure 32. Plutchik primary emotions and dyads forms tested in taxonomy study plotted on the valence-arousal circumplex (animated test object response values) with forms with only arousal values significantly similar to the hypothesis highlighted in: light orange for lower valence than hypothesis, medium orange for matching valance, dark orange for higher valance, and dotted line indicating that the valance data collected was not statistically significant (forms with neither valence or arousal significantly similar are shown faintly)

From these diagrams it can be seen that the primary emotion designs for ***trust, anticipation and fear have valence and arousal values that are significantly similar to the hypothesis***. The emotions associated to these forms were generally correct as well. The design for ***sadness has a similar arousal value***, but is much more positive than the hypothesis value. The emotions related to this design agree with this, as joy and anticipation were associated to this form, as well as sadness. ***Surprise and disgust have similar valence values to the hypothesis***, but surprise has a much lower arousal value, and disgust a slightly higher one. The emotions related to these forms also confirm this: surprise was associated to lower arousal emotions such as trust and joy, and disgust was perceived to be higher arousal emotions such as anger and fear. The emotion words surprise and disgust were, in fact, rarely associated to any of the emotive designs – the emotive design that was most associated with surprise was envious, and despair for disgust.

The ***primary emotions that do not match the hypothesis at all are anger*** - which has a much more positive valence value and slightly lower arousal value - ***and joy*** – that has a slightly less positive valence value and a much lower arousal value. The emotions associated to anger are correspondingly more positive, including surprise, joy and trust. Some of the participants correctly associated the emotion for joy, but less positive lower arousal emotions such as trust were also included.

Considering the complete set of test objects evaluated, an additional ***eight of the emotive dyad designs have both valence and arousal values significantly similar to the hypothesis***. The positive low-energy emotions that match, such as optimism and hope, also have the correct primary emotions associated to them, e.g. anticipation and joy for optimism. However, the matching positive high-energy emotions, such as aggression and anxiety, only have one out of the two related primary emotions matching, e.g. for aggression more positive emotions such as surprise were associated, rather than the expected emotion anger. Conversely, the negative high-energy emotions that match, such as outrage, have more negative emotions associated with them, e.g. fear and disgust are associated with outrage in addition to anger, rather than the expected emotion surprise.

Significant similarities to the valence hypothesis values were found for another seven of the dyad designs. The forms with matching negative valence values generally had higher arousal values than expected, e.g. submission and shame were predicted to have negative arousal values. Conversely, the forms with matching positive valence values generally had lower arousal values than expected, e.g. surprise and curiosity were predicted to have positive arousal values. The related emotions correlated less well with these designs. As might be expected, designs with arousal values higher than expected did not have lower energy emotions associated with them, and vice versa, e.g. trust was not associated to submission along with its dyadic emotion fear, and the lower energy emotions anticipation and sadness were related to curiosity instead of surprise and trust.

Significant similarities to the arousal hypothesis values were found for another different set of seven of the dyad designs. There is less correlation in the positioning of these forms around the valence-arousal circumplex. Of the designs which have much more positive valence values – cynicism, guilt, remorse, and disappointment – the related emotions were much more positive also, e.g. guilt was correctly related to high arousal emotions such as joy, but not negative valence emotions such as fear; remorse was correctly related to low arousal emotions such as sadness but also included positive emotions such as joy rather than the correctly paired emotion disgust.

From this analysis, it can be seen that ***the primary emotions perceived to be related to the emotive designs generally have valence and/or arousal values close to those perceived for the individual forms themselves***. For example, a test object perceived to be in the positive high-energy quadrant of the circumplex will more likely have positive high-energy primary emotions associated to it, i.e. joy and surprise.

This raises an interesting dilemma when considering the earlier discussion about the 'chimeric' forms that could result from the combination of diverse primary emotions. In these forms where primary emotions from both positive and negative valences or high and low arousals are combined, e.g. negative fear and positive surprise creating 'alarm', my hypothesized combination strategy aimed to incorporate the most important design features required to convey each of the emotions. However, the finding described just above shows that this strategy did not create forms perceived as being related to diverse emotions – the dissimilar design elements when combined in a single form might have been too blended together to differentiate the different emotional meanings. The above analysis shows that there is some correlation between the valence-arousal values perceived for the form of the emotive designs and those expected for the *overall* combined-emotion word (obtained from the ANEW database described earlier), e.g. alarm. However, the emotions considered to be related to the forms generally only fall into only one of the quadrants of the circumplex, neglecting the diversity of emotions expected to be related to some words. In summary it appears that, ***whilst the forms generated by the EmotiveModeler correspond in some extent to the hypothesized valence-arousal values, the 'chimeric' forms containing a more diverse selection of primary emotions did not distinguish these meanings effectively***.

In the following analysis, I will focus on examining the design elements of these emotive design forms and their general positioning on the valence-arousal circumplex in comparison to the expected values for the *overall* emotive word. I will address this issue of more clearly conveying diverse selections of primary emotions through 'chimeric' forms in a later chapter.

Similar analysis of the design elements of the test objects was carried out, and diagrams summarizing the various form, rhythm and direction design elements for the valence-arousal positioning perceived by the participants for the 2D animations are shown in Figures 33 to 36. Diagrams summarizing the various form, rhythm and direction design elements for the valence-arousal positioning for the 3D printed test objects are shown in Appendix 7.2.11.

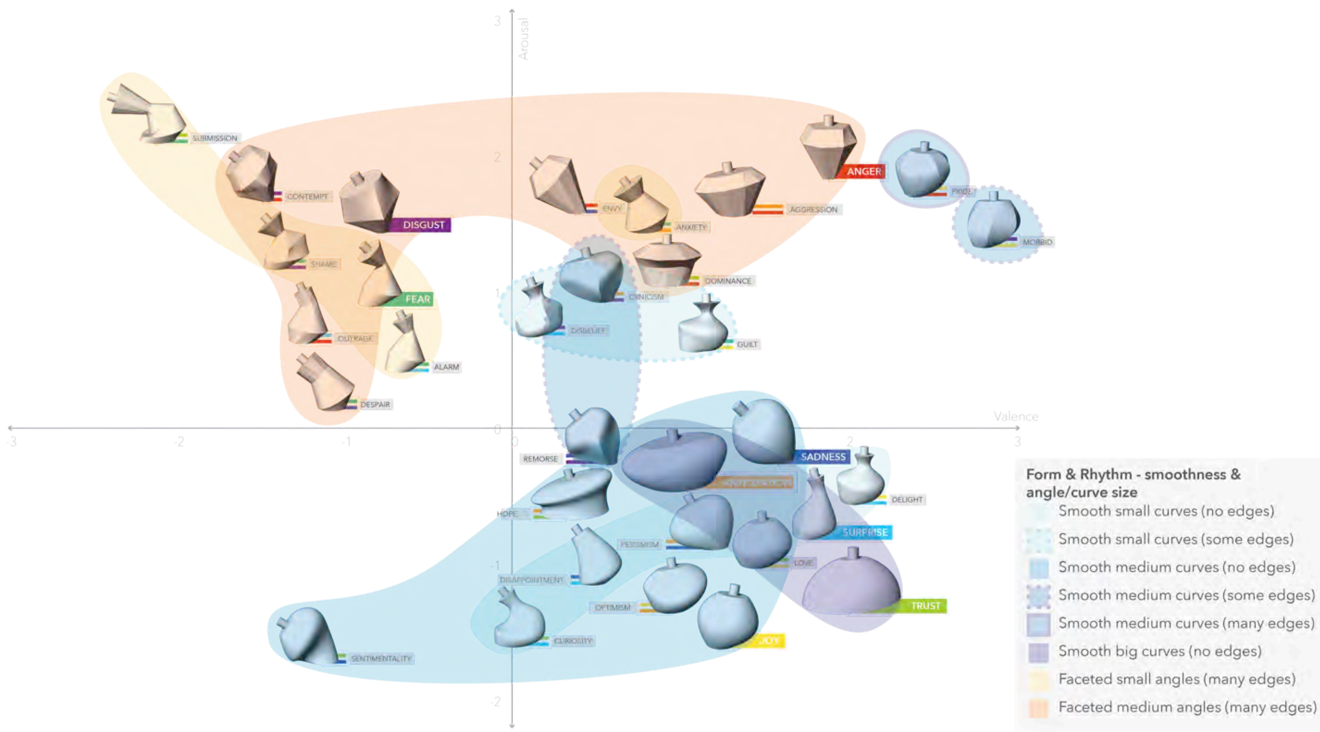

Figure 33. Form and rhythm design elements for the responses for the animations of the test objects

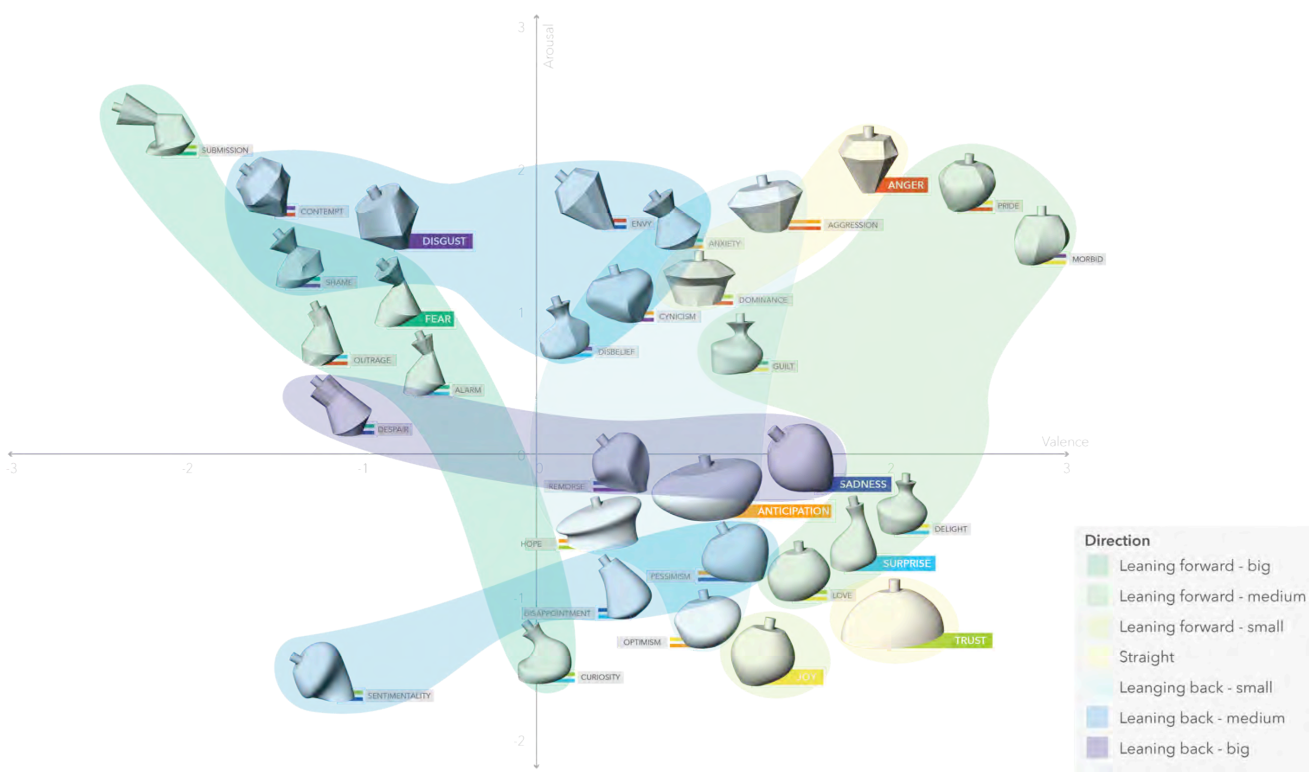

Figure 34. Directional design elements for the responses for the animations of the test objects

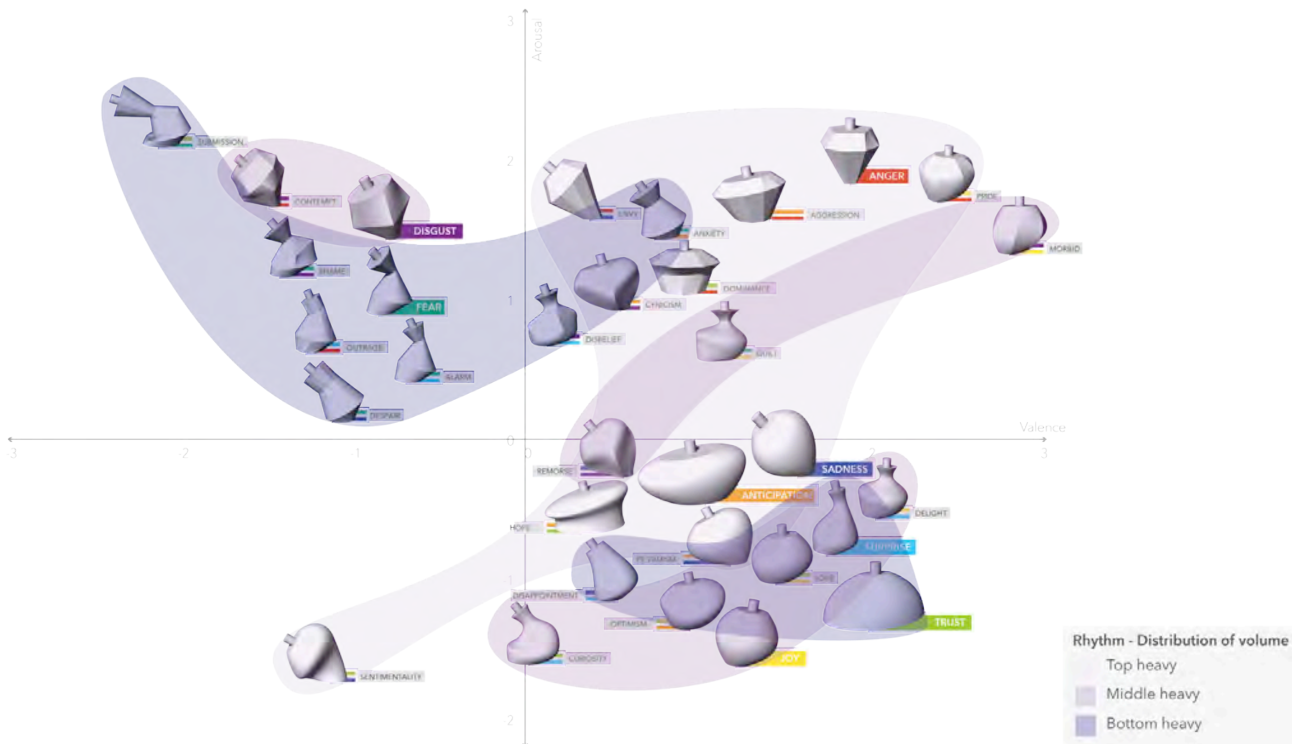

Figure 35. Direction-based rhythm design elements (i.e. the distribution of volume) for the responses for the animations of the test objects

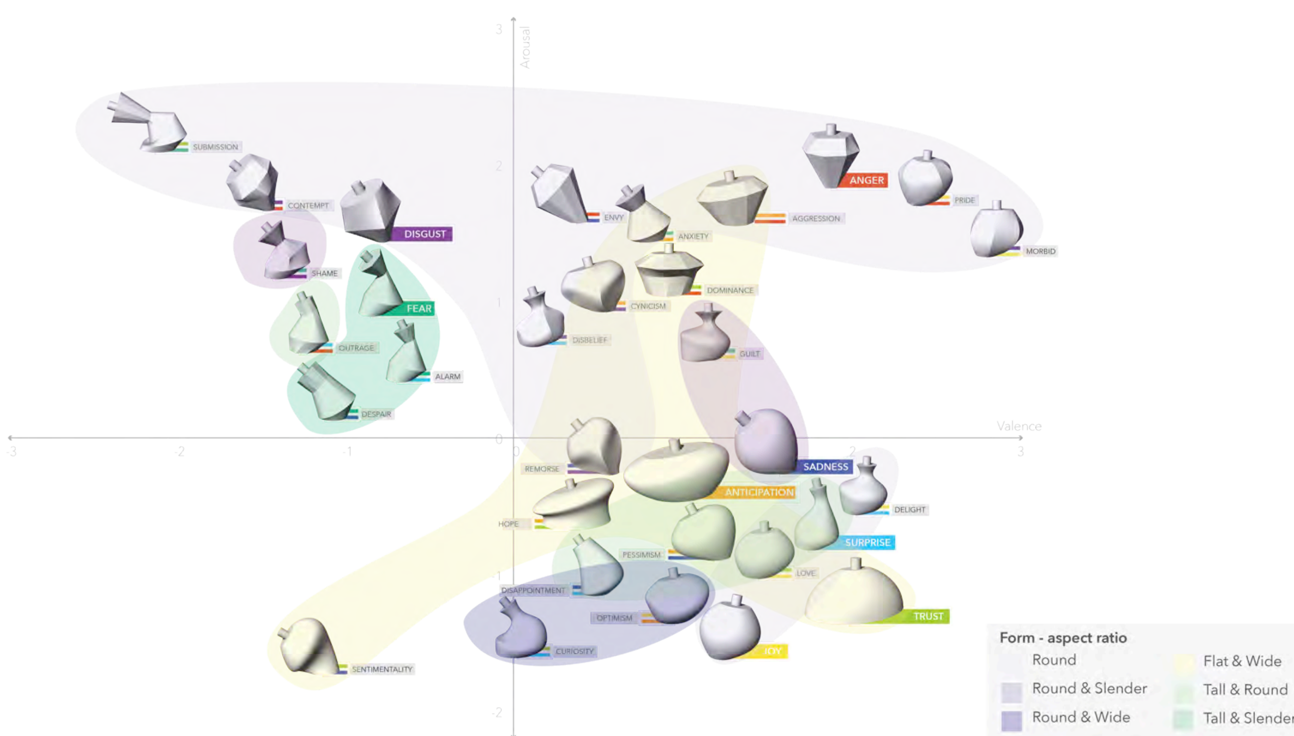

Figure 36. Direction-based form design elements (i.e. the aspect ratio) for the responses for the animations of the test objects

A summary of new distribution of design elements for the four quadrants of the valence-arousal circumplex is shown below:

- ***Positive, low-energy emotions*** are represented by bottom, middle or top-heavy forms with smooth small, medium and big curves leaning slightly forwards or backwards, and with aspect ratios ranging from flat and wide to tall and round
- ***Positive, high-energy emotions*** are represented by middle or top-heavy forms with slightly edged or angular small or medium curves leaning straight, slightly forwards or backwards, and with flat round and wide aspect ratios
- ***Negative, high-energy emotions*** are represented by bottom-heavy forms with angular small and medium curves leaning heavily forwards or backwards, and with tall, round and slender aspect ratios
- ***Negative, low-energy emotions*** are represented by top-heavy forms with smooth medium curves leaning heavily backwards, and with flat and wide aspect ratios

In general, responses to the forms created from the quantitative emotive design taxonomy show that the valence is mostly represented by the rhythm, direction and distribution of volume design elements (positive valence = top-heavy, medium or big curves, leaning straight or slightly forwards or backwards; negative valence = bottom-heavy, small or medium curves, leaning heavily forwards or backwards), and the arousal is represented by the form and aspect ratio design elements (low arousal = smooth, wide and flat forms; high arousal = angular, tall and slender forms).

Comparing the responses to the animated test objects to the hypothetical distribution of design elements that the quantitative emotive design taxonomy was based on, it can be seen that ***there are very few differences from the hypothesis for the negative-valence low-energy or the negative-valence high-energy quadrants of the circumplex***. As hypothesized, forms associated with negative high-energy emotions had irregular angular, heavily leaning forms, and forms for negative low-energy emotions generally had smoother, heavily leaning forms. The participants responses showed this trend more extremely than the hypothesis however, with ***higher arousal values allocated to angular forms than expected*** as participants considered these more jagged unsymmetrical forms to be ‘chaotic’ and ‘uneasy’. Another difference noticed was that for the negative-valence low-energy quadrant the curve size, i.e. the rhythm design element, was slightly smaller than the hypothesis. Qualitative feedback during the interview section of the study found that forms with small curves heavily leaning over were ‘constricted’ and ‘hunched’, suggesting that ***a smaller curve size combined with a strong leaning angle is perceived as negative whatever the arousal***. These forms were generally considered to be less functional as bottles as they were found to be harder to grasp and pour the contents from. This more utilitarian consideration of the designs may have also affected the participants’ emotional perception of the forms due to the lack of satisfaction they imagined when using the object. Correlating with these findings, participants generally related more negative emotions to these tightly curved, strongly leaning-over forms.

For the positive-valence areas of the circumplex, there was less correlation with the hypothesis. The positive-valence high-energy quadrant contained similar rhythm, direction and aspect ratio design elements, i.e. small or medium curves leaning straight, slightly forwards or backwards, and with flat round and wide aspect ratios. However, the designs contained in this area showed much more angular forms, and an opposite distribution of volume, i.e. top-heavy forms, rather than bottom-heavy as predicted. Participants regularly commented that ***angular forms conveyed more energy than expected for both positive and negative valences***, as they appeared 'active' and 'purposeful'. In particular, the ***forms appeared to be positive high-energy if the angular surfaces were more even*** as they seemed more 'fresh' and 'vibrant'. The ***top-heavy character of the forms were also perceived as having an 'uplifting' momentum and 'confidence', and therefore more energy***. This difference in attitude towards angular forms than expected explains the association of fewer low arousal or negative valance emotions with these forms, e.g. no sadness was associated to the test objects envy, and no anger was associated to dominance, pride or aggression.

Responses for the positive-valence low-energy quadrant matched the hypothesis for the form and direction design elements, i.e. smooth slightly leaning forwards or backwards forms, but show a taller aspect ratio than the wide and flat predicted forms. The curve size (rhythm) and distribution of volume design elements do not show a clear outcome in this quadrant, with designs ranging from small to big curves and bottom to top-heavy forms. Overall, most participants considered ***smooth forms to be 'calming' and 'comfortable' therefore positioned them in the positive low-energy quadrant***. In particular, the smoothness of forms with more rounded aspect ratios also appeared to overcome participants' generally negative perception of forms with backwards leaning spines. This correlates with the association of fewer negative primary emotions with these forms, e.g. no disgust was associated to the test objects remorse. These forms were also considered ***lower energy than hypothesized, as the more bottom-heavy forms looked more 'stable', trusting' and 'relaxed'***. This explains why the test objects for surprise or curious confused some participants, as some correctly interpreted the tall slender forms to be higher energy, but others perceived the more bottom-heavy distribution of volume as almost 'melting' therefore lower energy, and therefore related them to primary emotions with lower arousal, i.e. trust and anticipation.

From this analysis of the participants' perception of the forms created using the quantified emotive design taxonomy, the ***key differences with the hypothesis appear to be the distribution of the form, rhythm and volume design elements on the valence-arousal circumplex***. Figures 37 to 39 below show a simplified version of the form, rhythm and distribution of volume positioning for both the hypothesis and 2D responses to highlight these differences.

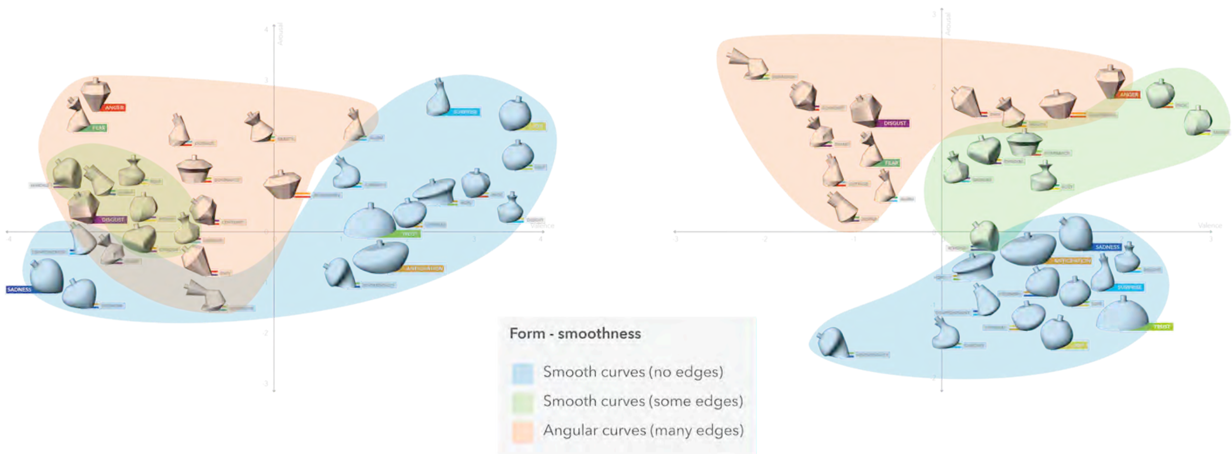

Figure 37. Comparison of the simplified form design elements for the hypothesis and responses for the animated test objects (smooth curves in blue, slightly edged curves in green, angular curves in orange)

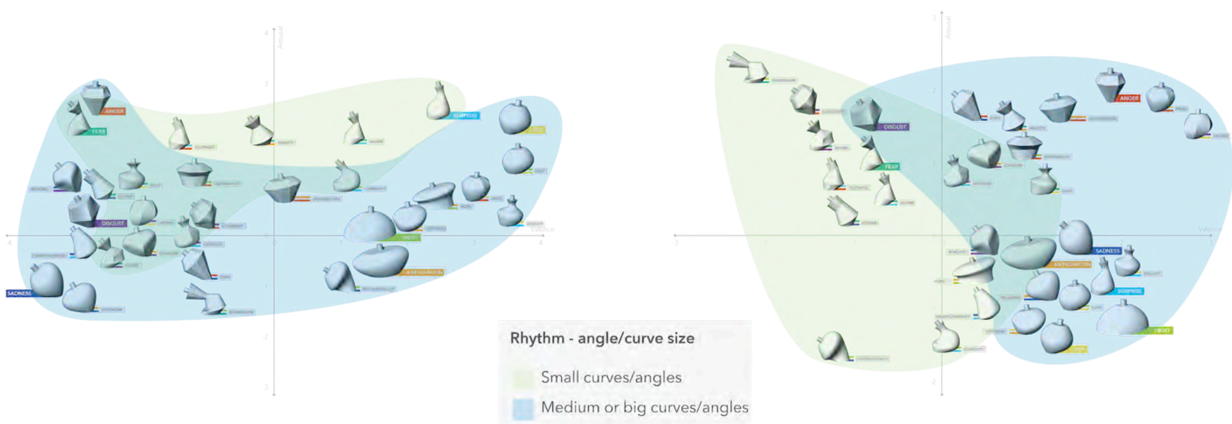

Figure 38. Comparison of the simplified rhythm design elements for the hypothesis and responses for the animated test objects (small curves/angles in green, big or medium curves/angles in blue)

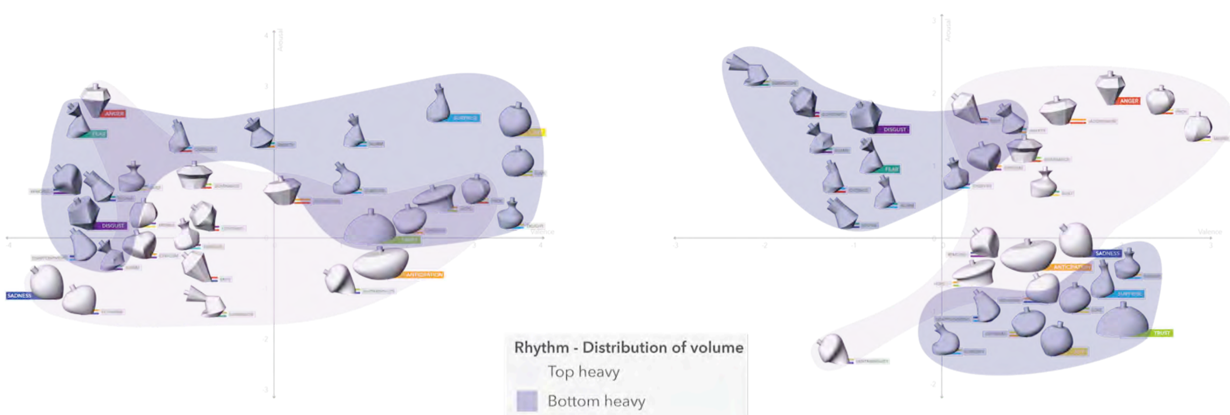

Figure 39. Comparison of the simplified distribution of volume design elements for the hypothesis and responses for the animated test objects (top-heavy in light purple, bottom-heavy in dark purple)

One major difference shown in this analysis of the responses to the animations of the emotive bottle designs, and highlighted in Figure 37 above, shows that ***form i.e. smooth or angular surfaces, is more important for indicating arousal than for valence as originally predicted***. As predicted, surfaces with more edges to tend to show higher arousal, but are not always perceived as a negative valence if the surfaces are more orderly and symmetric. Conversely, Figure 38 shows another major difference in that ***rhythm i.e. size of curves, is correlated more closely to valence than for arousal, as smaller curves were perceived as 'constraining' and therefore more negative***.

The ***distribution of volume design element showed a more complex diagonal division along the dimensions than predicted*** (see Figure 39). As predicted, ***bottom-heavy forms were related to high-arousal emotions but only for negative-valence. For positive-valence, bottom-heavy forms were smoother and lower arousal***. This was because the more angular leaning over bottom-heavy forms were considered to be more 'aggressive' and 'uneasy', therefore negative and higher energy, while the smoother bottom-heavy forms were considered to be more 'relaxed' and 'melting'. The opposite is true for top-heavy forms. Again, the more angular top-heavy forms were considered to be higher energy but also positive as they had 'uplifting' and 'proud' forms. Smoother more leaning over top-heavy forms were perceived as negative-valence low-arousal emotions as they projected an almost anthropomorphic quality of 'slumping' and therefore sadness. The heavily leaning over forms were also considered to be less functional as they would either have difficultly pouring through the hunched neck (if bottom-heavy) or just topple over (if top-heavy), which may have made the participants – either consciously or subconsciously - perceive them to have a more negative emotional valence.

The direction and aspect ratio design elements showed generally the same distribution as predicted in the hypothesis.

As summary of this analysis detailing which design elements hypothesized by the emotive design taxonomy are correct and which are incorrect is shown in Table 6 below (green shading indicates design element is same as hypothesis, red indicates that the responses indicate the hypothesized design element for that particular primary emotion is incorrect). Notes as to how the design element as hypothesized affected the participants' perception as found in this analysis are included in the incorrect design element cells.

Valence-arousal circumplex quadrant	Primary emotions	Form	Rhythm	Direction	Form & Direction: Aspect ratio	Rhythm & Direction: Distribution of volume
Positive, low-energy	Anticipation (matching valence & arousal)	Smooth	Big curves	Leaning slightly backwards	Flat and wide	Top-heavy
	Trust (matching valence & arousal)	Smooth	Big curves	Leaning straight	Flat and wide	Bottom-heavy
Positive, high-energy	Joy (no match)	Smooth (too low-energy)	Medium curves	Leaning slightly forwards	Round	Middle-heavy (too low-energy)
	Surprise (matching valence)	Smooth (too low-energy)	Small curves (slightly too negative)	Leaning forwards	Tall and round	Bottom-heavy (too low-energy)
Negative, high-energy	Fear (matching valence & arousal)	Angular	Small curves	Leaning heavily forwards	Tall and slender	Bottom-heavy
	Anger (no match)	Angular (too positive)	Medium curves (too positive)	Leaning straight (too positive)	Tall and round	Top-heavy (too positive)
	Disgust (matching valence)	Angular	Medium curves (too positive)	Leaning slightly backwards (too high-energy)	Round	Middle-heavy
Negative, low-energy	Sadness (matching arousal)	Smooth	Big curves (too positive)	Leaning heavily backwards	Round and slender	Top-heavy

Table 6. Breakdown of design elements in the qualitative taxonomy for each primary emotion, with green and red highlighting which design elements are correct and incorrect respectively, based on the participants' responses

Using this analysis, the following modifications can be made to the quantified design elements for the primary emotions in the taxonomy to create forms that more closely match the valence and arousal that are perceived by a wider group of people:

- ***Trust, anticipation*** and ***fear*** were considered significantly similar to the hypothetical design taxonomy therefore no modifications are required (i.e. trust is a bottom-heavy wide flat form with smooth big curves leaning straight; anticipation is a top-heavy wide flat form with smooth big curves leaning slightly backwards; and fear is a bottom-heavy tall slender form with angular small curves leaning heavily forwards)
- ***Sadness*** was perceived to have a correct low arousal, therefore the smooth form is correct. However, the symmetry of the form and big curves made it perceived more positively than it should – smaller more irregular curves, leaning backwards more heavily could make the form appear more negative in valence.
- ***Surprise*** was perceived to have correct positive valence, therefore the symmetrical, slightly leaning forward form is correct. However, the smoothness and bottom-heavy design elements of the form gave it an appearance of lower arousal than expected – a more top-heavy form with some slight edges could give the form more energy.
- ***Disgust*** was perceived to have a correct negative valence, therefore the angularity of the form is appropriate. However, smaller curves and slightly more leaning over could increase the negativity and lower the energy perceived in the form to the hypothesized value.
- ***Anger*** was perceived to be too positive due to the even angular surfaces and non-leaning top-heavy distribution of volume. More irregular angular surfaces and more leaning over could give the form a more negative perception.
- ***Joy*** was perceived to be too neutral and too low energy due to the smooth middle-heavy design elements. A more top-heavy form with some slight edges could give the form more positive energy.

The scaling factors can also be modified so that combinations of primary emotions generate forms with design elements suiting the valence-arousal values for the *overall* emotive word:

- When ***positive low-energy and positive high-energy primary emotions are combined***, e.g. anticipation and joy creating optimism, the form and distribution of volume design elements of the positive high-energy primary emotions (joy and surprise) could be weighted more heavily to create top-heavy slightly edged forms.
- When ***positive low-energy and negative low-energy primary emotions are combined***, e.g. trust and sadness creating sentimentality, the direction design element of the negative low-energy primary emotion (sadness) and the aspect ratio of the positive low-energy primary emotions (anticipation and trust) could be weighted more heavily to create slightly unsymmetrical rounded forms.
- When ***positive low-energy and negative high-energy primary emotions are combined***, e.g. anticipation and disgust creating cynicism, the curve smoothness design element – specifically the number of points in the curve – for the negative high-energy emotions could be weighted more heavily to create more irregular angular surfaces. If fear is combined with a positive low-energy primary emotion such as trust, e.g. trust and fear creating submission, and the resulting form is leaning over heavily, the form design element – specifically the loft smoothness – for the positive low-energy emotions should be weighted more heavily to create smoother, lower arousal forms.
- When ***positive high-energy and negative low-energy primary emotions are combined***, e.g. surprise and sadness creating disappointment, the direction design element of the negative low-energy primary emotion (sadness) could be weighted more heavily to create more negative slightly unsymmetrical forms.
- When ***positive high-energy and negative high-energy primary emotions are combined***, e.g. joy and fear creating guilt, the form design elements of the more positive high-energy primary emotions (joy and surprise) and the and direction design elements of the more negative high-energy primary emotions (fear, anger and disgust) could be weighted more heavily to create smooth slightly edged slightly leaning backwards forms that appear slightly positive with high-energy.
- When ***negative high-energy and negative low-energy primary emotions are combined***, e.g. anger and sadness creating envy, the curve smoothness design element – specifically the number of points in the curve – for the negative high-energy emotions could be weighted more heavily to create the more negatively perceived irregular angular surfaces. The direction design element of the negative low-energy primary emotion (sadness) should also be weighted more heavily to make the forms more leaning and unsymmetrical, and therefore lower arousal.

Integrating these modifications into the quantified emotive design taxonomy in future iterations of the software could improve the accuracy of the emotive perception of the forms, and hence make the EmotiveModeler a more effective semantically-driven CAD tool.

5.2. Evaluating the EmotiveModeler CAD Tool

The main goal of evaluating the EmotiveModeler CAD tool is in answering if a CAD tool with a more abstract level of input makes designing meaningful emotive objects easier for designers. Therefore to test the usability of the EmotiveModeler CAD tool, participants were asked to use the CAD tool to design several forms with different emotive meanings, some meaning pre-defined and others of their own choice. The base object used in the design study was again a bottle so that results could be compared to the taxonomy study.

After a short demonstration of the EmotiveModeler CAD tool functions, 8 participants of ranging design and CAD software abilities were asked to design bottles that conveyed the emotions 'delight', 'hope', 'contempt' and 'despair' by entering the words into the UI and manipulating the emotions of the resulting forms. These emotions (included in the Plutchik dyads) were selected as test objects from around the valence-arousal circumplex that the taxonomy study found to have similar valence and arousal perceptions to the hypothesis, and hence could be used as a benchmark in the feedback study. Participants were then asked to design bottles representing words of their own choosing: one single word design, and one multi-word design. The participants were then asked to evaluate their perception of the valence, arousal and associated emotions of the six designs they created, and discuss their experience using the software. Full details of the design study procedure are included in Appendix 7.2.12.

The aim of this study is to test the usability of the EmotiveModeler CAD tool as well as learn more about the accuracy of the taxonomy. The results will be used to understand the effectiveness of the EmotiveModeler CAD tool in helping participants design objects with emotive meanings in their form, and hence improve the user interface of the software.

5.2.1. Design Study Results and Discussion

As described above, bottle designs and related valence and arousal data were collected for 'delight', 'hope', 'contempt' and 'despair' dyad emotions as well as the participants own designs. In this analysis, I will first compare the design elements contained in the dyad emotion bottle designs that the participants created to the hypothesis. I will also evaluate the primary emotions used by the participants in the EmotiveModeler CAD tool to create them to understand how closely they correlate to the hypothesis, and also the participants own expectations for what primary emotions should be related to which forms.

I will then summarize the participants' evaluations of the software itself, and suggest modifications based on these experiences. The aim of this analysis is to add to any modifications required in the quantitative emotive design taxonomy or scaling factors, and consider alterations to the user-interface to make the EmotiveModeler a more intuitive CAD tool for creative emotively shaped designs using words.

I will not evaluate the designs created by participants using their own word choices in this section. These designs, and the evaluations of them by expert designers, will be discussed in section 5.3.

5.2.1.1. Analysis of the resulting designs for the four dyad emotions

The bottle designs for the four dyad emotions created by the participants (as well as the hypothesis design) are plotted on the valence-arousal circumplex using the valence and arousal values selected by the participants in Figure 40 below (designs for 'delight' are shown in yellow, 'hope' in green, 'contempt' in red, and 'despair' in blue). A similar analysis of the the distribution of the design elements for these new designs was carried out, and diagrams summarizing these findings are also shown in Figures 41 to 44.

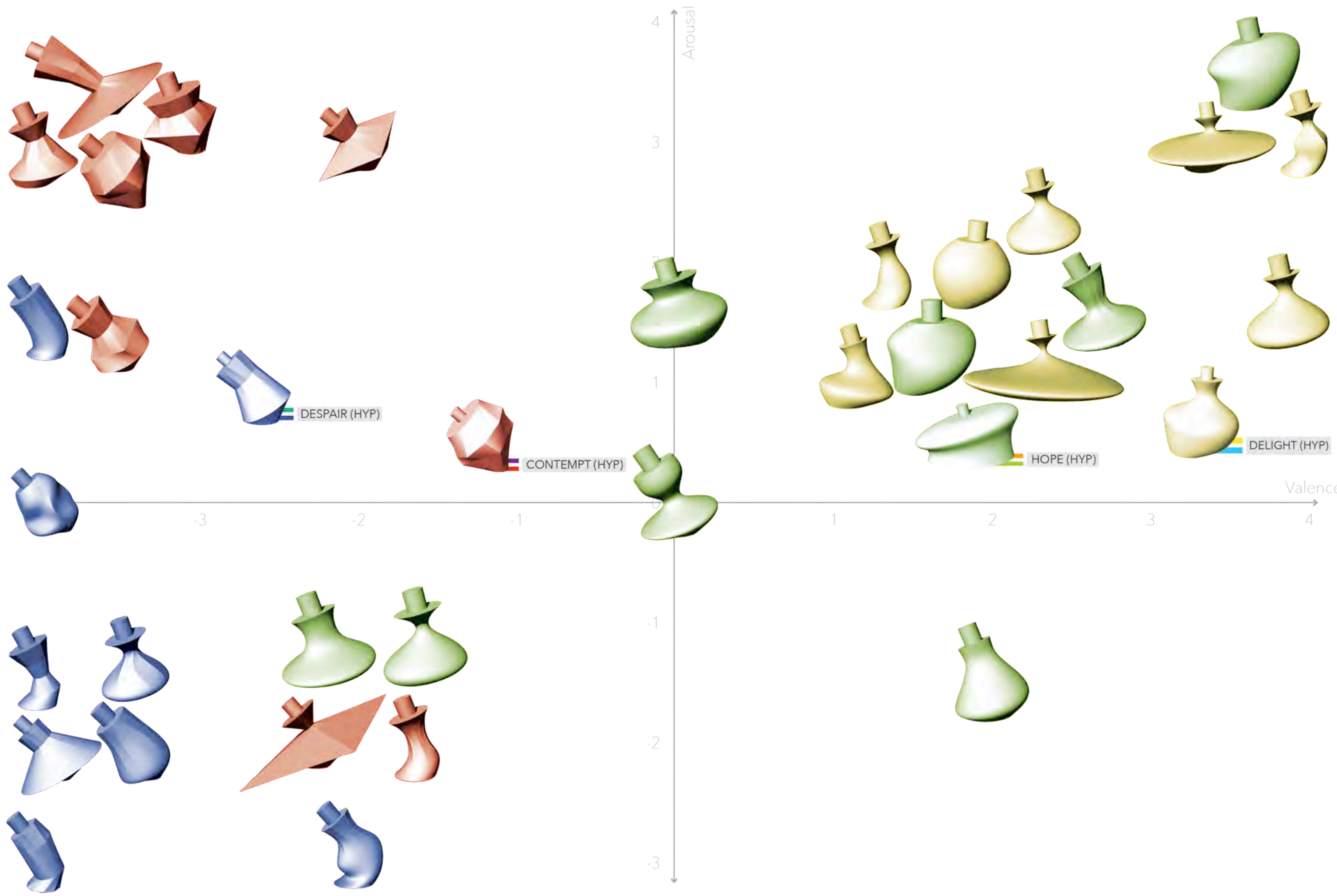

Figure 40. Delight (yellow), hope (green), contempt (red), and despair (blue) forms created on the EmotiveModeler by participants in the design study plotted on the valence-arousal circumplex using valence and arousal values selected by the participants

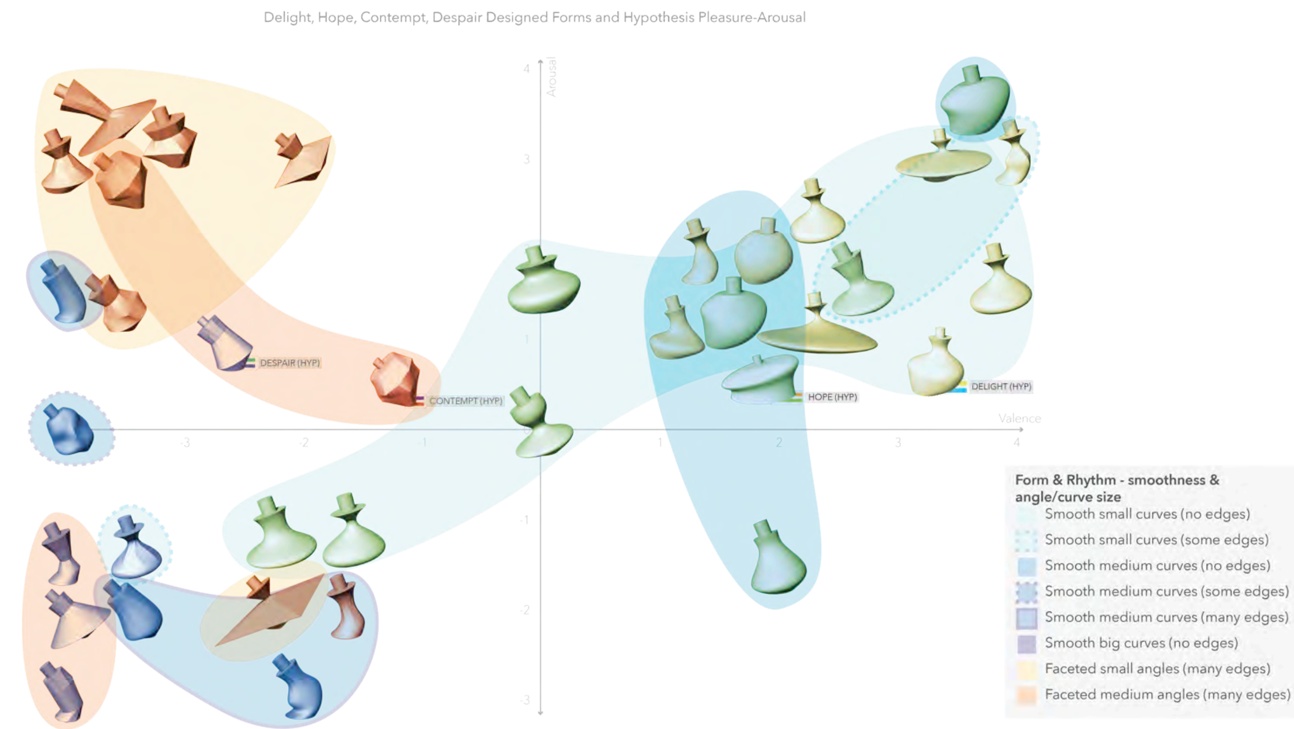

Figure 41. Form and rhythm design elements for the 'delight', 'hope', 'contempt' and 'despair' forms created by the participants

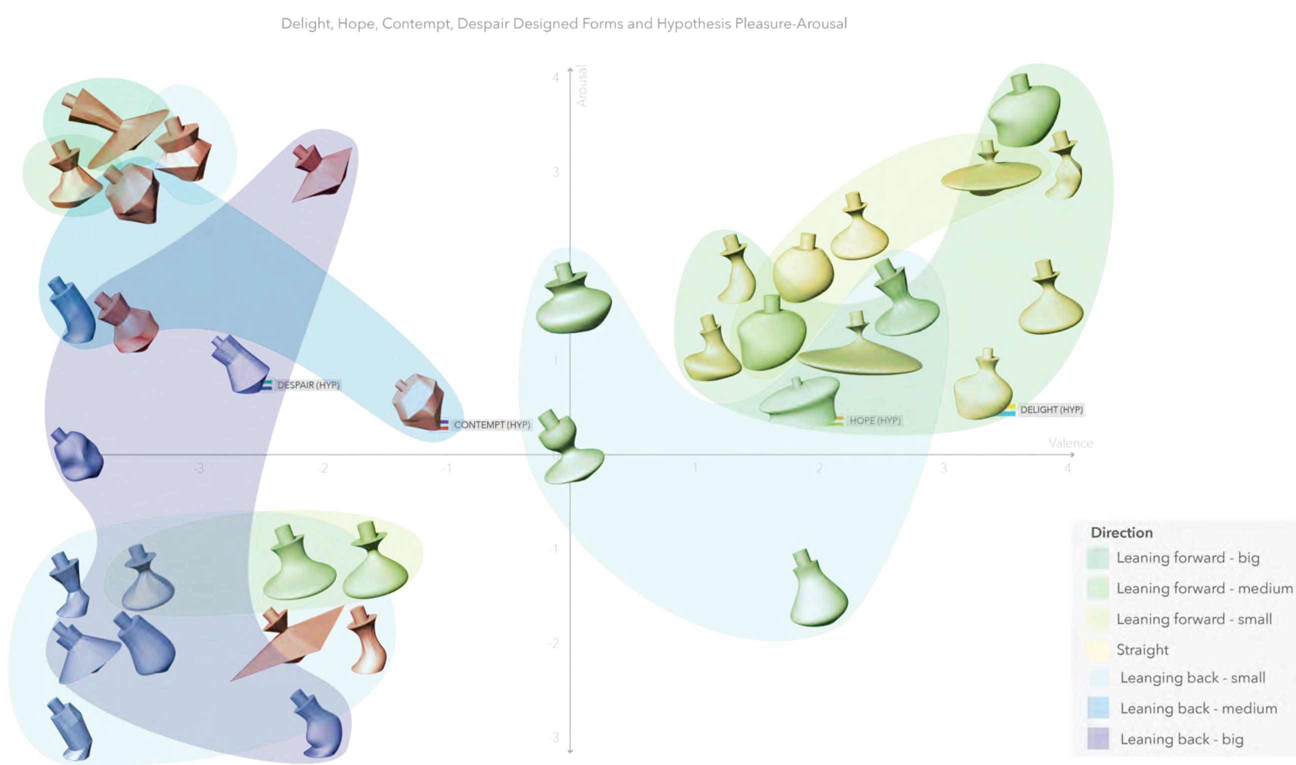

Figure 42. Directional design elements for the responses for the 'delight', 'hope', 'contempt' and 'despair' forms created by the participants

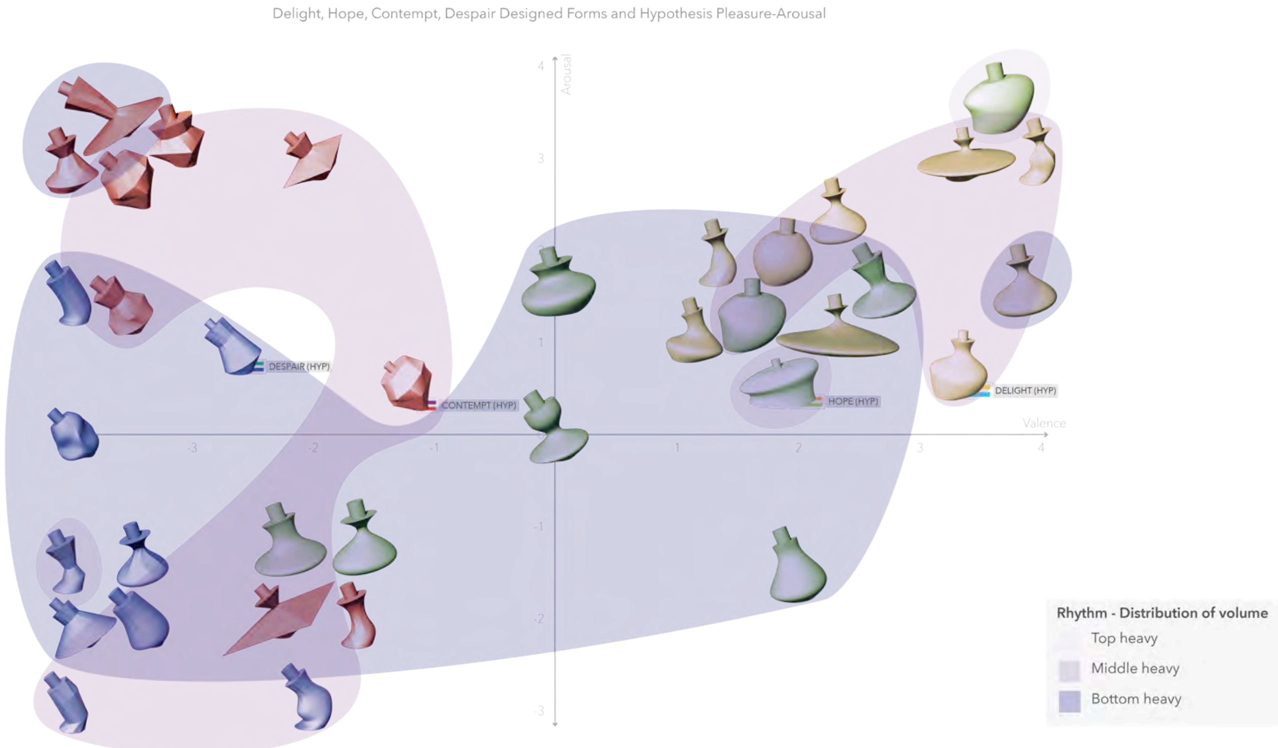

Figure 43. Direction-based rhythm design elements (i.e. the distribution of volume) for the 'delight', 'hope', 'contempt' and 'despair' forms created by the participants

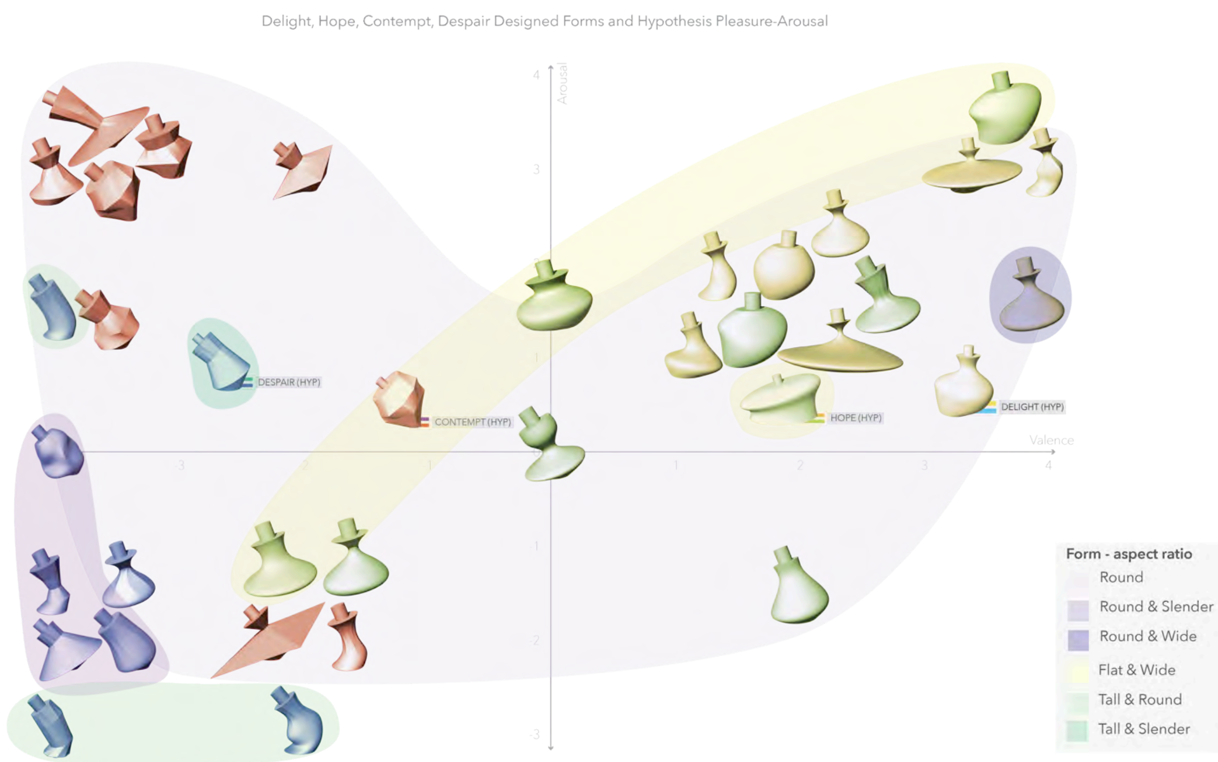

Figure 44. Direction-based form design elements (i.e. the aspect ratio) for the 'delight', 'hope', 'contempt' and 'despair' forms created by the participants

From these diagrams it can be seen that most of the participants' designs and their positioning on the valence-arousal circumplex correspond to the hypothesis. The distribution of the primary emotions used by the participants in creating their designs are also included in Appendix 7.2.13. The design elements for the four dyad bottle designs, and emotions used to create them, are discussed below.

All of the designs created for the emotion ***'delight'*** are positioned in the ***positive high-energy quadrant, matching the hypothesis***. The quantified emotive design taxonomy hypothesizes that the delight design has middle-heavy forms with smooth small curves leaning slightly forward, and with round aspect ratios. In general, the design elements for the participants' designs include ***middle-heavy forms with smooth small and medium curves leaning slightly forward, and with round aspect ratios***. Some designs show more ***bottom-heavy distribution of volume and smaller curves than expected***, but the forms still have smooth curves and uplifting shapes as expected. The primary emotions that the participants used to create these forms are mainly similar to the hypothesis – surprise and joy. Other primary emotions that were used to create the designs included the other positive valence primary emotions - trust and anticipation. The participants generally considered these ***positive high-energy primary emotions to be close to their expectations for which emotions should contribute to the designs they created***.

The designs created for the emotion ***'hope'*** are more scattered around the circumplex than expected. Most of the designs created were considered to be ***positive valence and high arousal, but some were perceived to have more negative valence and lower arousal***. The design elements expected from the hypothesis include top-heavy forms with smooth medium curves leaning slightly backwards, and with wide flat aspect ratios. However, the ***designs created by the participants show very varied design elements - mainly top or bottom-heavy forms with smooth small and medium curves leaning slightly forwards or backwards, and with flat, wide and round aspect ratios***. Despite this variation in the forms created, all of the shapes are still smooth uplifted shapes, with rounded aspect ratios. As expected from the variety of designs created by the participants, a wide range of primary emotions was used to create these forms. Many of the ***participants did indeed use the expected primary emotions – anticipation and trust – but joy was also regularly included, as well as more negative primary emotions such as fear and disgust***. Despite requiring to add these negative emotions to create the desired forms, participants did not consider these negative high-energy primary emotions to be related to their designs. Considering the modifications to the taxonomy suggested earlier, ***amending the design elements for joy and surprise to be more top-heavy and slightly edged may create the expected designs for hope without having to use these negative primary emotions.***

Most of the designs created for the emotion ***'contempt'*** are positioned in the ***negative high-energy quadrant, matching the hypothesis***. The design elements expected for the contempt emotion include middle-heavy forms with angular medium curves leaning backwards and with round aspect ratios. Most of these design elements can be seen in the designs created by the participants – the ***designs created contain bottom and middle-heavy forms with angular small and medium curves leaning backwards, and with round aspect ratios***. Similar irregular angular forms can be seen in all of the designs, however there are ***smaller curves and more extreme angles than expected present as well***. The primary emotions used to create these forms more closely matched the hypothesis for contempt – anger and disgust. All of the participants used these primary emotions in constructing their designs, but the ***other negative primary emotions such as fear and sadness were also often included***. Participants expressed the expectation for more of the primary emotion anger to be included in their designs. Again, building on the learning from the taxonomy study, ***modifying the design elements of anger to have more irregular angular surfaces and be leaning over more might eliminate the need participants found to include fear and sadness*** as primary emotions to provide this.

Again, most of the designs created for the emotion ***'despair'*** are positioned near to the hypothesized design – ***negative valence with a neutral to low arousal***. The design elements expected for the despair emotion included bottom-heavy forms with angular medium curves leaning heavily backwards, and with tall, slender aspect ratios. Most of these design elements are again present in the designs created by the participants - ***mainly bottom-heavy forms with slightly edged or angular medium curves leaning backwards, and with tall, slender and round aspect ratios*** – with the predominant smooth slightly edged leaning backwards forms being very similar to the hypothesis. Again, the hypothesized primary emotions for despair – fear and sadness - were used by all of the participants, but the trend is less clear as many other positive and negative primary emotions were also used in the designs. ***Surprise was often used to create smaller curves*** in the resulting designs. ***Modifying the taxonomy so that sadness has smaller more irregular curves may eliminate the need to include these positive high-energy primary emotions.***

The above discussion of the differences between the hypothesized design elements for the four dyad forms and those included in the forms created by the participants' is summarized in Table 7 below. Earlier comments as to how the design elements created in the forms could be modified to more closely resemble the participants' creations are included in the incorrect design element cells.

Dyad emotions		Associated emotions for design	Valence-arousal value	Form	Rhythm	Direction	Form & Direction: Aspect ratio	Rhythm & Direction: Distribution of volume
Delight	Hyp.	Surprise, joy	Positive, high-energy	Smooth	Small curves	Leaning slightly forwards	Round	Middle-heavy
	Resp.	Surprise, joy, trust, anticipation	Positive, high-energy	Smooth	Small and medium curves	Leaning slightly forwards	Round	Bottom or middle-heavy
Hope	Hyp.	Anticipation, trust	Positive, high-energy	Smooth	Medium curves	Leaning slightly forwards	Flat and wide	Top-heavy
	Resp.	Anticipation, trust, joy, fear, disgust (too negative – may improve with taxonomy modifications)	Positive or negative, high and low-energy	Smooth	Small and medium curves	Leaning slightly forwards or backwards	Flat, wide and round	Top or bottom-heavy (too low energy – may improve with taxonomy modifications)
Contempt	Hyp.	Anger, disgust	Negative, high-energy	Angular	Medium curves	Leaning backwards	Round	Middle-heavy
	Resp.	Anger, disgust, fear, sadness (too low energy – may improve with taxonomy modifications)	Negative, high-energy	Angular	Small and medium curves (may improve with taxonomy modifications)	Leaning backwards	Round	Bottom and middle-heavy
Despair	Hyp.	Fear, sadness	Negative, low-energy	Angular	Medium curves	Leaning heavily backwards	Tall and slender	Bottom-heavy
	Resp.	Fear, sadness, surprise (too positive and high energy – modify taxonomy so sadness has smaller curves)	Negative, low-energy	Slightly edged or angular	Small or medium curves	Leaning backwards	Tall and slender	Bottom-heavy

Table 7. Breakdown of design elements in the qualitative taxonomy for the four dyad emotions that participants were asked to re-design, with green, orange and red highlighting which design elements are correct, almost correct and incorrect based on the participants' designs

In general, it can be seen that the ***form design elements for the dyad test objects created by the participants matched the hypothesis***. This contradicts some of the findings discussed above, where forms that were perceived as positive high-energy emotions showed more angular surfaces. However, a key characteristic that agrees with the findings from the taxonomy study shows that these more ***positive high-energy emotions have generally more top-heavy 'uplifting' forms, and vice versa***. Smaller curves, i.e. the rhythm design element, did not show as close correlation to negative valence as the taxonomy study showed. Small curves are present in the designs created for the delight and hope emotions, however these designs were generally all leaning straight or slightly forward which explain the positive perception of these forms. The direction and aspect ratio design elements generally matched the hypothesis.

Building on this analysis, ***the modifications to the taxonomy suggested in the previous section still stand, with the caveat that small curves are can be included in positive high-energy emotions so long as the direction is leaning straight or forwards***. ***Amending the scaling factors so that positive high-energy emotions have a heavier weighting for the direction design element*** could also ensure that combinations including these emotions – such as hope or delight – have straight or forwards leaning directions, and hence are more likely to be considered as positive valence.

5.2.1.2. Analysis of the software user-experience

During the design user study, particpants were also asked questions about their experience of using the EmotiveModeler CAD tool, and how such software could benefit their general design process. The following is a summary of some of the responses about how the software could be improved, and how the participants could find it useful in designing objects with meaningful forms.

In general, all of the participants found the EmotiveModeler a very interesting concept for designing objects. They quickly picked up the strategy of creating initial designs using words and then modifying the forms using the primary emotion sliders, and enjoyed the process of exploring the forms that could be created by considering the primary emotions that related to the words entered into the UI. Many of the participants used trial and error to experiment with the functionality of the primary emotion sliders, to understand what affect these different elements had on the forms. It was suggested that ***some feature in the UI that showed users what effects these sliders would have on the forms would help to build an intuition for using the software effectively.*** Despite this, most of the participants also became frustrated when they wanted to modify the designs created at a more detailed level. They often wanted to be able to ***use more design focused words, such as 'taller', 'thinner', 'rounder', to modify the form more intuitively***. The participants who had design experience especially wished to be able to manipulate the form directly once they reached a form that was close to their expectations.

Reflecting on how useful the EmotiveModeler could be in their design process, all of the participants agreed that it would be a very useful tool in early stages of form creation. The use of words as an input medium was considered consistent with the initial stages of their own design processes. Both the expert and non-expert design participants mentioned that they often use words early in their ideation to encapsulate the abstract ideas and more focused design aesthetics that contribute to the ongoing narrative of the object they are designing. These underlying inspirational words are collected early in the design process, for example in a mood-board often used by expert designers, from which initial sketches of designs are created. Participants considered this ***early 'brainstorming' stage of the design process, where conceptual ideas are beginning to be transformed into initial designs, to be the most useful period to use the EmotiveModeler***. The fluidity of the design experience that the EmotiveModeler provides – suggesting sometimes unexpected designs based on abstract words, and then allowing the user to modify them using more emotive concepts rather than detailed design attributes – enabled the participants to 'design in the moment'. By 'releasing the brain' from focusing on numerical design features present in the more traditional CAD tools, conceptual ideas can be transformed quickly into initial design impressions with more intuition, and less concentrated thought.

Whilst the participants all agreed that the EmotiveModeler was ***not advanced enough to produce finished designs*** that did not need tweaking in a more refined 3D modeling environment, it was considered ***useful at helping designers to generate example designs for the descriptive words related to their designs***. These example designs could then be used to build a framework for their more refined designs, or even act as visualizations of a design narrative to help gain a common vision in conversations during a design process, e.g. helping to teach non-designers about the design language of objects to facilitate more productive collaborations [16].

Based on the findings from these discussions, some proposed modifications to improve the effectiveness of the EmotiveModeler in future iterations are listed below:

- ***UI modifications:***
    - 'Create design' and 'Add word to design' buttons often confused, therefore separate on separate lines.
    - Modify the UI so that the design changes shape in real-time when the primary emotion sliders are manipulated to give participants a more instantaneous feel for the effect of each of the functions.
- ***Current feature modifications:***
    - More precisely calibrate the primary emotion scales - or even set some boundary conditions in the software - to prevent very extreme and unrealistic designs from being created. Creating negative values for the primary emotions on the sliders was also suggested as a more intuitive way to associate the presence, or absence, of an emotion in a design.
    - Communicate the effects on the design that each primary emotion slider has on the resulting form, and suggest their relationship to the overall valence and arousal of the design, to allow a more intuitive grasp of their functionality. This could be executed through visualisations in the UI toolbar – for example showing examples of the forms that would be created at the extreme end of each primary emotion scale - or by highlighting the curves or surfaces being manipulated in the 3D model itself.
- ***Functionality additions:***
    - Implement a 'Revert to original dictionary' button to allow users to return to the hypothesized design if they desire.
    - Implement an 'Add word to dictionary' button to allow users to create a new emotion combination for a word that is not currently in the system dictionary
    - Implement 'Design element' sliders that allow precise manipulation of the forms using more design focused words such as 'taller', 'thinner', 'rounder' etc.
    - Enhance the 'Save' feature to enable users to save, and also reload, their favourite designs for a certain word and emotion combination, so that they can work on it again at a later stage. This could also be expanded to allow users to upload designs related to the word entered that have been created by other users of the system, so that they can be inspired by other designers work.

5.3. Evaluating the Communication of Emotive Meaning through Form

In order to more objectively evaluate the embodiment of emotive meaning in the designs created by the participants in the design study, the resulting new designs were shown (in 2D and 3D formats) to a small selection of expert designers to evaluate using a study procedure similar to that of the taxonomy study described earlier. The forms that were used as stimuli included the eight primary emotion forms and the additional four dyad forms explored in the design study (delight, hope, contempt and despair), as well as the 16 new designs created by the participants in the design user study. Including the original primary emotion and dyad designs in this study allows the emotive perception of these known forms to be evaluated, and hence provide a benchmark for the analysis of the other new designs. A full description of the feedback study procedure is included in Appendix 7.2.15.

The aim of this study is to see how close an expert designer's perception of the emotive shapes created in the design study is to the original design intent, and hence assess how effective the EmotiveModeler CAD tool was at creating designs whose meanings could be communicated to more than just the original designer.

5.3.1. Feedback Study Results and Discussion

As in the taxonomy study, valence and arousal values for both the animations of the test objects and most of the 3D printed bottle designs were collected, and averages for the responses for each bottle design calculated. (Not all of the designs created by the participants were 3D printed as the size and complex shapes of some would not have been manufacturable in their current forms.) Due to the small number of samples in this study (n=10), statistical power calculations would not provide a meaningful comparison of the data. Hence, a simple T-test was carried out to compare the average response values for the 2D animations and 3D printed forms. As with the taxonomy study, this also showed that ***most of the designs have averages for the animations of the test objects and 3D printed designs with significant similarities to the hypothesis*** (19 out of the 20 3D forms tested were perceived to have valence and arousal values significantly similar to the animations of the same designs). Contrary to the taxonomy study, many of the expert designers in this study did not consider the 3D forms to convey a different emotive perception to the animations of the test objects. As hoped, their more intuitive knowledge of design allowed them to evaluate forms in many media.

This analysis, therefore, will again focus on the data set collected for the animated versions of the bottle designs. I will follow a similar analysis strategy here: first evaluating the positioning of the forms on the valence-arousal circumplex compared to the hypothesized valence and arousal values, and then analyzing the overall distribution of design elements in comparison to the original intent by the design study participants. The aim of this analysis is to assess how close another designer can perceive the emotive meaning of a form to the creator's original intent, and thus determine if my overarching thesis question – can a CAD tool that uses descriptive adjectives as an input aid designers in creating objects that can communicate emotive character – is correct.

First, to evaluate how similarly the expert designers perceived the primary emotion and dyad forms to the hypothesis, a diagram comparing valence and arousal values of the primary emotion forms for the hypothesis and 2D responses is shown in Figure 45 below. As was found in the taxonomy study, it can be seen that trust and anticipation were perceived to be positive low-energy emotions. Disgust, anger and sadness were also perceived to be more positive than expected. The lower arousal positioning of both joy and surprise also corresponds to the findings in the taxonomy study. Fear was perceived as much lower arousal than either the hypothesis or the findings in the taxonomy study. The expert designers considered the 'constrained' neck and 'bowing' form to be 'shy' rather than fearful. The four dyad designs also tested in this study were perceived to be roughly similar valence and arousal values as the taxonomy study.

This simple analysis shows that the ***expert designers evaluated the primary emotion and dyad forms similarly to the larger group of participants in the taxonomy study, and any taxonomy modifications suggested earlier will likely be relevant in the analysis of the new designs***.

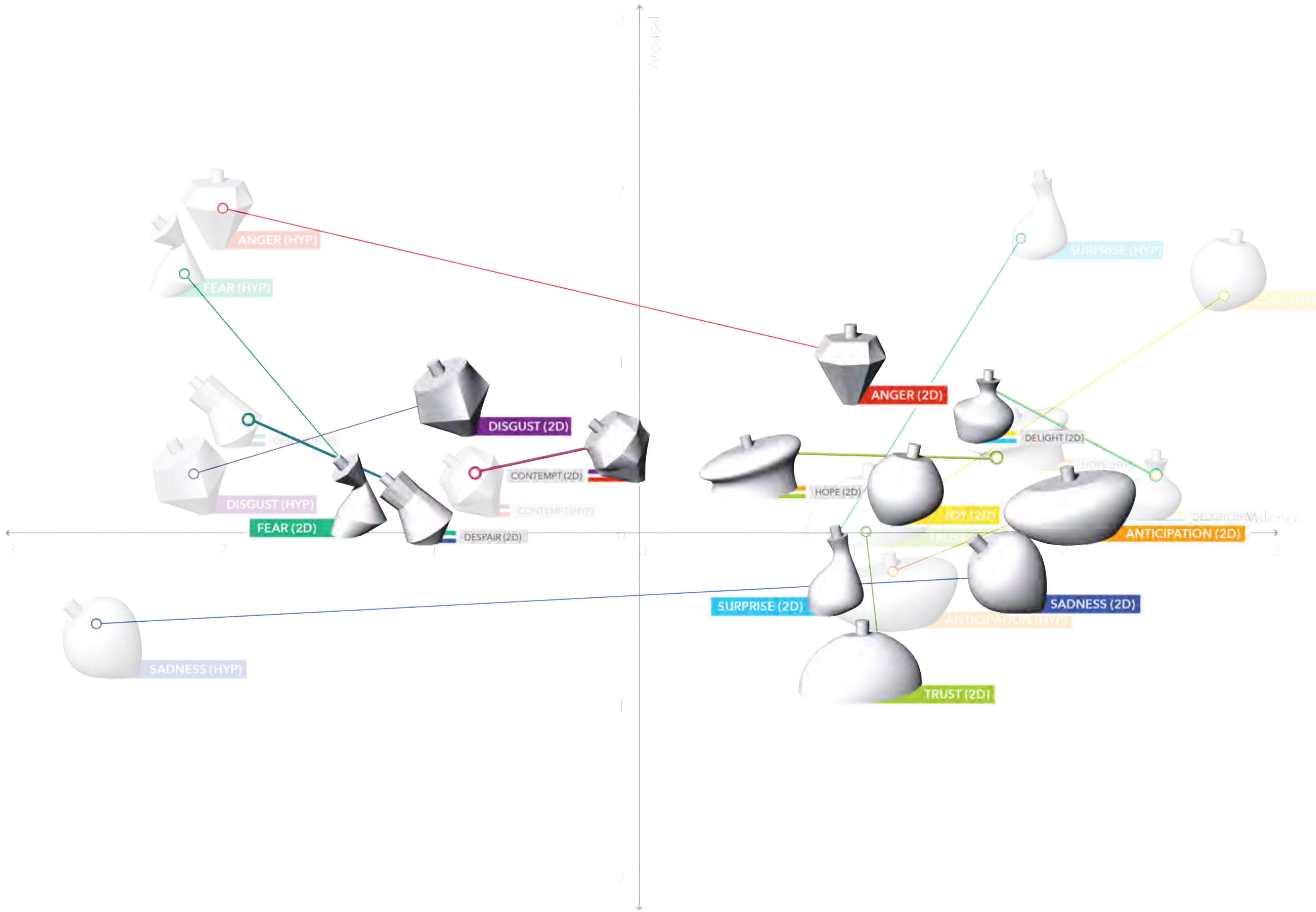

Figure 45. Primary emotion and dyad designs plotted on valence-arousal circumplex (hypothesis – faded - and expert designer's perception – not faded)

The following pages discuss the expert designer's perception of the new forms created in the design study, and assess the ability of the EmotiveModeler to create forms with communicative emotive meaning.

The full collection of designs created by the design study participants using their own emotive word choices are shown in Appendix 7.2.14. Figure 46 below plots these new designs on the valence-arousal circumplex, and compares the valence and arousal values assigned by the creators to those perceived by the expert designers (creator's original valence-arousal intent shown faded).

Figures 47 to 49 on the following page also show simplified versions of the form, rhythm and distribution of volume positioning for both the creator's original intent and animated test object responses from the expert designers to highlight the differences in perceptions. The detailed design element diagrams for both the creator's and expert designers perceptions are included in Appendix 7.2.16.

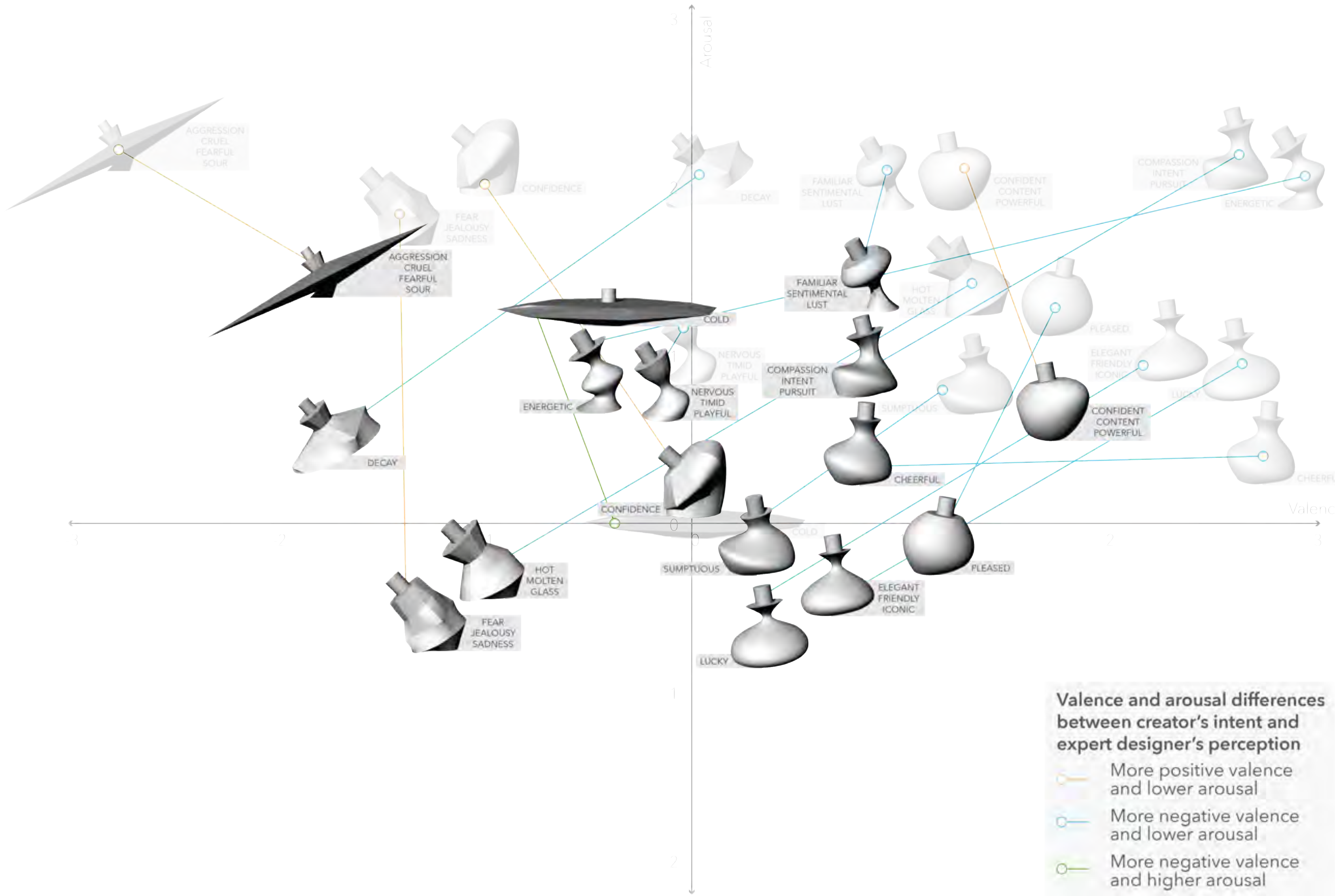

Figure 46. New emotive designs plotted on valence-arousal circumplex (creator's intent – faded - and expert designer's perception – not faded)

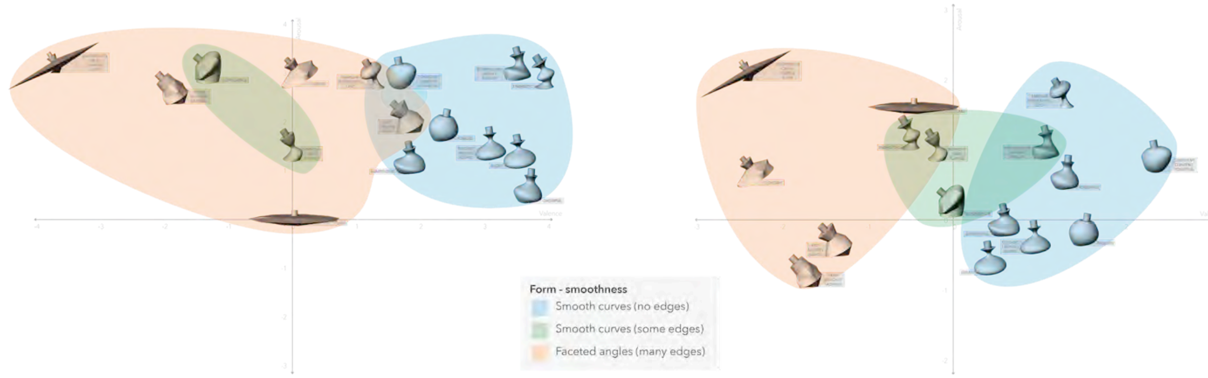

Figure 47. Comparison of the simplified form design elements for the hypothesis and responses for the animated test objects (smooth curves w/ no edges in blue, smooth curves w/ some edges in green, angular curves w/ many edges in orange)

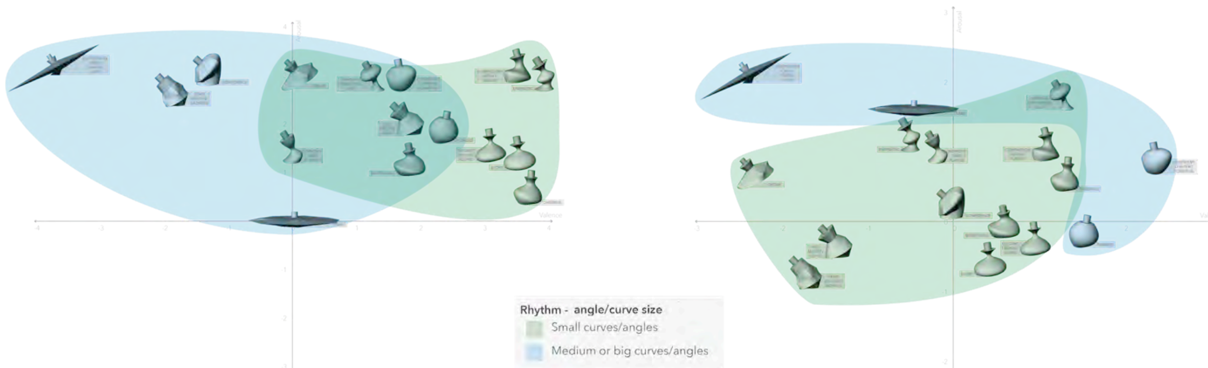

Figure 48. Comparison of the simplified rhythm design elements for the hypothesis and responses for the animated test objects (small curves/angles in green, big or medium curves/angles in blue)

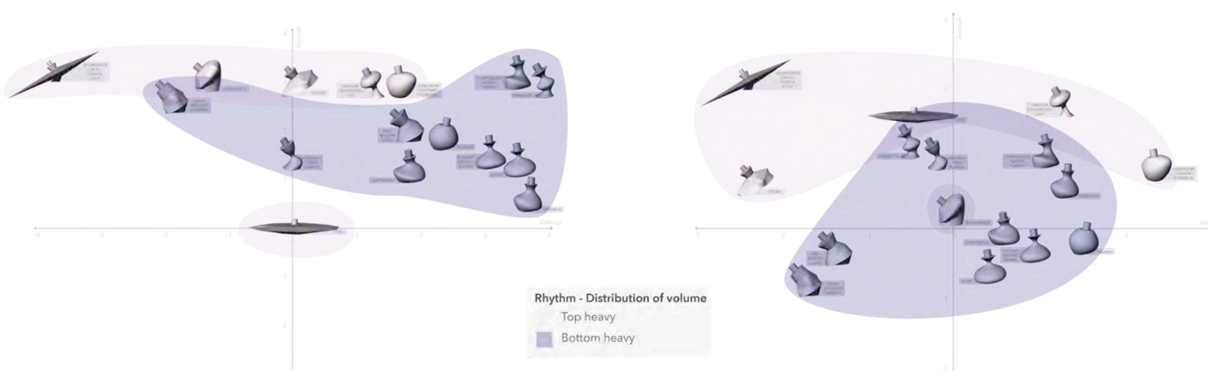

Figure 49. Comparison of the simplified distribution of volume design elements for the hypothesis and responses for the animated test objects (top-heavy in light purple, bottom-heavy in dark purple)

Again, due to the small sample size, a simple T-test and qualitative analysis was carried out to compare the average valence and arousal values for the creator's intent and the expert designer's perception. 9 out of the 16 new designs were perceived to have valence and arousal values fairly similar to the creator's original intent ('cold', 'sumptuous', 'cheerful', pleased', 'nervous timid playful', 'confident content powerful', 'aggression cruel fearful sour', 'familiar sentimental lust', 'neutral'). The other seven designs had valence or arousal values that did not match the creator's intent. Both single word and multi-word designs appear to have a similar level of accuracy in their valence and arousal perception.

The designs created to portray '***decay' and 'hot molten glass' were perceived by the expert designers as more negative and lower arousal than the creator's intent***. Both of these ***forms include irregular angular leaning backwards forms, and so the expert designers' evaluation matches the findings from the taxonomy study***. These similar distributions of form (i.e. smooth for more positive valence and vice versa) can be seen in Figure 47. Despite this resemblance, the creator of these designs did not actually consider the concepts of 'decay' or 'hot molten glass' to be negative, and therefore perceived these more angular forms to be more positive than others did. Correlating with this more negative perception of these designs, the creator had to use several of the negative high-energy primary emotions to generate the forms that she desired, despite her not considering these emotions to be relevant to the words she was designing for.

The designs created for 'lucky', 'elegant friendly iconic' and 'jealousy fear sadness' were all perceived to have lower arousal than the creators' expected. The creators described these bottom-heavy forms with smaller necks at a slight angle to be 'reaching upwards' and therefore were conveying more positive energy. However, the ***expert designers considered these bottom-heavy forms to look 'stable' and 'weighty' – therefore lower energy - and the small necks 'constraining', which fits with the findings from the taxonomy study***. This lower arousal perception also correlated to the association of positive low-energy primary emotions – such as trust and anticipation – to these forms. This disparity in perception of arousal in bottom-heavy forms can also be seen in Figure 49 – ***bottom-heavy forms are more present in the positive low-energy quadrant of the expert designers' distribution, in comparison to the positive high-energy quadrant that was expected by the creators***. This provides an interesting insight into the perception of dynamism in forms when the meaning of the form is known: if the design is known to be conveying higher energy, does this mean that we are more likely to see an 'uplifting' motion rather than a 'melting' motion in the form? The stability perceived in these more bottom-heavy forms could also be related to how functional the experts considered the bottles to be – bottom-heavy bottles wouldn't topple over when filled. As expert designers consider many aspects of a design during their creation, the functionality of the object could be a more conscious consideration in their evaluations, and hence affect their emotional perception of the forms.

The design for ***'compassion intent pursuit' was also perceived to be slightly lower arousal and less positive than the creator intended***. Based on the findings in the taxonomy study, the ***bottom-heavy small curves and slight leaning over direction would correlate with these responses from the expert designers***. However, the creator again considered these small curves and bottom-heavy form to show potential energy – in his eyes the form looked like it was ready to 'spring upwards'. The dynamic words used to create this form – 'intent' and 'pursuit' – also relate to this more energetic perception of the form, which may have again affected the creator's perception of the motion in the form.

The ***small curves and slight leaning over direction of the 'energetic' design also conveyed a more negative perception to the expert designers than expected***. The creator expressed perceiving positive energy in this form as it had many small curves making the form look like it was 'twisting around'. Despite this satisfaction with the form, the creator did not agree with the inclusion of negative primary emotions such as fear and disgust to generate the form. The expert designers disagreed however, as many of them associated negative primary emotions with this design. This contradiction in the perception of small curves can be seen in Figure 48, where the ***expert designers generally considered smaller curves to be more negative than the creators***. Again, this could be due to a difference in the perception of the motion of the form – the creator of this design thought that the form had a more positive 'dancing' motion, whereas the expert designers often considered this slightly hunched form to be more negative and 'creepy'.

Table 8 below summarizes the breakdown of design elements of the designs created by the participants in the design study, and highlights the above discussion regarding which design elements agreed with, almost agreed with and did not agree with those perceived by the expert designers.

Emotive word	Associated emotions for design	Creator's intended Valence-arousal value	Form	Rhythm	Direction	Form & Direction: Aspect ratio	Rhythm & Direction: Distribution of volume
Cheerful	Joy, surprise, trust	Positive, high-energy	Smooth	Small curves	Leaning forwards	Round	Bottom-heavy
Cold	Anger	Negative, high-energy	Angular	Medium curves	Leaning straight	Round	Top-heavy
Confidence	Trust, joy, anger	Negative, high-energy	Slightly edged	Medium curves	Leaning heavily forwards	Flat and wide	Top-heavy
Decay	Anger, disgust, fear	Negative, high-energy (difference in creator perception)	Angular	Small curves	Leaning heavily backwards	Round	Middle-heavy
Energetic	Trust, disgust, joy, anger	Positive, high-energy(difference in creator perception)	Smooth	Small curves (difference in creator perception))	Small curves (difference in creator perception))	Round	Middle-heavy
Lucky	Joy, trust, anticipation	Positive, high-energy	Smooth	Small curves (difference in creator perception))	Leaning slightly forwards	Round	Bottom-heavy (difference in creator perception)
Pleased	Joy	Positive, high-energy	Smooth	Medium curves	Leaning slightly forwards	Round	Middle-heavy
Sumptuous	Trust, joy	Positive, high-energy	Smooth	Small curves	Leaning forwards	Round and wide	Bottom-heavy
Aggression, cruel, fearful, sour	Anger, disgust, surprise	Negative, high-energy	Angular	Medium curves	Leaning slightly backwards	Round	Middle-heavy
Compassion, intent, pursuit	Fear, joy, trust	Positive, high-energy	Slightly edged	Small curves (difference in creator perception))	Leaning forwards	Round	Bottom-heavy (difference in creator perception))
Confident, content, powerful	Joy, trust, anticipation, disgust	Positive, high-energy	Smooth	Medium curves	Leaning slightly forwards	Flat and wide	Top-heavy
Elegant, friendly, iconic	Joy, anticipation, surprise, trust	Positive, high-energy	Smooth	Small curves (difference in creator perception))	Leaning slightly forwards	Round	Bottom-heavy (difference in creator perception))
Familiar, sentimental, lust	Sadness, anticipation, disgust	Positive, high-energy	Smooth	Medium curves	Leaning slightly backwards	Flat and wide	Top-heavy
Fear, jealousy, sadness	Sadness, fear, anger, disgust	Negative, high-energy	Angular	Medium curves	Leaning heavily backwards	Round	Middle-heavy (difference in creator perception))
Hot, molten, glass	Anger, anticipation, fear, trust	Positive, high-energy (difference in creator perception)	Angular	Small curves	Leaning heavily backwards	Round	Bottom-heavy
Nervous, timid, playful	Anticiaption, fear, joy, sadness, surprise, trust	Negative, high-energy	Slightly edged	Small curves	Leaning heavily backwards	Round	Bottom-heavy

Table 8. Breakdown of design elements of the single-word designs participants created in the design study, with green, orange and red highlighting which design elements agreed with, almost agreed with and did not agree with those perceived by the expert designers

The ***one key difference discovered in this feedback study is the difference in arousal perception of bottom-heavy forms with small curves***, such as 'lucky' or 'elegant friendly iconic'. The creators of these forms visualized a potential energy in this forms – they imagined them springing upwards, and hence assigned them a higher energy arousal. As the creator has an understanding of what the form is endeavoring to portray, their perception of the form could take on an almost anthropomorphic dynamic animation. However, ***it appears to be a challenging thing to convey this upwards dynamism present in the creator's imagination in an object to another person***. The expert designers perceived a more static 'sinking' character in these same forms, resulting in a lower energy arousal. One way to tackle this disparity in conveying dynamic energy in a design could be to enlarge the area at the very top of the designs after the 'neck' of the bottle. This could ***give the form more volume at the top as well as the base, possibly conveying more of an upward motion within the design***. Another approach to more clearly convey this 'motion' in a design could be to modify the texture of the form, adding edges or waves to show the flow of movement in the object.

Integrating these design attribute modifications as well as the outcomes from the taxonomy study discussed earlier could improve the ability of the EmotiveModeler to create forms with communicative emotive meaning. Pending these modifications and re-testing, based on these findings one could hypothesize that the expert designers' perception of the creators' bottle forms might transpire to be fairly similar to their originally intended emotive meanings. Thus validating my overarching thesis question: ***yes, it appears that the EmotiveModeler CAD tool can aid designers in creating objects – specifically bottles - that can communicate emotive character.*** A wider application of this tool to the design of any objects is not yet well understood, but suggestions for extending the research to include many more objects are discussed in the following section.

Chapter 6
Conclusion

> *"The practice of design turns upon some system of values, whether intuitive or conscious.... Does the autonomic designer operate in a universe of absolute values, or does he have built-in values special to himself; are the values imposed for the occasion; does he develop them for himself, or are they random? How far, indeed, is he autonomic?" - S. A. Gregory [20]*

The research presented in this thesis looks to brush the surface of these deep philosophical questions of design. One of the founding assumptions of this research is that there is indeed some collection of universal values for how we perceive meaning in objects, particularly their forms. We may not all be consciously aware of these perceptions, but existing research that this work builds on suggests that these are not in fact random. The product semantics of an object are embodied in its colour, its material, and its form, and these are the attributes that designers can employ to embody meaning in their creations.

In the introduction and background, I discussed how form is one of the key design attributes that contributes to how we can perceive meaning in objects. Form is also one of the major design elements by which expert designers can embody meaning in the objects they design, often through the use of CAD tools. It is in these CAD tools that designers can transform the abstract meanings they imagine early in the conceptual phase of a design into the concrete numerical geometries required to generate the physical designs that users will interact with. But this takes years of experience – how can novice designers use the word-based language they would use to describe the character they *perceive* in an object to *create* said object too?

To attempt to solve these issues, I asked: can a CAD tool that uses descriptive adjectives as an input aid designers in creating objects that can communicate emotive character?

In this document, I presented the EmotiveModeler – an emotive semantically-driven CAD tool that uses a quantitative emotive form design taxonomy to create 3D models using descriptive words, whose forms endeavor to convey the emotive character of the words.

The quantitative emotive form design taxonomy on which this CAD tool is based aimed to connect words to emotions to shapes. Situating the reader in the existing research relevant to this work, established emotion theories were discussed and mappings of words to both Plutchik's primary emotions and Russell's valence-arousal circumplex model presented. Summaries of existing shape-emotion research led to the development of a hypothetical qualitative taxonomy of design elements related to each of the eight primary emotions. The functionalities related to these different design elements available in the Rhinoceros 3D Modelling software were then introduced, and a strategy for transforming this qualitative taxonomy into a quantitative one suitable for integration into the EmotiveModeler CAD tool was presented. The culmination of this stage of the research was the functional EmotiveModeler CAD tool, which used the Python programming plug-in to execute the computational calculations required to generate the designs requested by the users through the UI.

Three in-depth user studies were carried out to test the underlying hypotheses in the quantitative emotive design taxonomy and EmotiveModeler CAD tool itself (focusing on bottle forms for this thesis).

Initially, a study to test the taxonomy looked at how closely people perceived the forms generated by the EmotiveModeler to their hypothetical valence and arousal values, and through these findings highlighted some modifications to the taxonomy that could enable people to more accurately perceive the meaning in forms. These included making more of the higher arousal primary emotions such as surprise and joy more even angular surfaces and top-heavy to convey a more 'uplifting' and 'purposeful' character. Including smaller more irregular curves and angles in the negative valence emotions such as anger, disgust and sadness might also improve the accuracy of the perception of these forms. Despite participants appropriately associating forms to primary emotions with similar valance and arousal values to the overall word they were conveying, the more 'chimeric' forms did not clearly convey both of the primary emotions if they had very different valence and arousal values. Thoughts on how these diverse emotions can be communicated through the design of an object are discussed in the next section.

Another study looked at the actual use of the EmotiveModeler CAD tool so as to understand if it might be a useful tool for designers – expert or novice. Benchmarking design studies showed that similar design features were often created in forms designed for specific meanings, indicating that the taxonomy was fairly intuitively integrated into the tool. Whilst participants were frustrated by the lack of detailed design element manipulation available in the current EmotiveModeler prototype, it was this intuitive and instantaneous connection between words and basic forms that was found to be the most interesting and useful aspect of the tool. As hoped, this tool did indeed make the early stage of transforming abstract ideas into concrete geometries more visible and easier to create initial designs for both novices and experts.

Finally, the last study looked to close the perception feedback loop by assessing if other expert designers perceived a similar meaning in forms as their creators intended, and hence determine if my overarching thesis question – can a CAD tool that uses descriptive adjectives as an input aid designers in creating objects that can communicate emotive character – was correct. Despite one interesting difference found in how the creators of a design and the viewers of a design perceive the energy in a bottom-heavy form, the findings in this study suggested that if modifications from the taxonomy study were integrated into the EmotiveModeler then users might indeed be able to create forms that communicated emotive character.

6.1. The Future of Designing Emotive Forms

The research presented in this thesis is a first step in understanding how we may create design tools that take advantage of our intuitive perception of the emotive meaning embedded in objects. Not all of the many musings on work to explore this area were able to be completed in this thesis, but the following discusses how this research may be expanded to consider more ways in which we can communicate meaning through design.

Initially, integrating the modifications to the taxonomy described above and repeating the taxonomy user study especially could improve the efficacy of the EmotiveModeler CAD tool as it is. Allowing users to calibrate these underlying values as well might help to make the EmotiveModeler a more personally connected design tool. This calibration process could try to take into account a more in-depth analysis of the way in which the designer perceives forms: do they consider the objects in an anthropomorphic manner where the object is imagined to interact with themselves or other surrounding objects? Or does the designer consider more of the physical and mechanical processes which go into creating the actual form? How much is the overall function of the object considered and how does that effect the emotional perception? Researching the effect of how these different psychologies affect the perception of design and integrating them into a calibration process in the software could enable the tool to really learn about the personal perceptions of the user and hence create forms which have a closer mapping to their mental models [51].

The interesting finding that the animations of the test objects were perceived similarly to the 3D printed forms suggests that a much larger online study could generate reasonably reliable data to investigate some of these questions. A study such as this could also be easily expanded to collect information about the different times and contexts in which people viewed the designs to explore if there might there be a difference in peoples' perception of objects at different times of days or in different environments.

As Mohammad says: "Terms may evoke different emotions in different contexts, and the emotion evoked by a phrase or a sentence is not simply the sum of emotions conveyed by the words in it" [36]. Modifying the EmotiveModeler CAD tool itself could also build on this idea of context-based perception. A natural-language processing system such as the ConceptNet semantic network [23] could help to extend the meanings associated with the words input into the EmotiveModeler – the affective character of whole sentences could be analyzed as a whole, so that the forms generated are more than just the sum of the emotions of the individual words. Deeper research into how our emotional associations are layered and evolve through the experience of even just a single word – and hence how these fluctuating layers of emotions apply to different design attributes - could also provide a more profound understanding of how to break these complex meanings into more comprehensible and communicative physical design language.

Understanding more about the context of the design and the meaning endeavored to be embodied in it could also help to integrate other more directly referential associations or design inspirations into the design. For example, if designing a hot sauce bottle, words such as 'fiery' and emotions such as anger and disgust may create an appropriately shaped form. Integrating design attributes that are reminiscent of the shape of an actual chili pepper may serve to enhance the meaning conveyed through the design. Imagine if the EmotiveModeler could directly upload other design material such as inspirational images and other base objects, and then allow users to manipulate these abstract descriptions as well as their more concrete design attributes. Such a design tool as this could provide a method for designers to funnel their early abstract ideas into the tool so that they might be able to perform the more complex computational procedures in a faster, more intuitive way. Experimenting with such a tool as this, where the interface seamlessly links modifications made in the abstract words or images to changes in the design, could help novice designers learn more quickly about the representation of different meaning through aesthetic qualities.

Form is not the only aesthetic quality that conveys meaning in objects, however. As discussed at the very beginning of this thesis, design attributes such as colour, surface texture, materials, etc. play an important role in our perception of an object. Experiments to explore how these attributes affect our emotive perception of an object, or create any cross-modal 'synesthetic' correspondences [47], would be an interesting next step. In particular, colour and a 2D simulation of materials and their reflectance could be easily integrated into the existing EmotiveModeler CAD tool to see how these attributes affect our perception of form. Considering these other potential methods for embodying emotive information in a design could also enable a greater diversity of emotions to be conveyed in more 'chimeric' forms. Layers of emotional information could be conveyed in a hierarchy of design elements - for example, form could convey the most prominent emotion, followed by texture, and then perhaps colour or material. Further research into how dynamism in these design attributes affects our perception – such as investigating the movements animals use to convey emotion - could also expand the taxonomy, and potentially lead to inspiration for the creation of objects that can dynamically change their design to reflect a changing emotional meaning.

This avenue of investigation could also be expanded to explore how less common mediums of design inspiration – such as continually changing numerical data instead of descriptive words – could be integrated into a total 'synesthetic-communication' design tool.

Currently expert designers are this 'synesthetic-communication' design tool. Giving both novices and expert designers more tools to communicate their thoughts in many mediums could enable everyone to become more consciously conversant in the language of the physical world, and through this more meaningfully engage with the objects that surround us. This research has hopefully presented a first step in making this vision a reality by embedding some of this intangible design knowledge into a more quantifiable and accessible design process.

Chapter 7
References & Appendix

7.1. References

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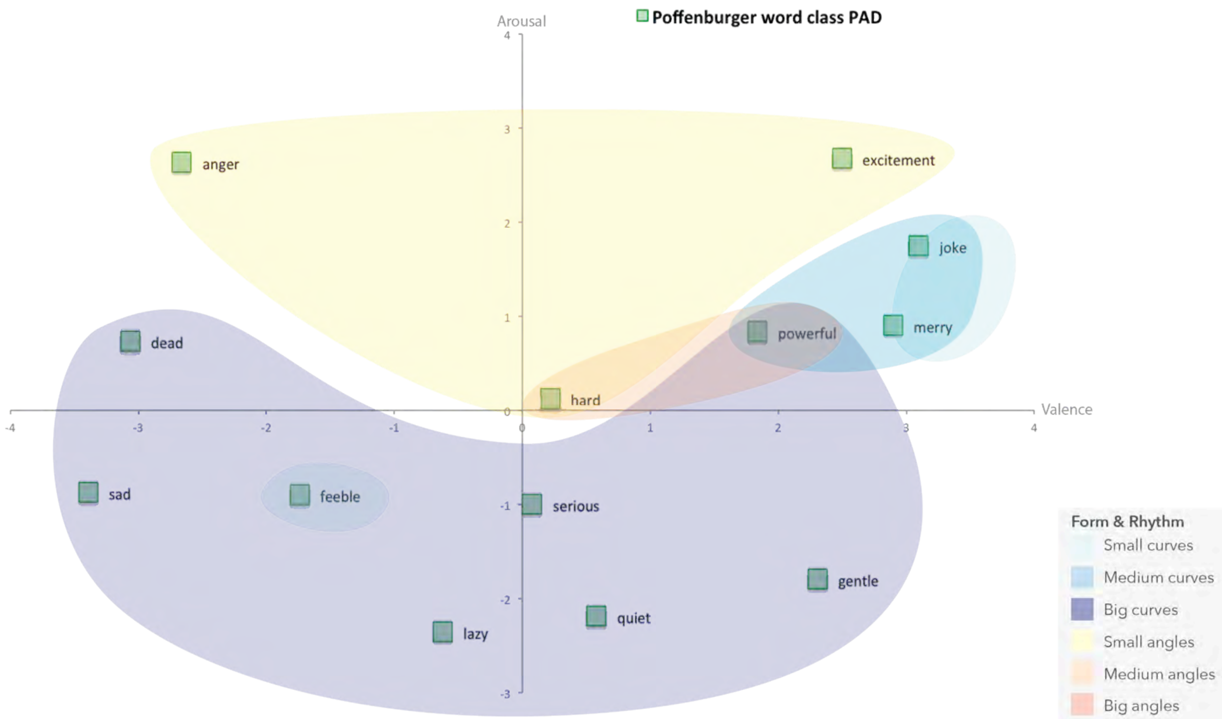
7.2. Appendix

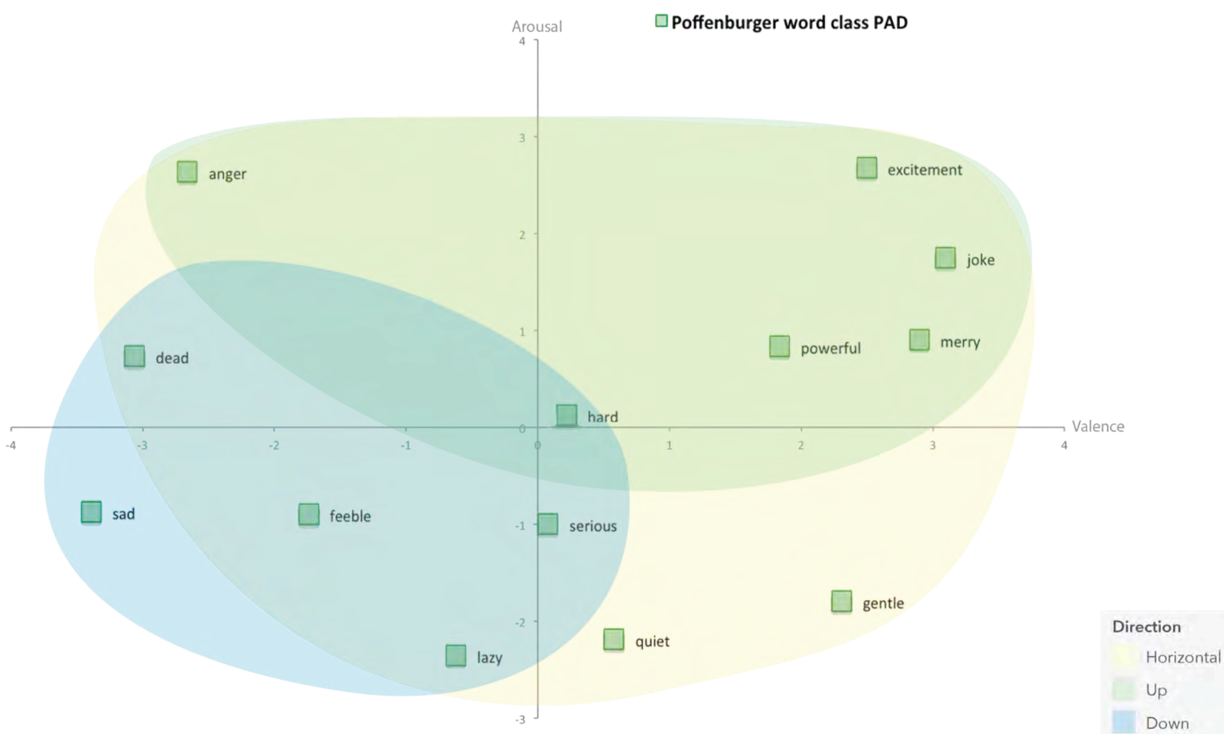
7.2.1. Valence and arousal values of Plutchik primary emotions and dyads

Emotion	Valence	Arousal
Trust	1.68	0.3
Joy	3.6	2.22
Surprise	2.47	2.47
Fear	-2.24	1.96
Anger	-2.66	2.63
Disgust	-2.55	0.42
Sadness	-3.39	-0.87
Anticipation	1.39	-0.17
Aggression	0.1	0.83
Optimism	1.95	0.34
Contempt	-1.15	0.28
Alarm	1.2	1.85
Love	3.72	1.44
Remorse	-2.72	0.74
Disappointment	-2.61	-0.08
Submission	-1.13	-1.2
Pride	3.03	0.56
Hope	2.05	0.44
Cynic	-1.98	0.04
Despair	-2.57	0.68
Guilt	-2.37	1.04
Envious	-1.24	-0.53
Disbelief	-1.32	0.04
Curiosity	1.08	0.82
Dominance	-1.2	1.1
Anxiety	-0.19	1.92
Morbid	-2.13	0.06
Shame	-2.5	-0.12
Outrage	-1.48	1.83
Sentimentality	0.98	-0.59
Delight	3.26	0.44
Pessimism	-3.12	-1.17
Neutral	0	0

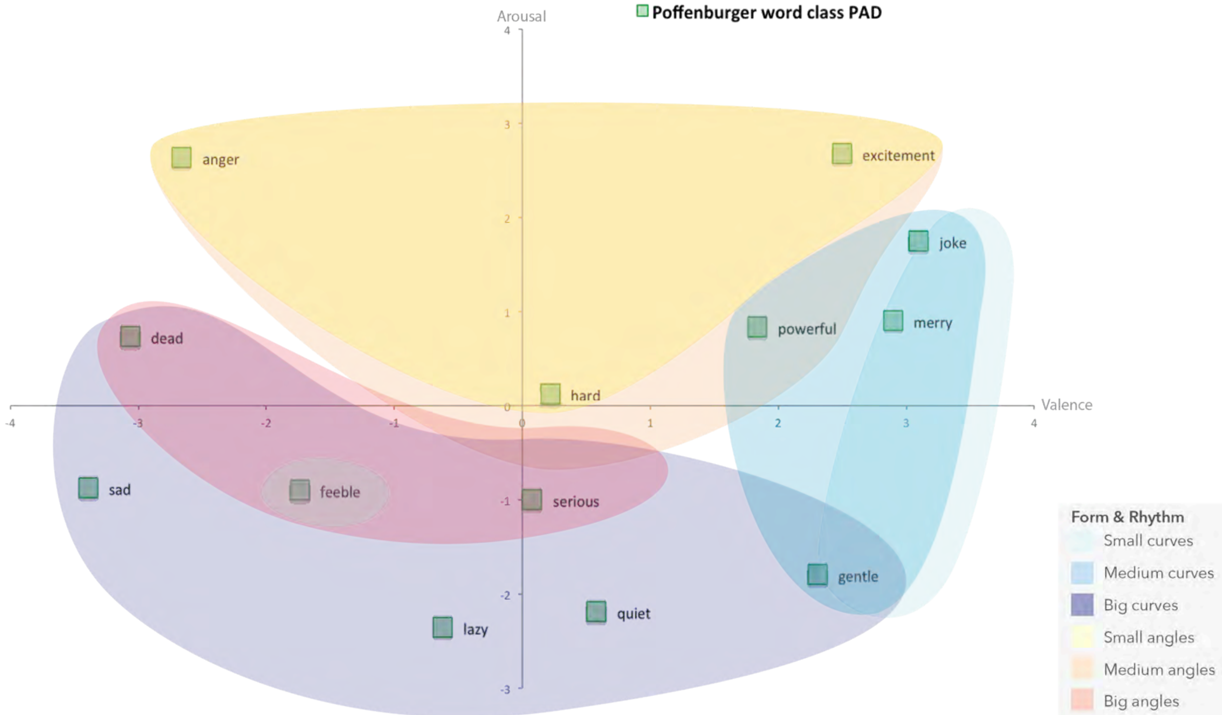
7.2.2. Emotive Perception of Shapes: Design Elements from Existing Research



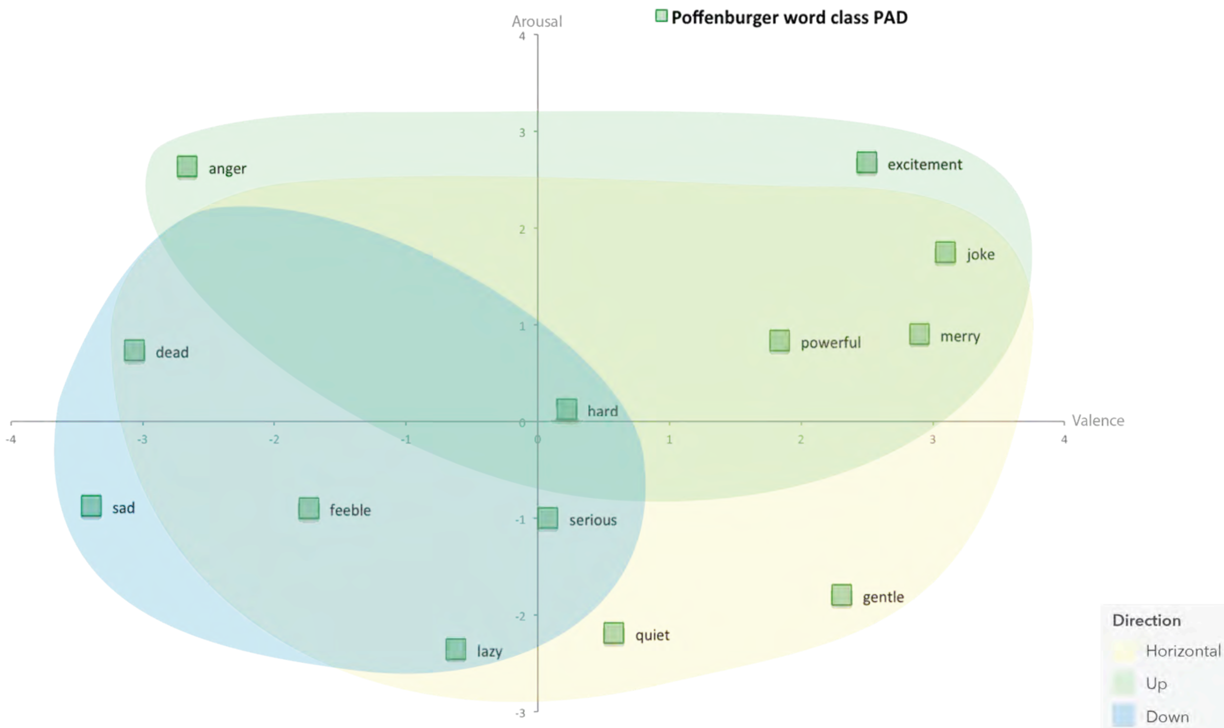
Summary of the form and rhythm elements of the 2D design language defined by Lundholm [poff]



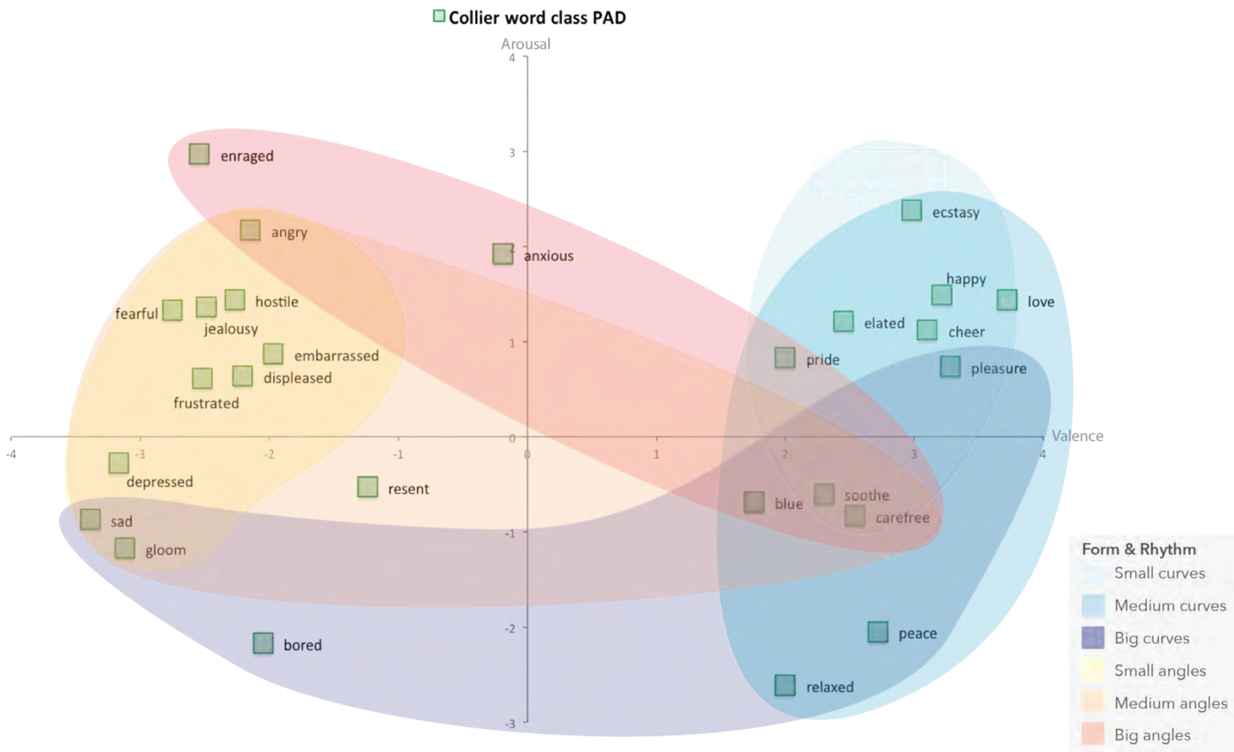
Summary of the direction elements of the 2D design language defined by Lundholm [poff]



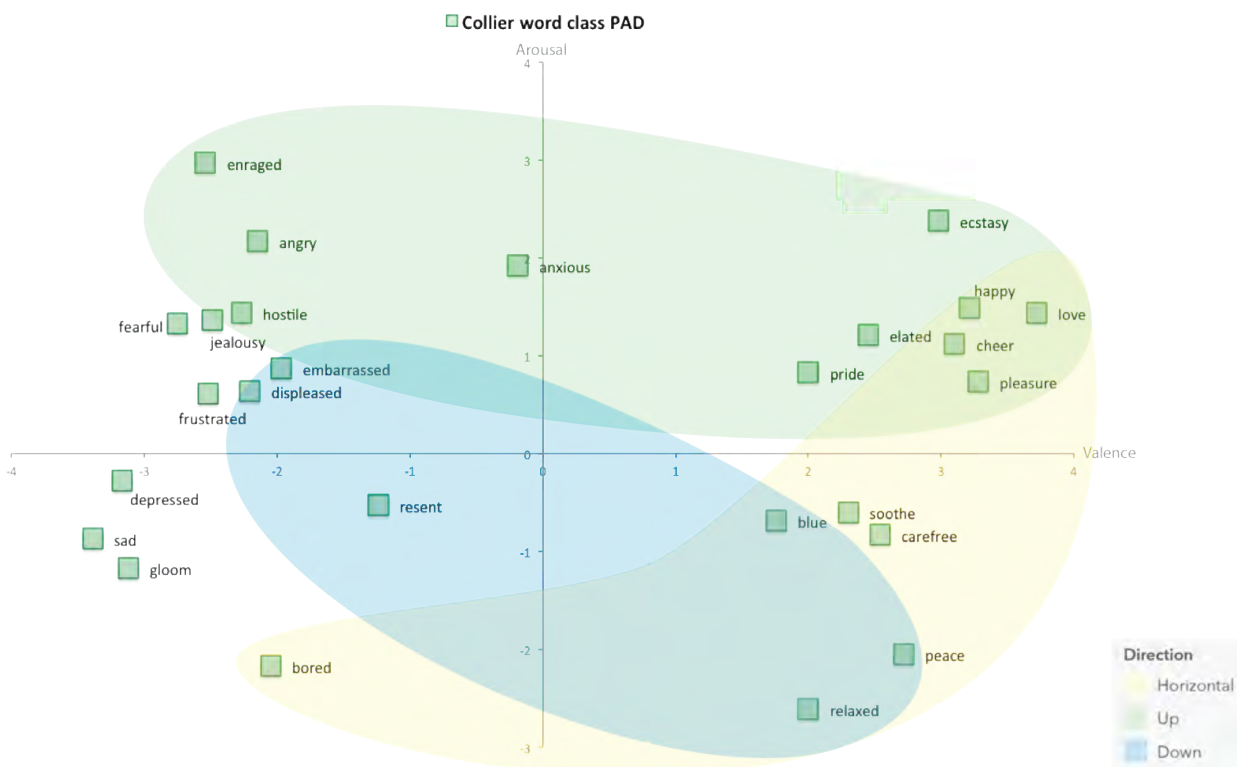
Summary of the form and rhythm elements of the 2D design language defined by Poffenberger [poff]



Summary of the direction elements of the 2D design language defined by Poffenberger [poff]



Summary of the form and rhythm elements of the 2D design language defined by Collier [collier]



Summary of the direction elements of the 2D design language defined by Collier [collier]

7.2.3. *Qualitative Taxonomy of Emotive Shapes: Breakdown of design elements for primary emotions*

Design elements	**Primary Emotion**							
	Anticipation	**Trust**	**Joy**	**Surprise**	**Fear**	**Anger**	**Disgust**	**Sadness**
Lund-holm [ref]	Smooth or angular medium or big curves, facing horizontal	Smooth big curves, facing horizontal or upwards	Smooth small or medium curves, facing horizontal or upwards	Angular small curves, facing horizontal or upwards	Angular small curves, facing horizontal, upwards or downwards	Angular small curves, facing horizontal or upwards	Smooth small or big curves, facing horizontal or downwards	Smooth big curves, facing downwards
Poffen-berger [ref]	Smooth or angular medium curves, facing horizontal or upwards	Smooth or angular medium curves, facing horizontal or upwards	Smooth small or medium curves, facing upwards	Smooth or angular small or medium curves, facing upwards	Angular small or medium curves, facing horizontal, upwards or downwards	Smooth or angular small or medium curves, facing upwards	Smooth or angular big curves, facing horizontal or downwards	Smooth big curves, facing horizontal or downwards
Collier [ref]	Smooth or angular medium or big curves, facing horizontal or downwards	Smooth or angular medium and big curves, facing horizontal or upwards	Smooth small or medium curves, facing upwards	Smooth small or medium curves, facing upwards	Angular small or medium curves, facing upwards	Angular big curves, facing upwards	Angular small or medium curves, facing downwards	Smooth or angular medium or big curves, facing downwards
Isbister [ref]	Smooth medium or big curves, facing horizontal or downwards	Smooth medium or big curves, facing horizontal or upwards	Smooth small or medium curves, facing upwards	Smooth small or medium curves, facing upwards	Angular small or medium curves, facing upwards	Angular small or medium curves, facing upwards	Angular medium or big curves, facing horizontal or downwards	Angular medium or big curves, facing horizontal or downwards
Qualit-ative taxon-omy of emotive design	**Top-heavy round, flat and wide forms with smooth medium or big curves, leaning straight or slightly backwards**	**Bottom-heavy round, flat and wide forms with smooth medium or big curves leaning straight or slightly forwards**	**Middle-heavy round forms with smooth small or medium curves, leaning slightly forwards**	**Bottom-heavy tall, round forms with smooth small or medium curves, leaning forwards**	**Bottom-heavy tall, round and slender forms with angular small or medium curves, leaning straight or heavily forwards**	**Middle-heavy tall and round forms with angular small or medium curves, leaning straight or heavily forwards**	**Middle-heavy round forms with angular medium or big curves, leaning straight or backwards**	**Top-heavy round and slender forms with smooth big curves, leaning straight or heavily backwards**

7.2.4. Quantitative Taxonomy of Emotive Shapes: Breakdown of design elements for Plutchik's primary emotions

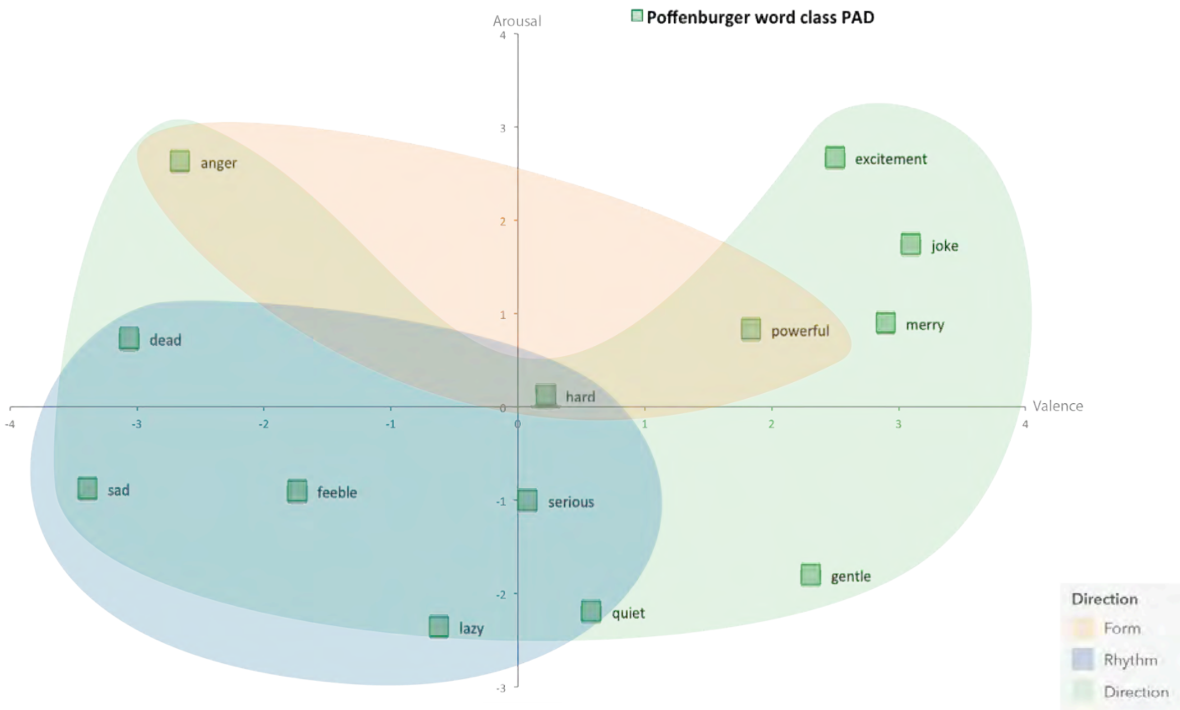
Design Elements				Plutchik Primary Emotions			
				Anger	Anticipation	Disgust	Fear
Direction	**Spine equation**		*a term:*	0	0.65	2.619	2.918
			b term:	0	4.34	2.619	1.008
			h term:	0	-0.54	-2.571	-2.707
			k term:	0	-2.42	-0.571	0.383
Form & Direction	**Aspect ratio**		*Global vertical AR:*	0.857	2	1	0.625
			Global horizontal AR:	1	2	1	0.75
Rhythm (& Direction)	**Profile curves ratio**		*Level 1*	0.33	0.7	0.33	0.75
			Level 2	0	0	0	1
			Level 3	0	0	1	0
			Level 4	1	1	0	0.325
			Level 5	0.75	0.6	0.75	0.8
Form	**Curve smoothness**	*Level 1*	*Horizontal AR (x value)*	1	1	1	1
			Horizontal AR (y value)	1	0.75	1	0.75
			No. points in curve	5	20	10	20
			Curve smoothness degree	1	2	2	2
		Level 2	*Horizontal AR (x value)*	0	0	0	1
			Horizontal AR (y value)	0	0	0	0.9
			No. points in curve	0	0	0	20
			Curve smoothness degree	0	0	0	2
		Level 3	*Horizontal AR (x value)*	0	0	1	0
			Horizontal AR (y value)	0	0	1	0
			No. points in curve	0	0	4	0
			Curve smoothness degree	0	0	1	0
		Level 4	*Horizontal AR (x value)*	1	1	0	0.8
			Horizontal AR (y value)	1	0.65	0	1
			No. points in curve	9	20	0	10
			Curve smoothness degree	1	2	0	1
		Level 5	*Horizontal AR (x value)*	1	1	1	0.86
			Horizontal AR (y value)	1	0.65	1	1
			No. points in curve	5	20	10	7
			Curve smoothness degree	1	2	2	1
	Loft curvature degree			2	3	2	2

Breakdown of design elements in the quantitative taxonomy for each primary emotion

			Design Elements	Joy	Sadness	Surprise	Trust	Neutral
				Plutchik Primary Emotions				
Direction	**Spine equation**		*a term:*	2.619	2.209	2.164	0	0
			b term:	2.619	2.694	1.322	0	0
			h term:	-2.381	-1.941	-2.007	0	0
			k term:	1.158	-1.305	0.498	0	0
Form & Direction	**Aspect ratio**		*Global vertical AR:*	1	0.95	0.625	2	0.8
			Global horizontal AR:	1	0.77	1	2	1
Rhythm (& Direction)	**Profile curves ratio**		*Level 1*	0.5	0.5	0.75	1	1
			Level 2	0	0	1	0	0
			Level 3	1	0	0	0.85	0
			Level 4	0	1	0.325	0	0
			Level 5	0.5	0.5	0.4	0.3	1
Form	**Curve smoothness**	*Level 1*	*Horizontal AR (x value)*	1	1	1	1	1
			Horizontal AR (y value)	1	1	1	0.65	1
			No. points in curve	20	20	20	20	20
			Curve smoothness degree	2	2	2	2	2
		Level 2	*Horizontal AR (x value)*	0	0	1	0	0
			Horizontal AR (y value)	0	0	1	0	0
			No. points in curve	0	0	20	0	0
			Curve smoothness degree	0	0	2	0	0
		Level 3	*Horizontal AR (x value)*	1	0	0	1	0
			Horizontal AR (y value)	1	0	0	0.65	0
			No. points in curve	20	0	0	20	0
			Curve smoothness degree	2	0	0	2	0
		Level 4	*Horizontal AR (x value)*	0	1	1	0	0
			Horizontal AR (y value)	0	0.9	0.75	0	0
			No. points in curve	0	20	10	0	0
			Curve smoothness degree	0	2	2	0	0
		Level 5	*Horizontal AR (x value)*	1	1	1	1	1
			Horizontal AR (y value)	1	1	0.75	0.5	1
			No. points in curve	20	20	10	20	20
			Curve smoothness degree	2	2	2	2	2
	Loft curvature degree			3	3	3	3	2

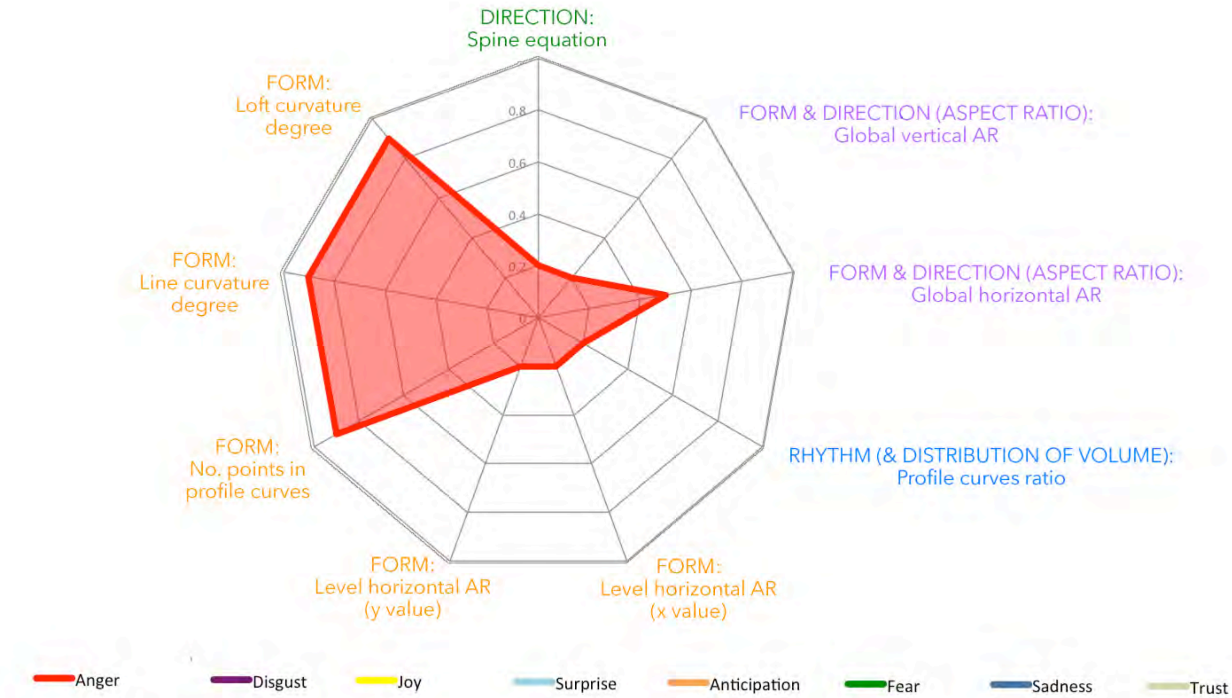
Breakdown of design elements in the quantitative taxonomy for each primary emotion (cont)

7.2.5. Mapping Words to Forms: Existing Research Scaling Factors

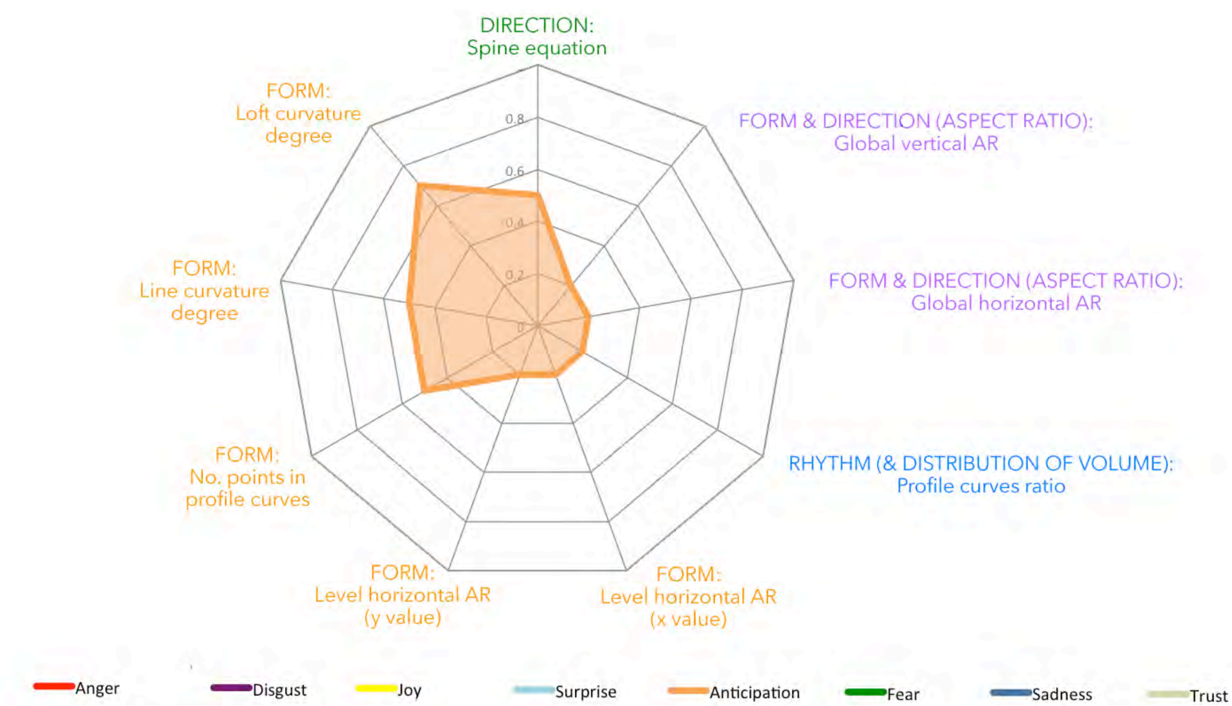


Summary of the scaling factors of the 2D design language defined by Poffenberger [poff]

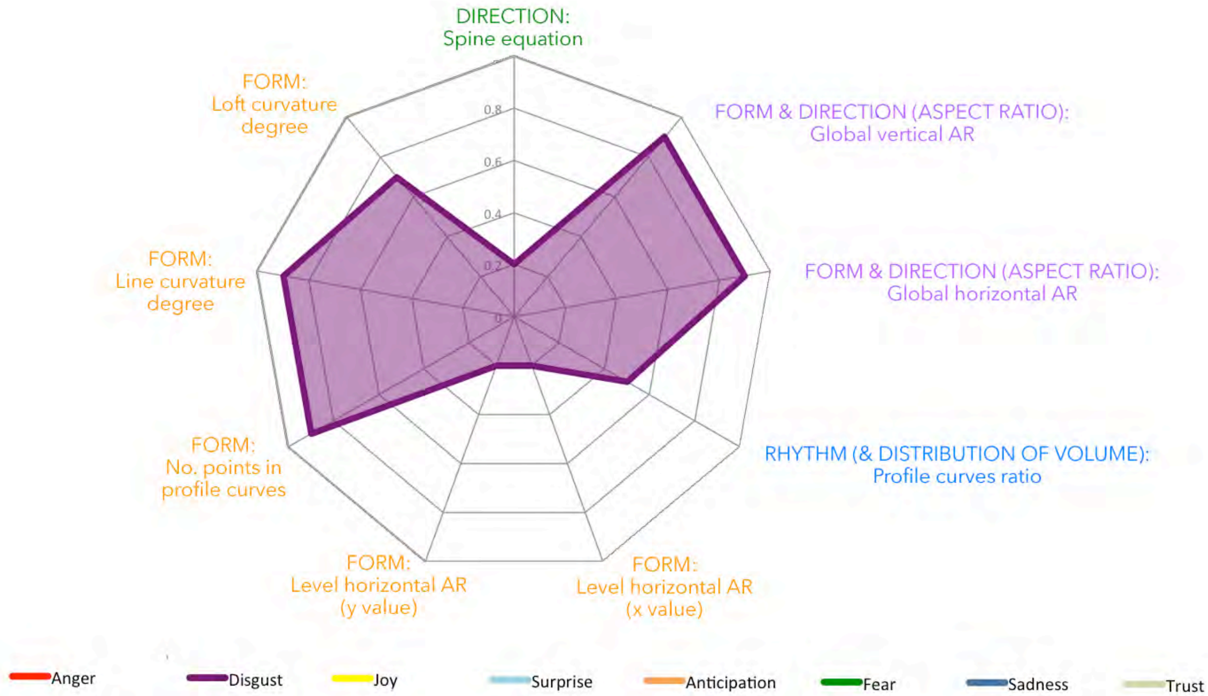
7.2.6. Mapping Words to Forms: Emotive Design Taxonomy Scaling Factors



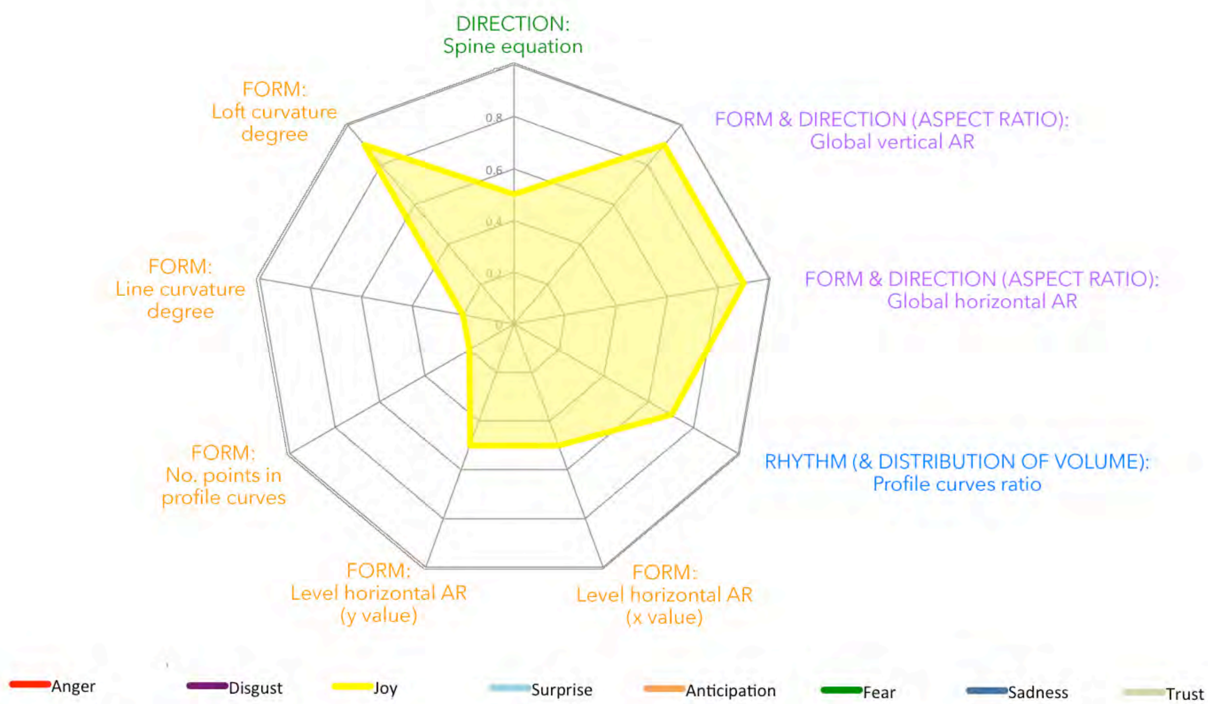
Detailed breakdown of scaling factors for the design elements in anger



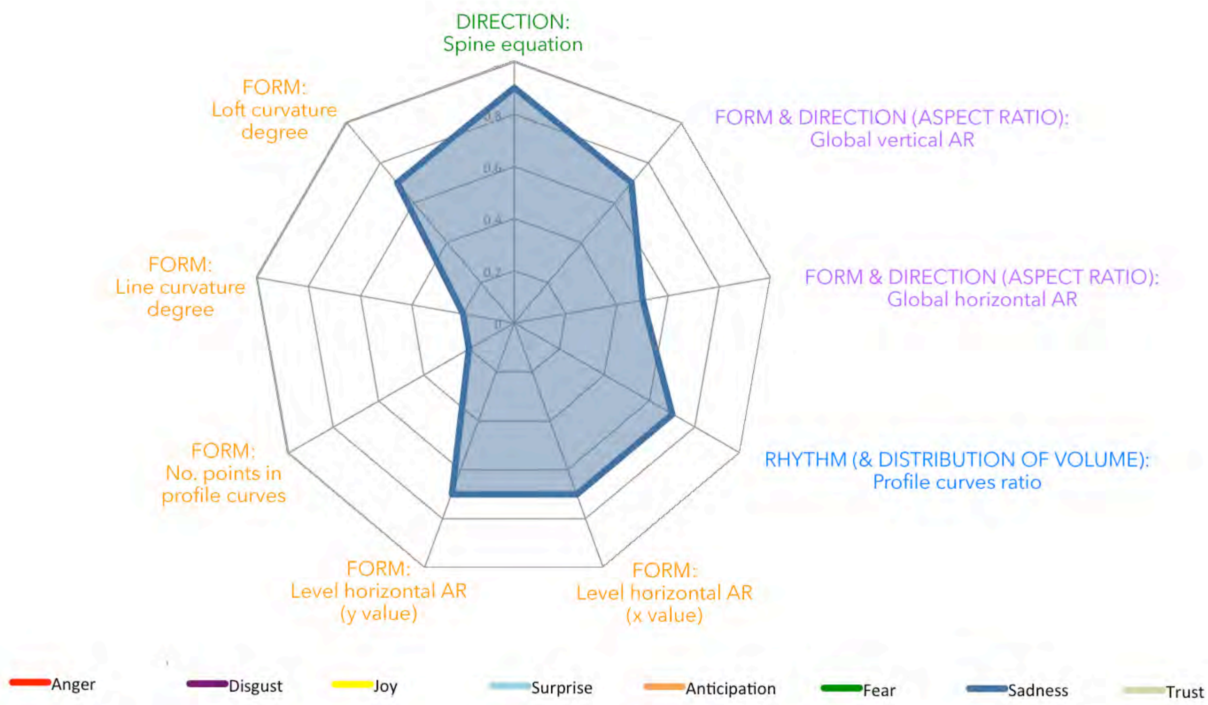
Detailed breakdown of scaling factors for the design elements in anticipation



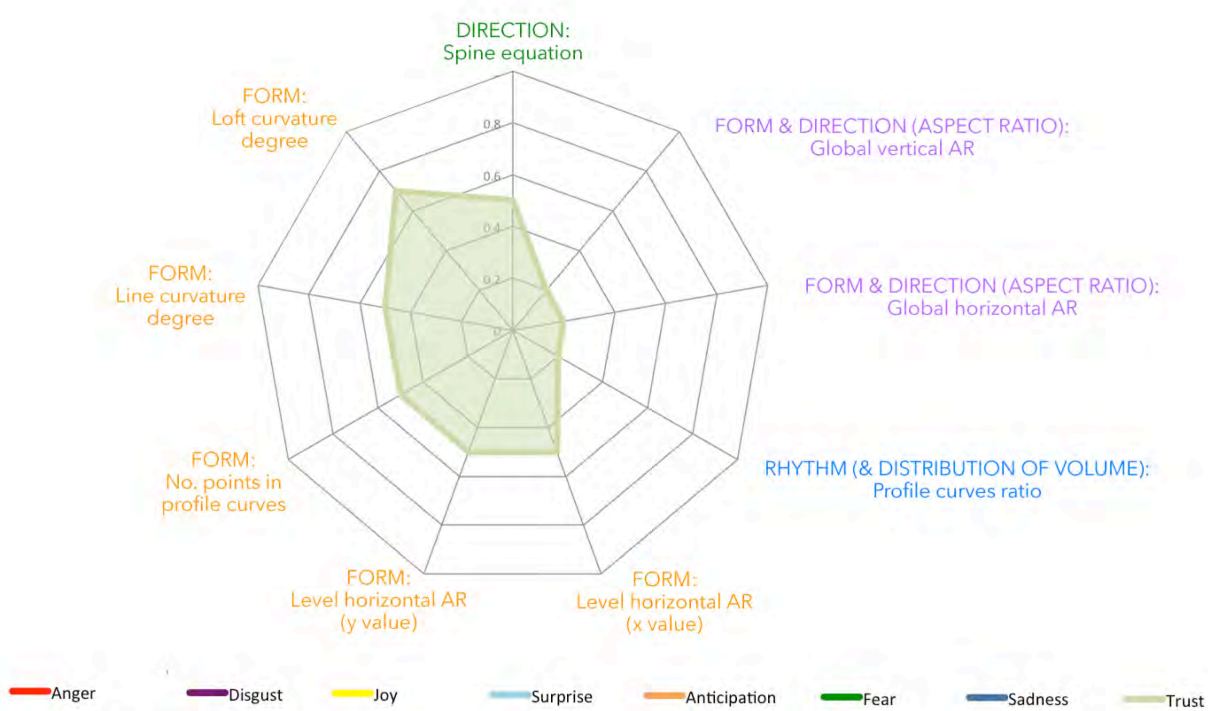
Detailed breakdown of scaling factors for the design elements in disgust



Detailed breakdown of scaling factors for the design elements in joy



Detailed breakdown of scaling factors for the design elements in sadness



Detailed breakdown of scaling factors for the design elements in trust

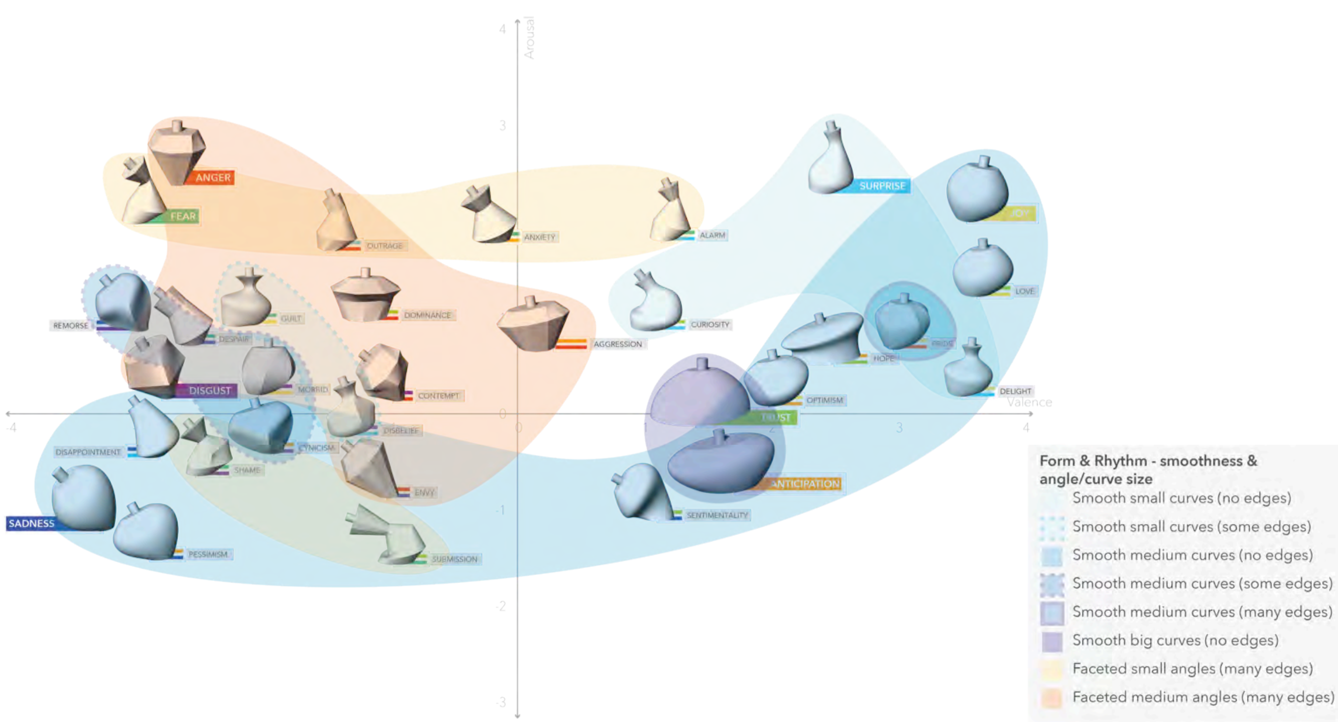
Design Elements Scaling Factors			Plutchik Primary Emotions								
			Anger	Anticipation	Disgust	Fear	Joy	Sadness	Surprise	Trust	Neutral
Direction	**Spine equation**		0.2	0.5	0.2	0.9	0.5	0.9	0.9	0.5	0
Form & Direction	**Aspect ratio**	*Global vertical AR:*	0.2	0.2	0.9	0.9	0.9	0.7	0.9	0.2	0
		Global horizontal AR:	0.5	0.2	0.9	0.9	0.9	0.5	0.9	0.2	0
Rhythm (& Direction)	**Profile curves ratio**		0.2	0.2	0.5	0.9	0.7	0.7	0.9	0.2	0
Form	**Curve smoothness**	*Horizontal AR (x value)*	0.2	0.2	0.2	0.5	0.5	0.7	0.7	0.5	0
		Horizontal AR (y value)	0.2	0.2	0.2	0.5	0.5	0.7	0.7	0.5	0
		No. points in curve	0.9	0.5	0.9	0.9	0.2	0.2	0.2	0.5	0
		Curve smoothness degree	0.9	0.5	0.9	0.9	0.2	0.2	0.2	0.5	0
	Loft curvature degree		0.9	0.7	0.7	0.9	0.9	0.7	0.7	0.7	0

Breakdown of design elements in the quantitative taxonomy for each primary emotion

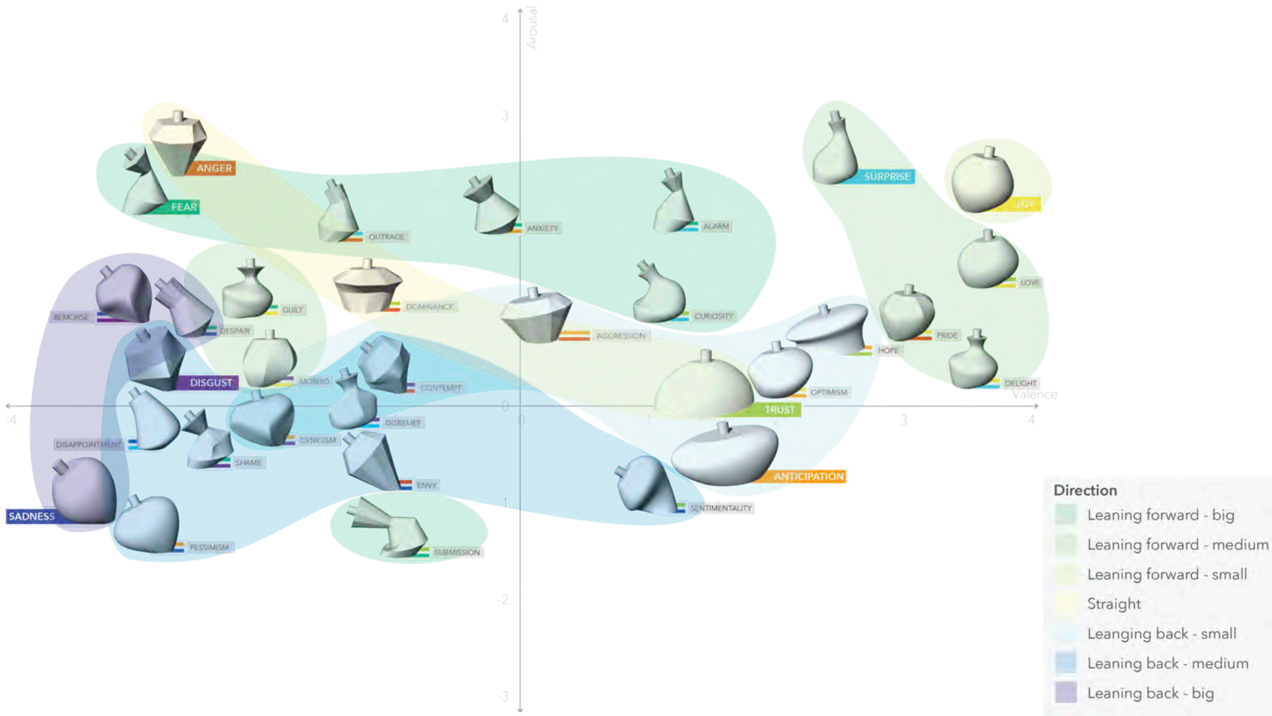
7.2.7. *Mapping Words to Forms: Diagrams of quantitative taxonomy design elements*

The resulting distribution of the design elements is almost perfectly matched to the qualitative emotive design taxonomy. A summary of design elements for the four quadrants of the valence-arousal circumplex for the quantitative taxonomy of emotive shapes is below:

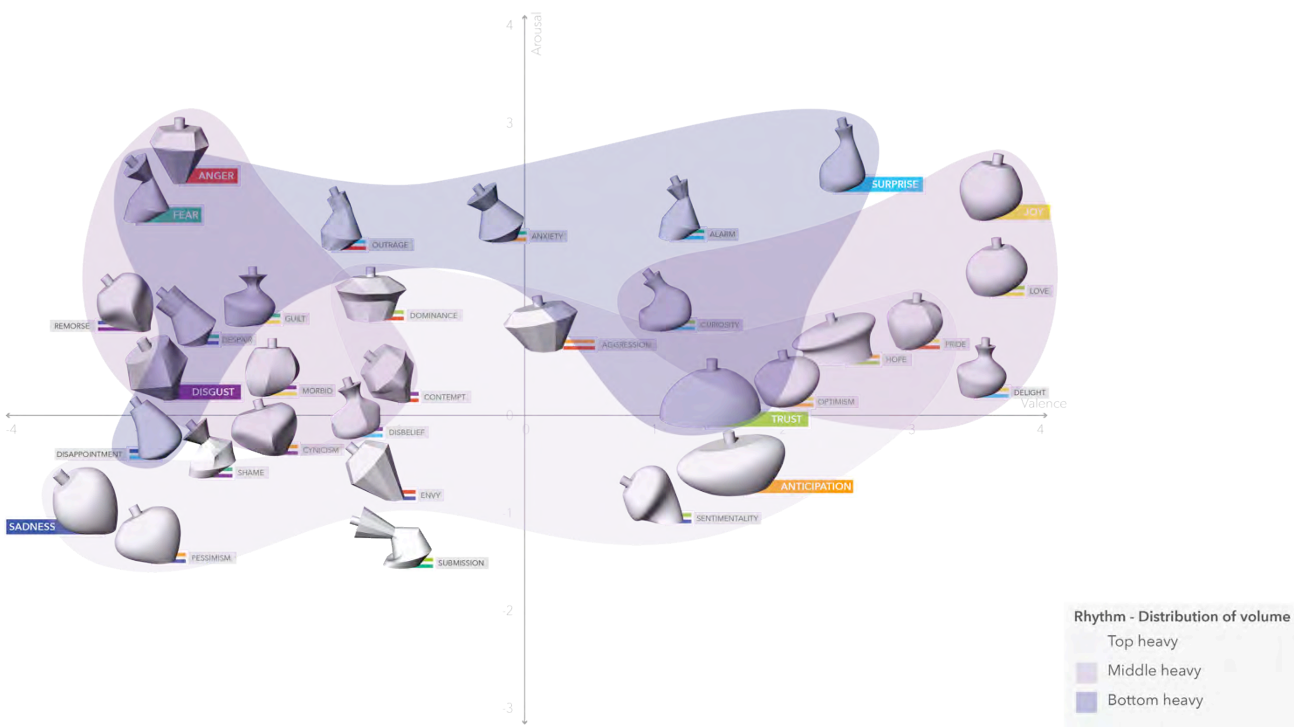
- ***Positive, low-energy emotions*** are represented by top-heavy forms with smooth big and medium curves leaning slightly back or horizontal, and with flat and wide aspect ratios
- ***Positive, high-energy emotions*** are represented by mainly middle or bottom-heavy forms with smooth or slightly angular medium and small curves leaning forwards or slightly backwards, and with aspect ration ranging from flat and wide to tall, round and slender
- ***Negative, high-energy emotions*** are represented by mainly middle or bottom-heavy forms with angular small and medium curves mostly leaning heavily forwards or backwards, and with predominantly round, tall and slender aspect ratios
- ***Negative, low-energy emotions*** are represented by mainly top-heavy forms with mostly smooth or slightly angular medium and big curves leaning heavily backwards, and with round, flat and wide aspect ratios



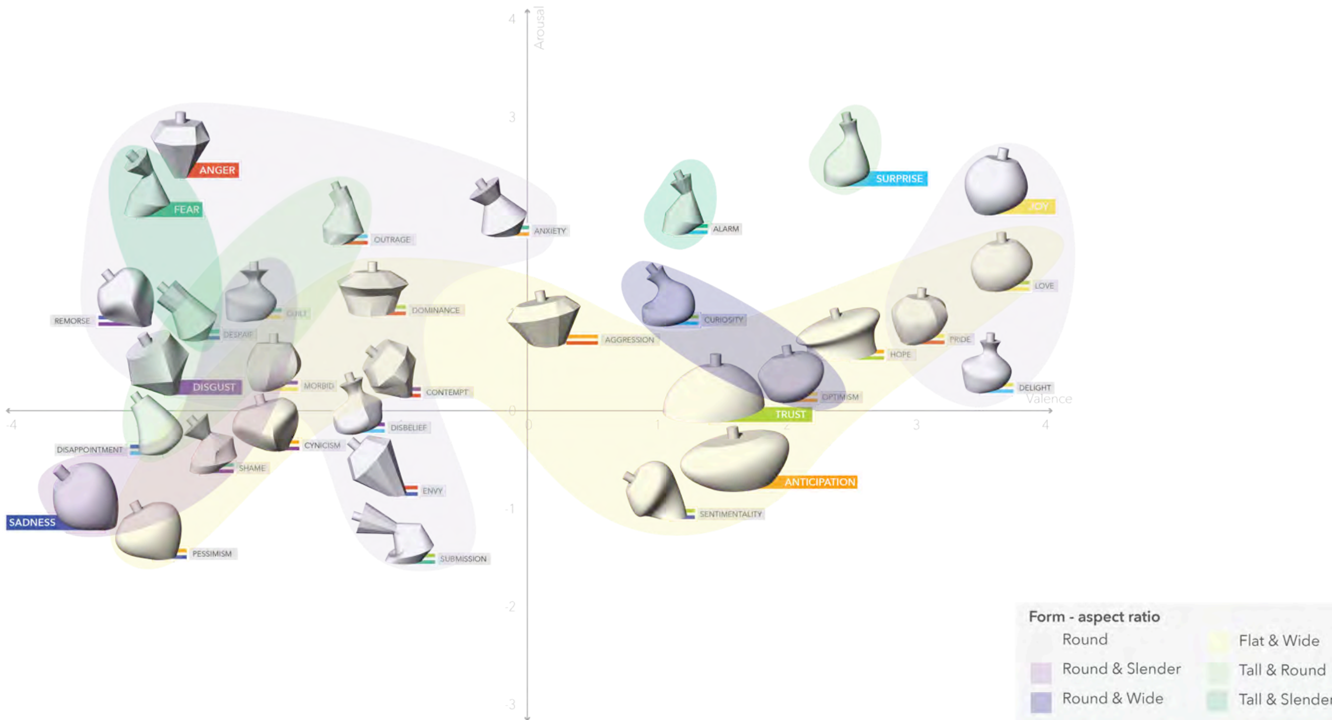
Form and rhythm design elements for the Plutchik primary emotion and dyad forms created from the quantitative emotive design taxonomy



Directional design elements for the Plutchik primary emotion and dyad forms created from the quantitative emotive design taxonomy



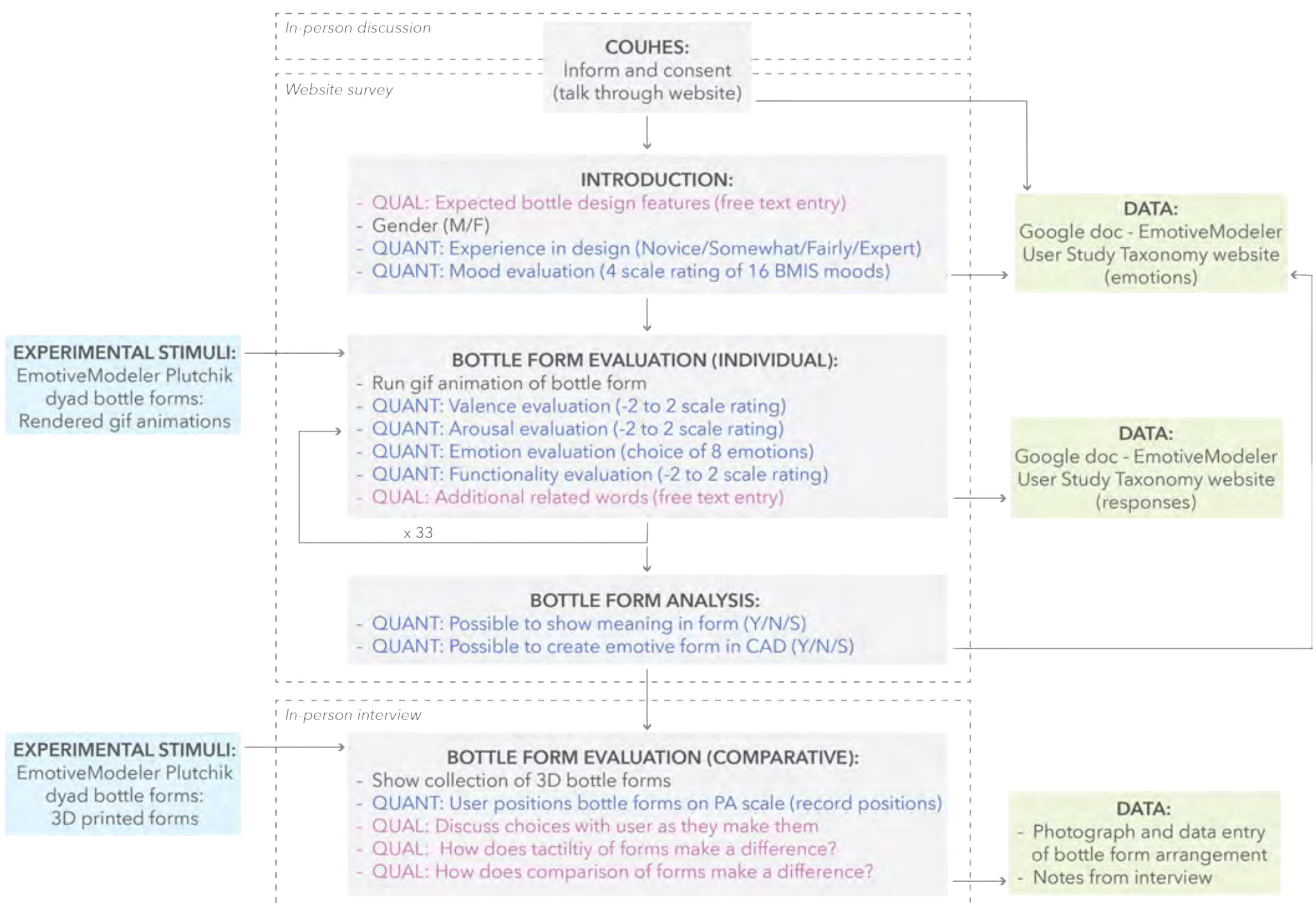
Direction-based rhythm design elements (i.e. the distribution of volume) for the Plutchik primary emotion and dyad forms created from the quantitative emotive design taxonomy



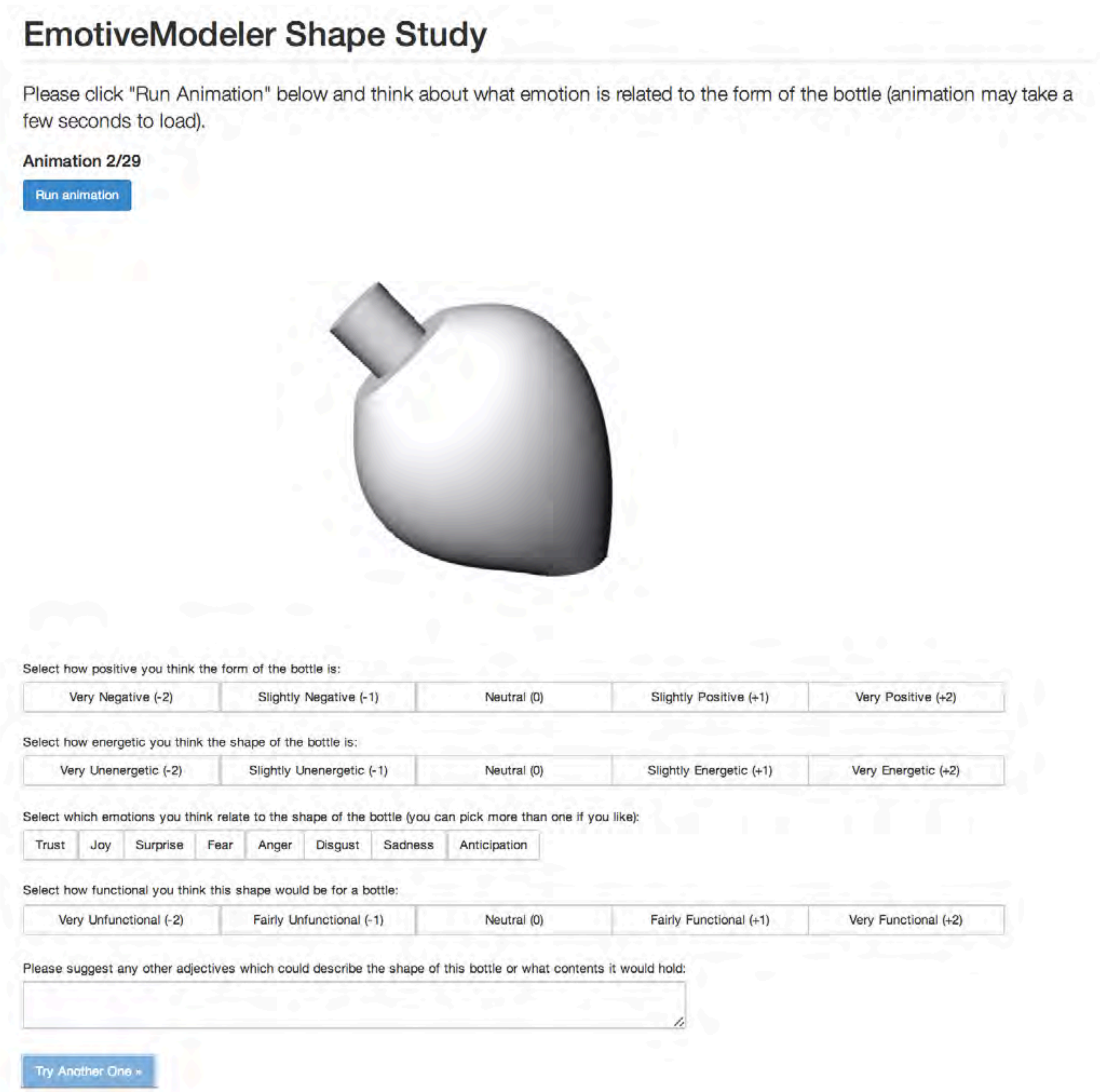
Direction-based form design elements (i.e. the aspect ratio) for the Plutchik primary emotion and dyad forms created from the quantitative emotive design taxonomy

7.2.8. Taxonomy Study Procedure

The taxonomy user study collected information on participants emotive perception of the 33 test forms. In an in-person computer based survey, 30 participants of ranging design abilities were asked to evaluate 2D animations of the test forms generated by the EmotiveModeler. Participants were first asked to rank each form for its perceived valence and arousal on a 5-point scale individually, and also asked to select an emotion and adjective that they relate to that shape from a list of words. Figure 30 shows the website used in this section of the study (data from this website was collected directly into a Google spreadsheet for further analysis after the study). In an in-person interview following this, participants were then given the full collection of physical 3D printed forms and asked to position them together on the valence-arousal circumplex, and discuss their perception of the forms and any effect the tactility and comparison had on their perception. Figure 31 shows the collection of 3D forms shown to the participants. Figure 32 shows a flow chart describing the questions and data collected in this study.



Taxonomy user-study flow diagram



Taxonomy study website to evaluate emotive perception of 2D animated forms

The 3D printed forms mapped onto the valence-arousal circumplex

7.2.9. Taxonomy Study Results: Summary of valence and arousal perception for the hypothesis and collected data for each emotive form

Emotion	Hypothesis		2D animations		3D printed forms	
	Valence	Arousal	Valence	Arousal	Valence	Arousal
Trust	Positive	High-energy	Positive	Low-energy	Positive	*Low-energy*
Joy	Positive	High-energy	*Positive*	*Low-energy*	*Positive*	*Low-energy*
Surprise	Positive	High-energy	Positive	*Low-energy*	*Positive*	*Low-energy*
Fear	Negative	High-energy	Negative	High-energy	Negative	*High-energy*
Anger	Negative	High-energy	*Positive*	*High-energy*	*Positive*	*High-energy*
Disgust	Negative	High-energy	Negative	*High-energy*	*Negative*	High-energy
Sadness	Negative	Low-energy	*Positive*	High-energy	*Positive*	Low-energy
Anticipation	Positive	Low-energy	Positive	Low-energy	Positive	*Low-energy*
Aggression	Positive	High-energy	Positive	High-energy	Positive	High-energy
Optimism	Positive	High-energy	Positive	Low-energy	Positive	*Low-energy*
Contempt	Negative	High-energy	Negative	*High-energy*	Negative	High-energy
Alarm	Positive	High-energy	*Negative*	*High-energy*	*Negative*	*High-energy*
Love	Positive	High-energy	*Positive*	*Low-energy*	*Positive*	*Low-energy*
Remorse	Negative	High-energy	*Positive*	High-energy	*Negative*	Low-energy
Disappointment	Negative	Low-energy	*Positive*	Low-energy	*Positive*	Low-energy
Submission	Negative	Low-energy	Negative	*High-energy*	Negative	*High-energy*
Pride	Positive	High-energy	Positive	*High-energy*	Positive	High-energy
Hope	Positive	High-energy	Positive	Low-energy	Positive	*Low-energy*
Cynic	Negative	High-energy	*Positive*	High-energy	Negative	High-energy
Despair	Negative	High-energy	*Negative*	High-energy	*Negative*	High-energy
Guilt	Negative	High-energy	*Positive*	High-energy	*Positive*	High-energy
Envious	Negative	Low-energy	Positive	*High-energy*	Negative	*High-energy*
Disbelief	Negative	High-energy	Positive	High-energy	*Positive*	High-energy
Curiosity	Positive	High-energy	Negative	*Low-energy*	Negative	*Low-energy*
Dominance	Negative	High-energy	Positive	High-energy	*Positive*	High-energy
Anxiety	Negative	High-energy	Positive	High-energy	Negative	*High-energy*
Morbid	Negative	High-energy	*Positive*	*High-energy*	*Positive*	High-energy
Shame	Negative	Low-energy	Negative	*High-energy*	Negative	High-energy
Outrage	Negative	High-energy	Negative	High-energy	Negative	*High-energy*
Sentimentality	Positive	Low-energy	*Negative*	Low-energy	Negative	Low-energy
Delight	Positive	High-energy	*Positive*	Low-energy	*Positive*	*Low-energy*
Pessimism	Negative	Low-energy	*Positive*	*Low-energy*	*Positive*	Low-energy
Neutral	Negative	Low-energy	Negative	Low-energy	Positive	Low-energy

(Key: green highlight = matches hypothesis; red highlight = does not match hypothesis; non-italics = statistically significant; italics = not statistically significant)

7.2.10. Taxonomy Study Results: Breakdown of related emotions for significantly similar emotive forms

	Emotive form with significantly similar valence & arousal	Most frequently associated emotions (hypothesis in bold)	Emotive form with significantly similar valence	Most frequently associated emotions (hypothesis in bold)	Emotive form with significantly similar arousal	Most frequently associated emotions (hypothesis in bold)
Positive-valence low-arousal	Trust	trust, anticipation (ok)	Surprise	trust, joy (no **surprise** - close, less energy)	Sadness	**sadness**, anticipation, joy (more positive)
	Anticipation	**anticipation**, trust, sadness (more negative)	Curiosity	sadness, anticipation (no **trust, surprise** - lower energy and more negative)	Remorse	**sadness**, trust, joy (no **disgust** - more positive)
	Optimism	sadness, **anticipation**, trust, **joy** (ok, more negative)			Disappointment	**sadness**, joy (not **surprise** but close, less energy)
	Hope	sadness, **anticipation**, **trust**, surprise, joy (ok, little bit more negative)			Delight	trust, **joy** (no **surprise** - not as high energy)
Negative-valence low-arousal	Outrage	**anger**, fear, disgust, sadness (no **surprise** - more negative)	Submission	anger, **fear**, surprise (no **trust** - high energy)	Despair	**fear, sadness**, disgust, anticipation (ok with a little more positive)
	Fear	**fear**, anticipation, sadness (more positive and lower energy)	Shame	anger, anticipation, surprise (no **fear, disgust** - more positive)		
			Disgust	anger, fear, anticipation (no **disgust** - higher energy)		
			Contempt	**anger**, fear, **disgust**, sadness (ok)		

Taxonomy Study Results: Breakdown of related emotions for significantly similar emotive forms (cont.)

	Emotive form with significantly similar valence & arousal	**Most frequently associated emotions (hypothesis in bold)**	**Emotive form with significantly similar valence**	**Most frequently associated emotions (hypothesis in bold)**	**Emotive form with significantly similar arousal**	**Most frequently associated emotions (hypothesis in bold)**
Positive-valence high-arousal	Aggression	surprise, joy, **anticipation** (no **anger** - more positive)	Pride	surprise, anticipation, **joy** (no **anger** - more positive)	Cynical	**anticipation**, surprise, joy (no **disgust** - more positive)
	Disbelief	sadness, anticipation, **surprise** (no **disgust** - not as negative high energy)	Envy	surprise, anticipation (no **anger, sadness** - more positive)	Guilt	anticipation, **joy** (no **fear** - more positive)
	Dominance	**trust**, surprise, joy (no **anger** - more positive)				
	Anxiety	**anticipation**, surprise, sadness (no **fear** - more positive and low energy)				
Negative-valence low-arousal	Neutral				Sentimentality	**sadness**, disgust (no **trust** - more negative)

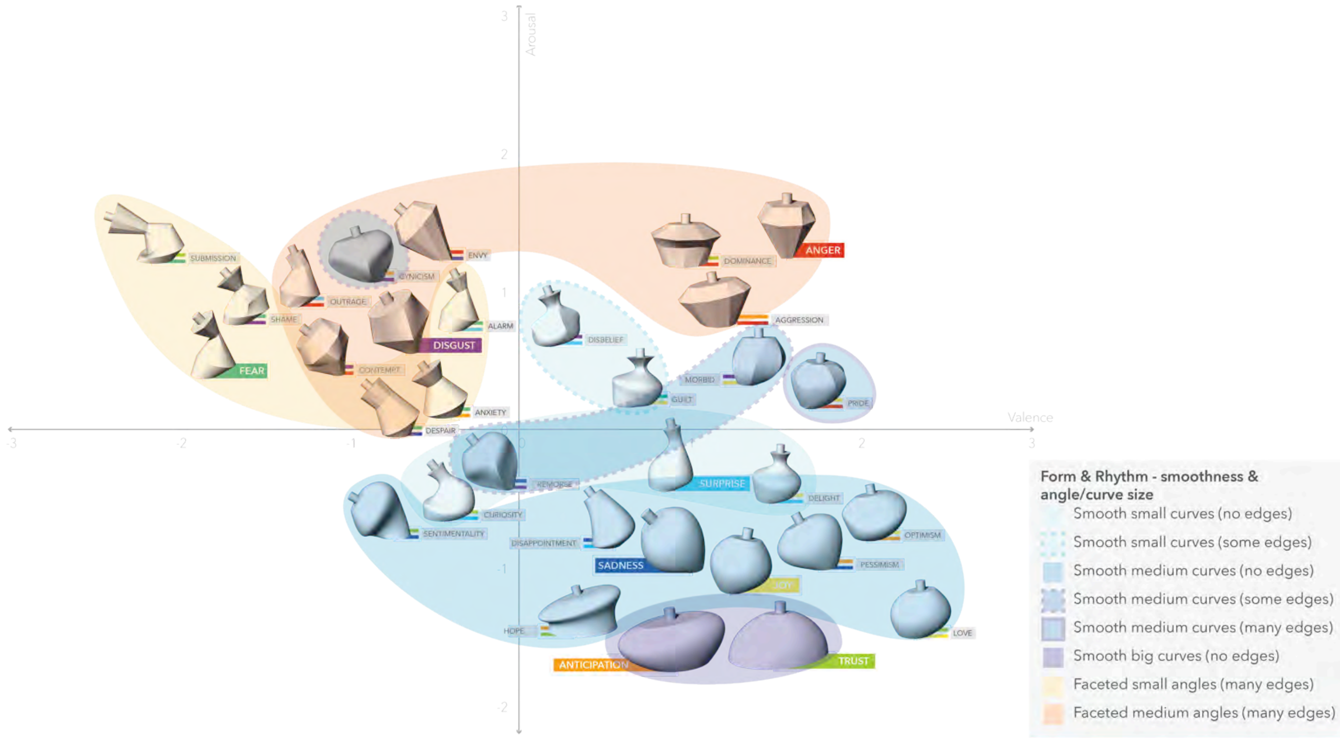
7.2.11. Taxonomy Study Results: Design elements for responses for the 3D form evaluations

- ***Positive, low-energy emotions*** are represented by bottom, middle or top-heavy forms with smooth small, medium and big curves leaning slightly forwards or backwards, and with flat, round and wide aspect ratios
- ***Positive, high-energy emotions*** are represented by middle or top-heavy forms with slightly edged or angular small or medium curves leaning straight or slightly forwards, and with flat round and wide aspect ratios
- ***Negative, high-energy emotions*** are represented by bottom-heavy forms with angular small or medium curves leaning heavily forwards or backwards, and with tall, round and slender aspect ratios
- ***Negative, low-energy emotions*** are represented by middle or top-heavy forms with smooth small or medium curves leaning heavily backwards, and with flat, round and wide aspect ratios

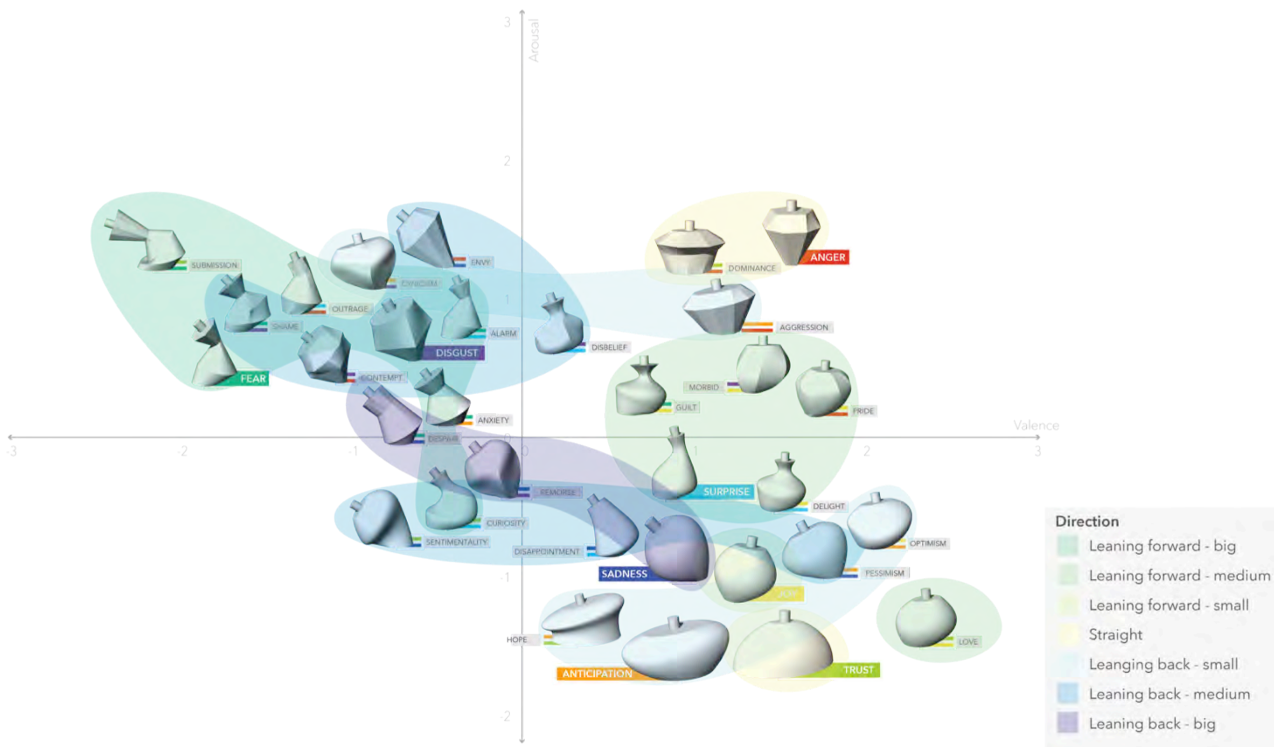
In general, responses to the forms created from the quantitative emotive design taxonomy show that the valence is generally represented by the rhythm, direction and distribution of volume design elements (positive valence = top-heavy, medium or big curves, leaning straight or slightly forwards or backwards; negative valence = bottom-heavy, small or medium curves, leaning heavily forwards or backwards), and the arousal is represented by the form and aspect ratio design elements (low arousal = smooth, wide and flat forms; high arousal = angular, tall, round and slender forms).

From these diagrams, it can be seen that the distribution of design elements for the 3D designs is very similar to that of the 2D designs. Some slight differences noted include:

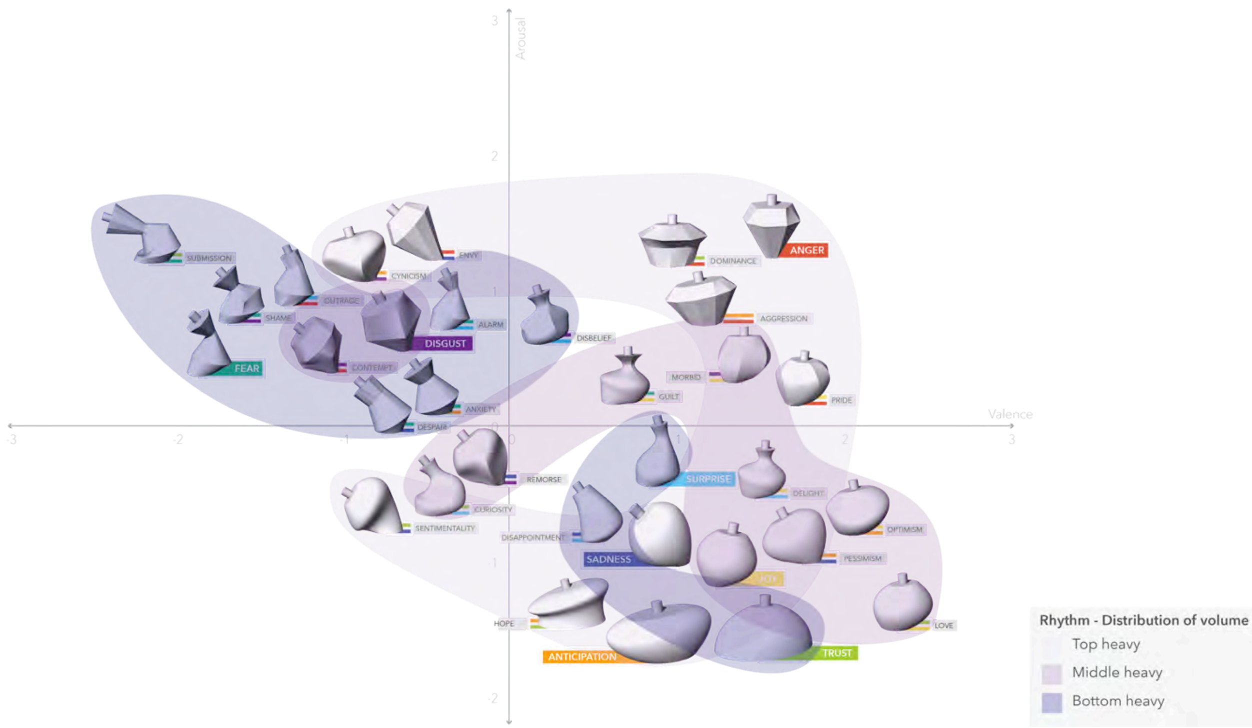
- Positive-valence high-arousal forms showed little leaning backwards direction design elements
- Negative-valence low-arousal forms showed more smaller curves



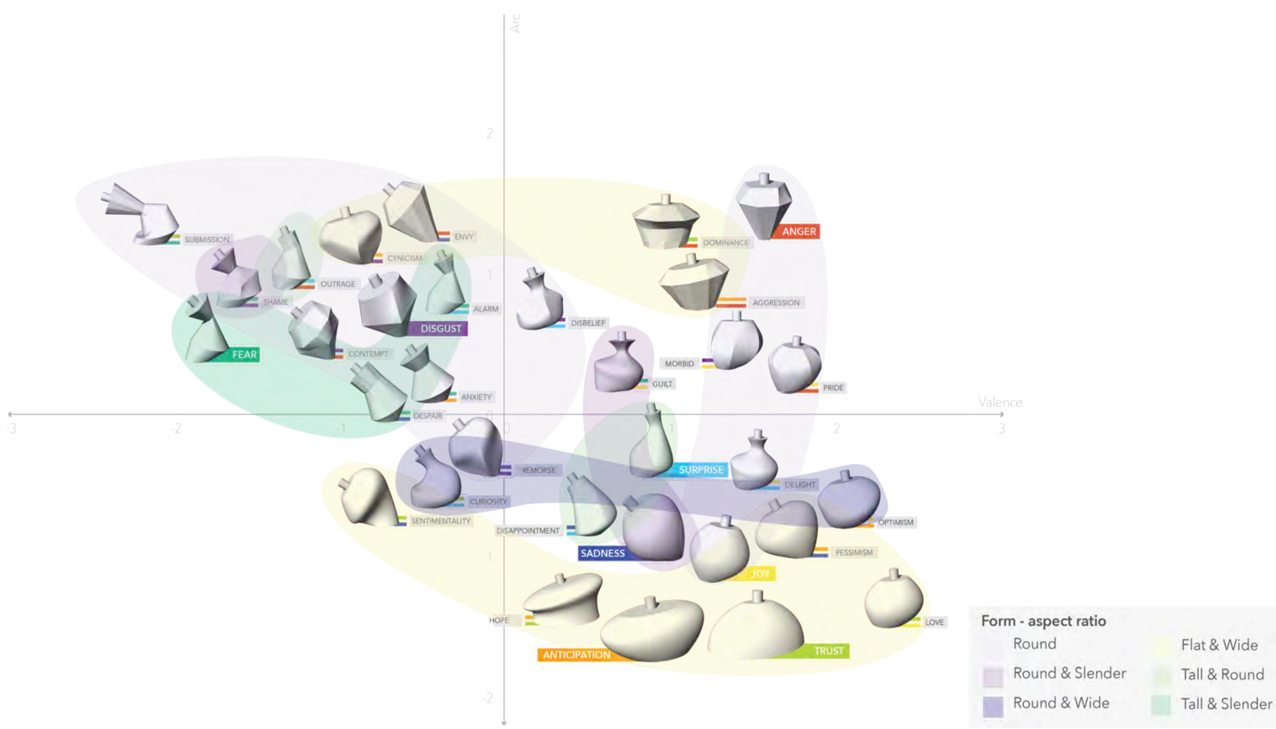
Form and rhythm design elements for the responses for the 3D stimuli



Directional design elements for the responses for the 3D stimuli



Direction-based rhythm design elements (i.e. the distribution of volume) for the responses for the 3D stimuli

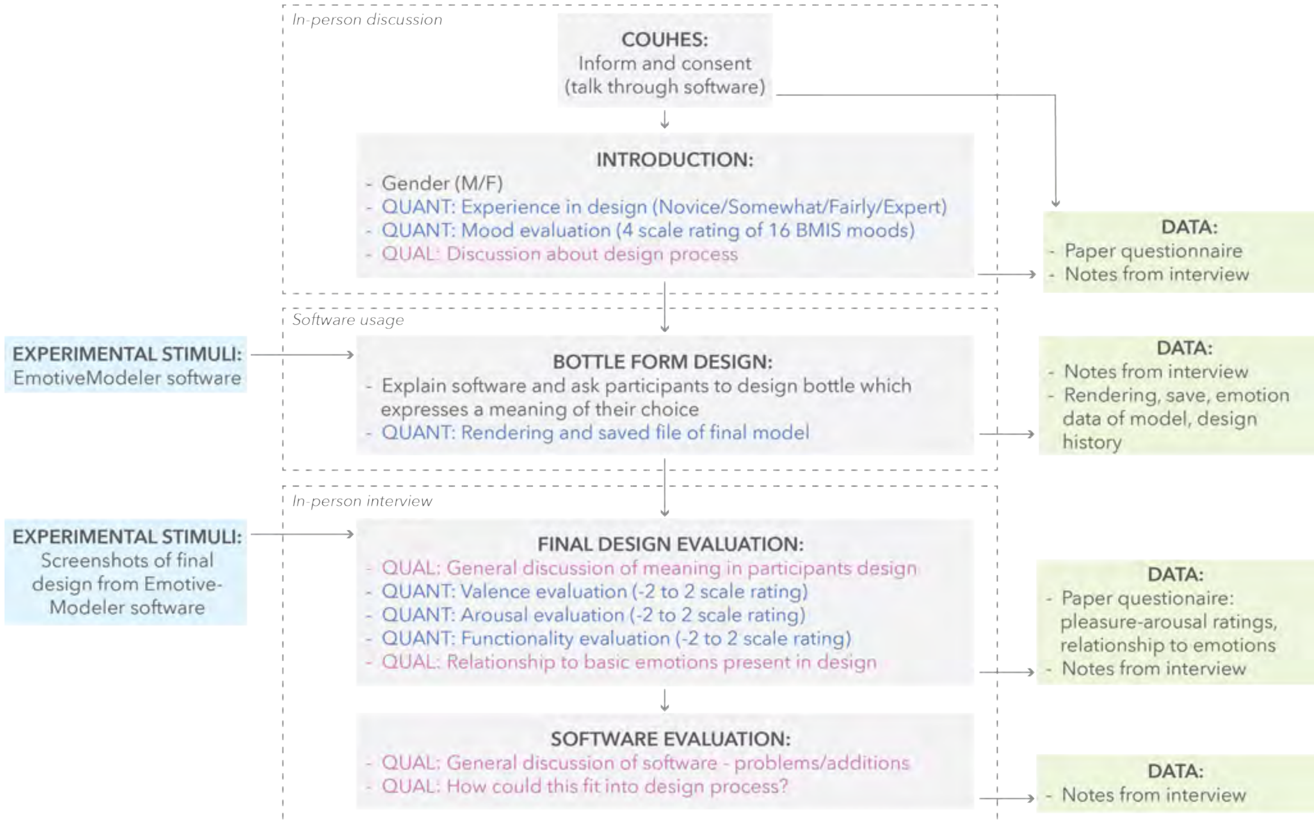


Direction-based form design elements (i.e. the aspect ratio) for the responses for the 3D stimuli

7.2.12. Design Study Procedure

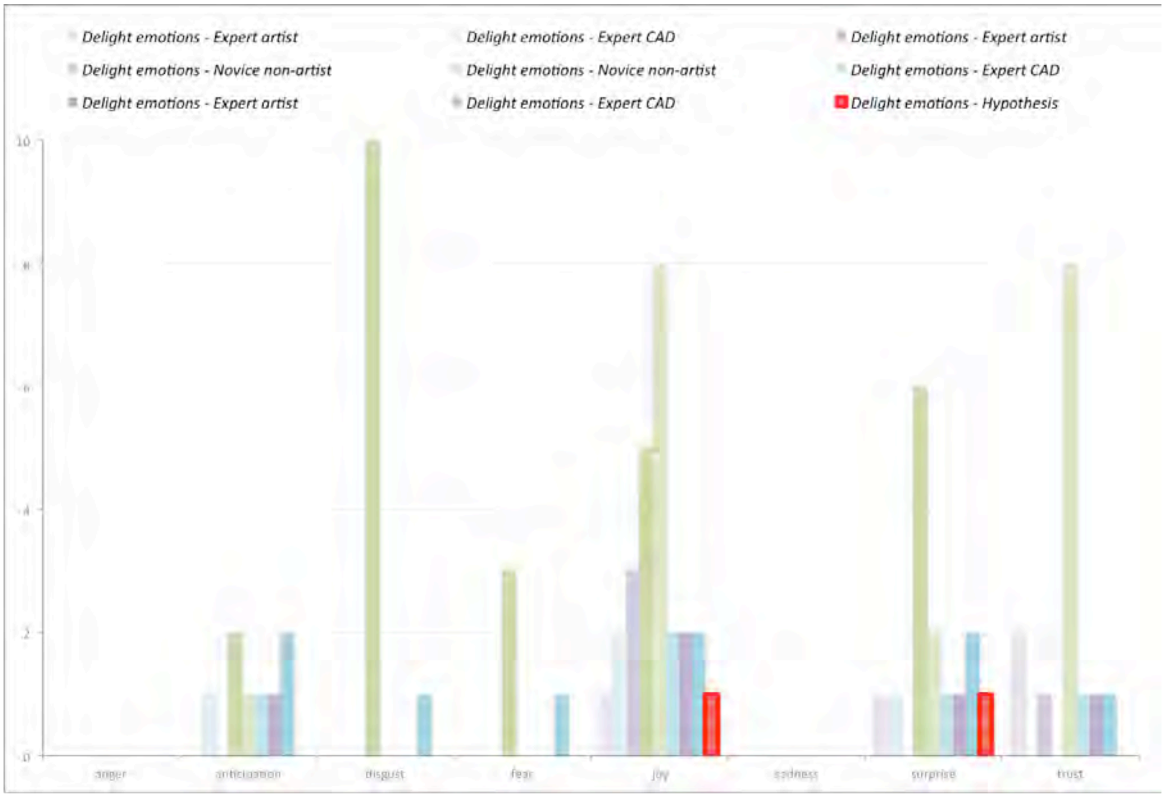
The design user study allowed participants to experiment with the CAD tool, and collected information on the designs created. After a short demonstration of the EmotiveModeler CAD tool functions, 8 participants of ranging design and CAD software abilities were asked to design bottles that conveyed the emotions ‘delight’, ‘hope’, ‘contempt’ and ‘despair’. These emotions (included in the Plutchik dyads) were selected as emotive forms from around the valence-arousal circumplex that the taxonomy study found to have similar valence and arousal perceptions to the hypothesis, and hence could be used as a benchmark in the feedback study. Participants entered these words individually into the EmotiveModeler and manipulated the primary emotion sliders in the UI until the form matched their expectations for the word. Participants were then asked to design bottles representing words of their own choosing: one single word design, and one multi-word design. In each of these design tasks, the final design and the emotions contained were saved as an image and a Rhino 3D model for further analysis.

After these design tasks were completed, these images of the six final designs and emotions contained were shown back to the participants and they were asked to rate their designs for their perceived valence, arousal and functionality on a 5-point scale. The participants were also asked to discuss how well they thought the allocation of primary emotions to generate the final form related to their expectations. Finally, the participants were then asked to discuss the usage experience of the software, and how it could be of use in their design process. Figure 41 shows a flow chart describing the design tasks, questions and data collected in this study.

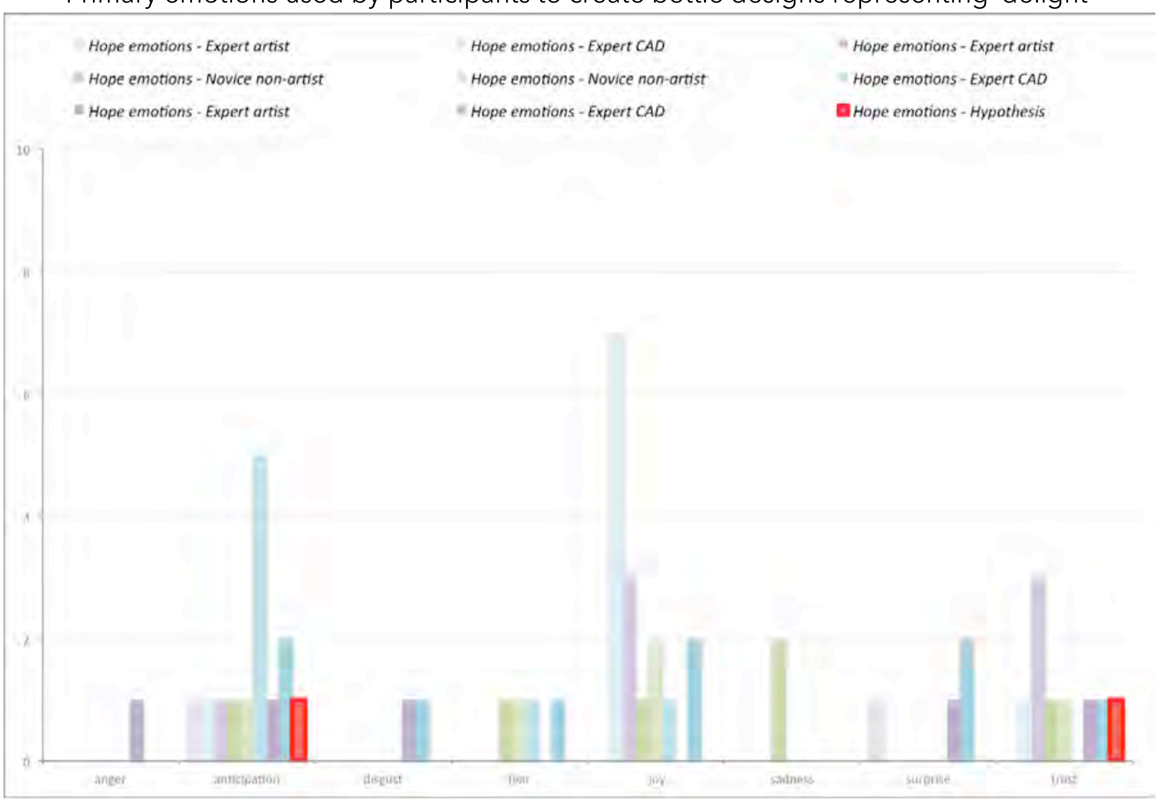


Design user-study flow diagram

7.2.13. Design Study Results: Primary emotions used in dyad designs

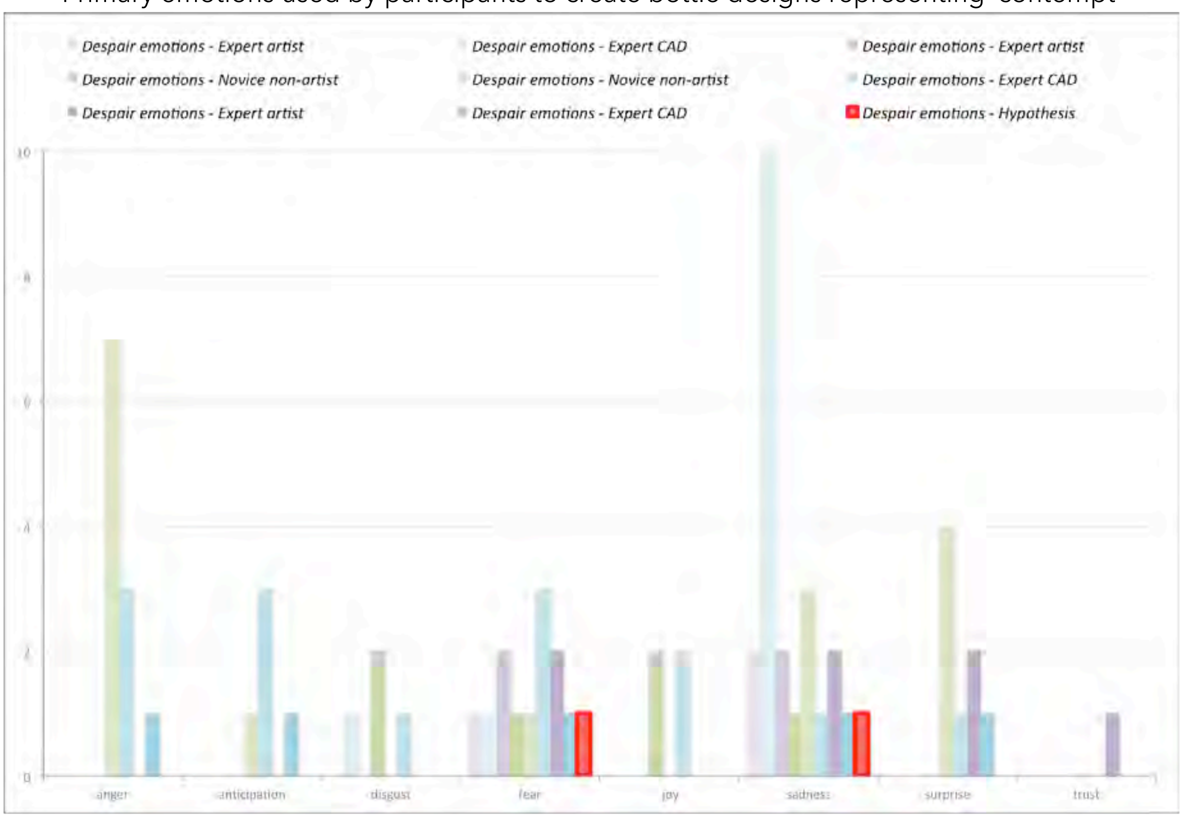


Primary emotions used by participants to create bottle designs representing 'delight'



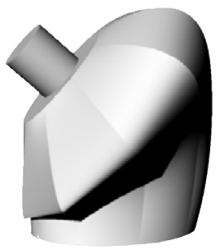
Primary emotions used by participants to create bottle designs representing 'hope'

Primary emotions used by participants to create bottle designs representing 'contempt'



Primary emotions used by participants to create bottle designs representing 'despair'

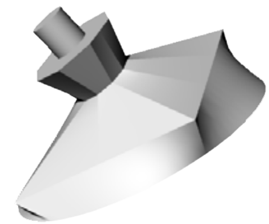
7.2.14. Design Study Results: Designs created using participants own emotive words



Confidence

Cold

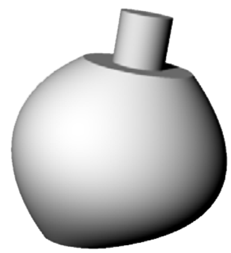
Cheerful



Decay

Energetic

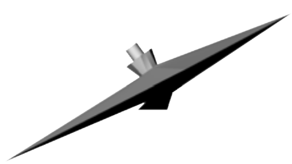
Lucky



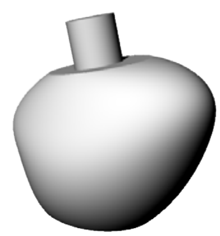
Pleased

Sumptuous

Compassion, intent, pursuit

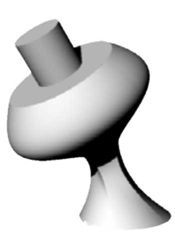


Aggression, cruel, fearful, sour

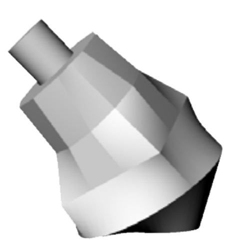


Confident, content, powerful

Elegant, friendly, iconic



Familiar, lust, sentimental



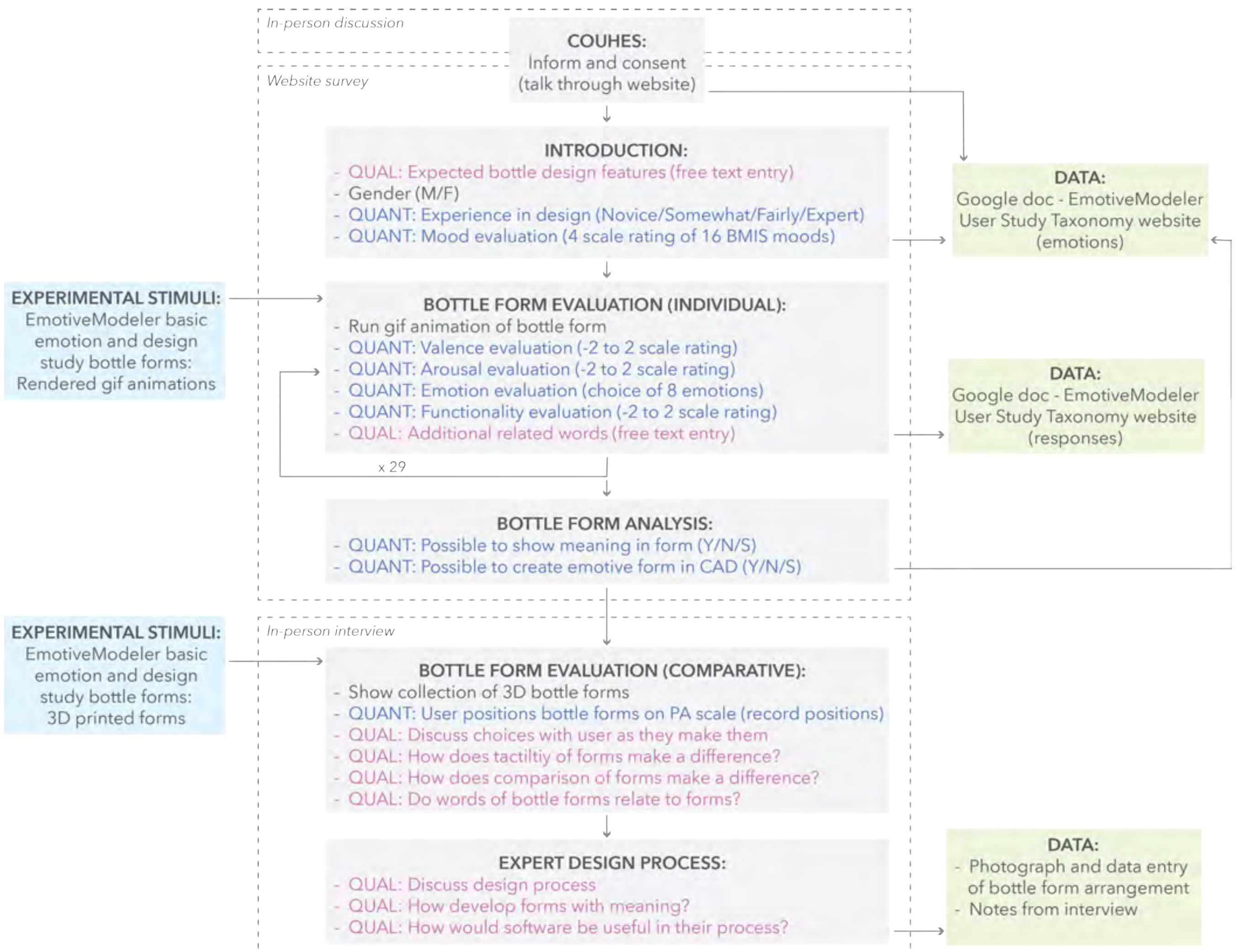
Fear, jealousy, sadness

Hot, molten, glass

Nervous, timid, playful

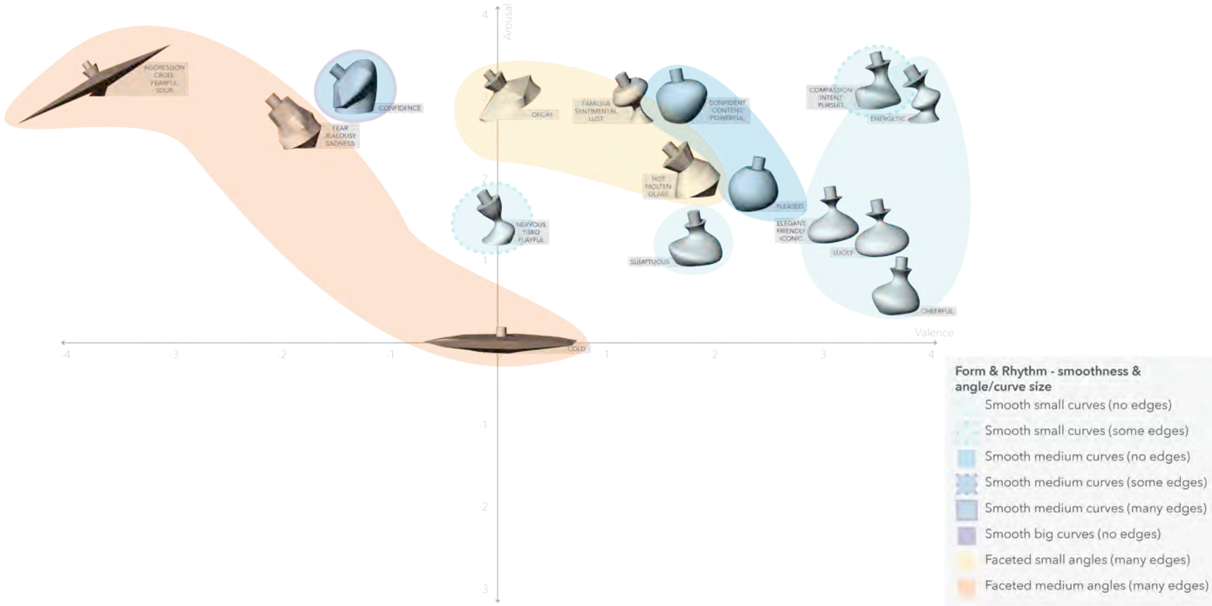
7.2.15. Feedback Study Procedure

The feedback user study has a very similar structure to the taxonomy study: an online survey collecting information about how participants perceive the 2D animated forms, and an in-person interview where participants arrange the 3D forms on the valence-arousal circumplex and discuss the designs. The forms that were used as stimuli included the eight primary emotion forms and the additional four dyad forms explored in the design study (delight, hope, contempt and despair), as well as the 16 new designs created by the participants in the design user study. Including the original primary emotion and dyad designs in this study allows the emotive perception of these known forms to be evaluated, and hence provide a benchmark for the analysis of the other new designs. Ten participants with an expertise in design were used in this study so that a knowledgeable opinion on the emotive designs could be obtained. Figure 42 shows a flow chart describing the questions and data collected in this study.

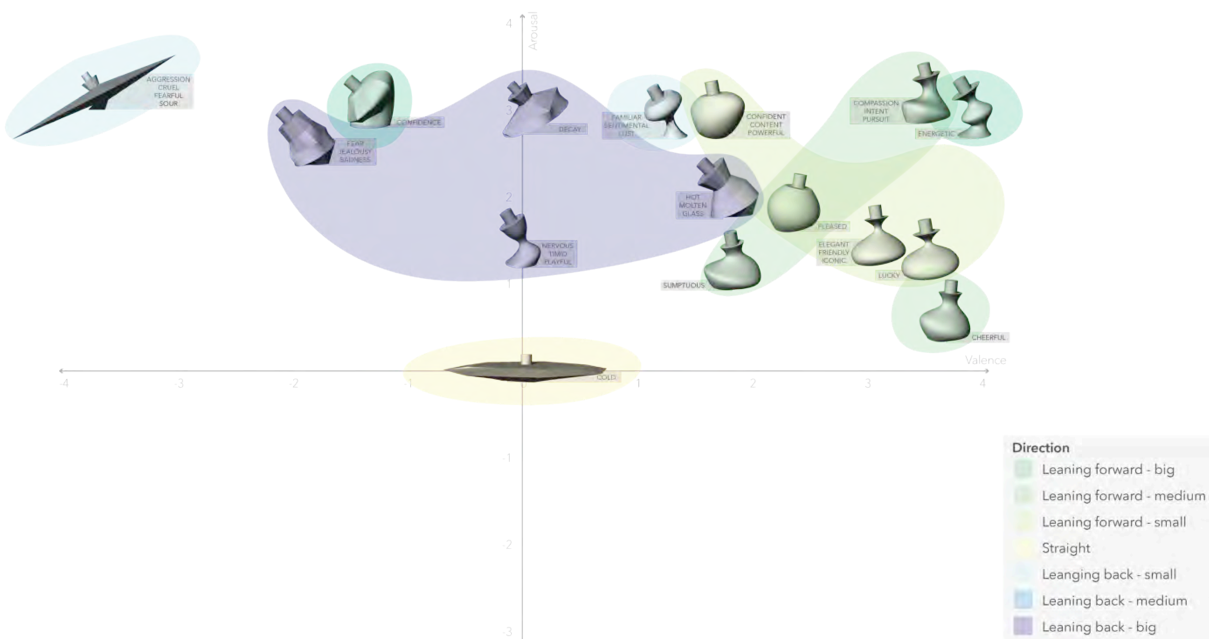


Feedback user-study flow diagram

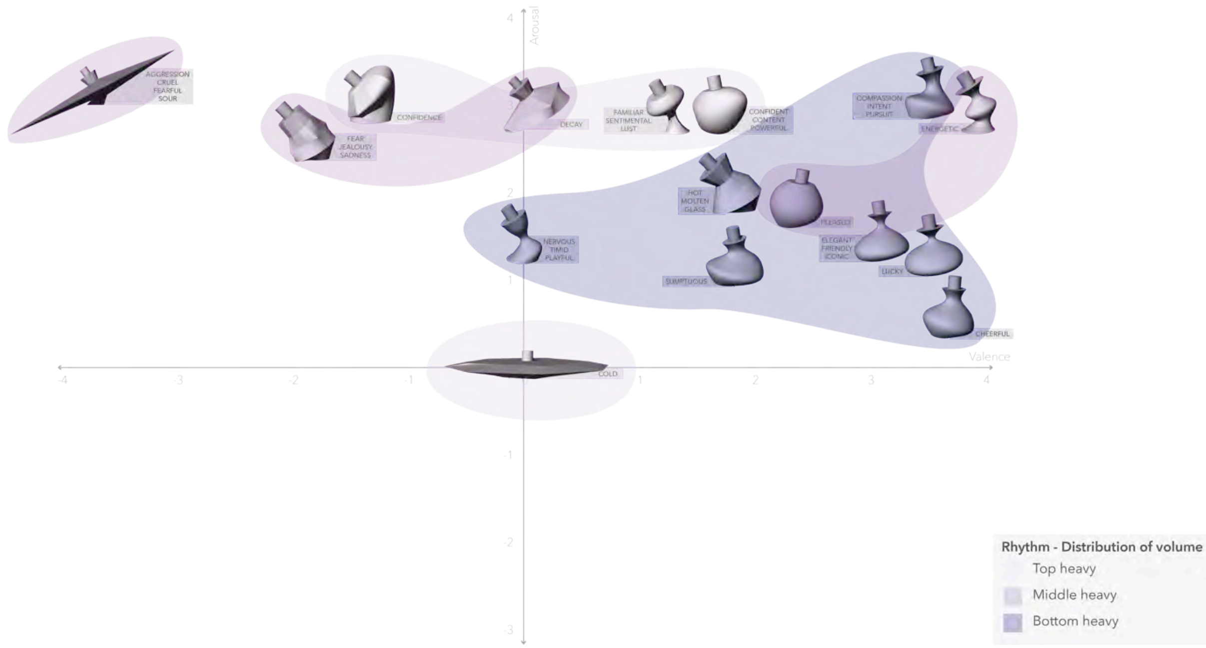
7.2.16. Feedback Study Results: Design elements for the designs created by the participants (designer's interpretation and animated test object responses valence-arousal values)



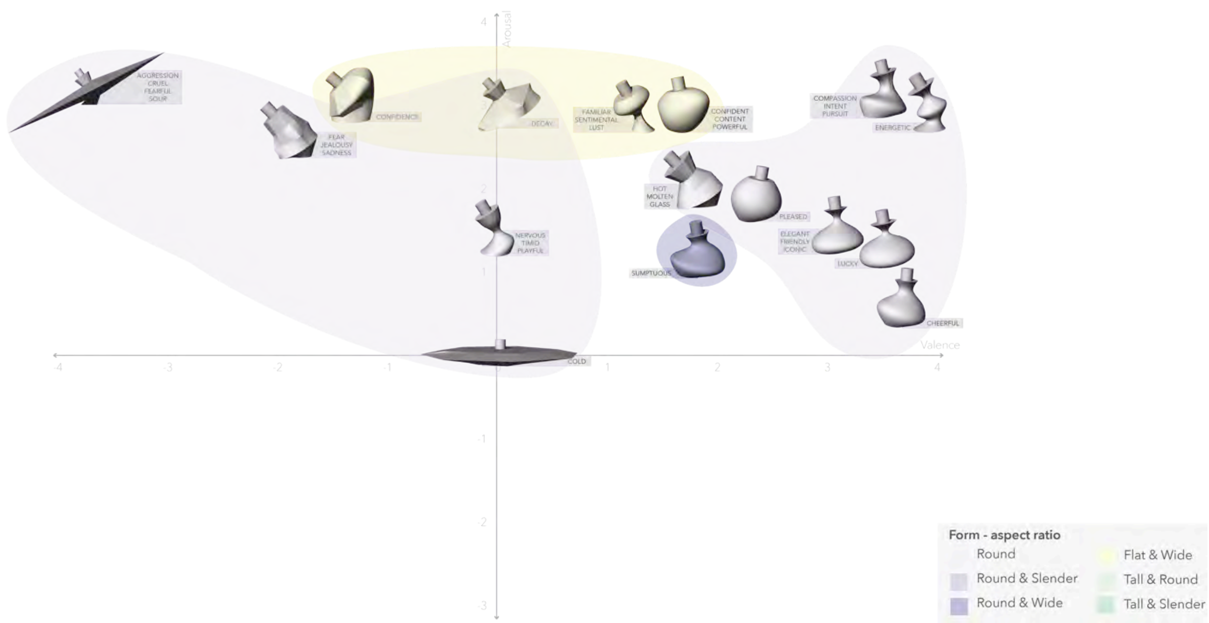
Form and rhythm design elements for the designs created by the participants, and their own valence-arousal interpretation



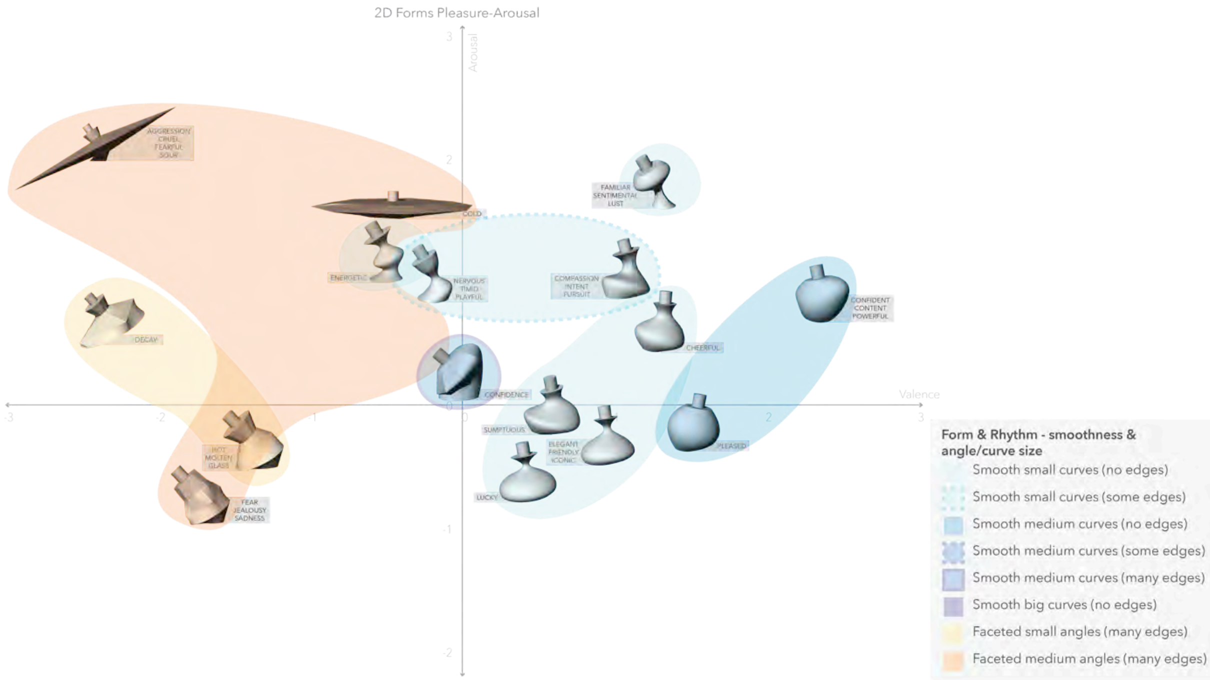
Directional design elements for the designs created by the participants, and their own valence-arousal interpretation



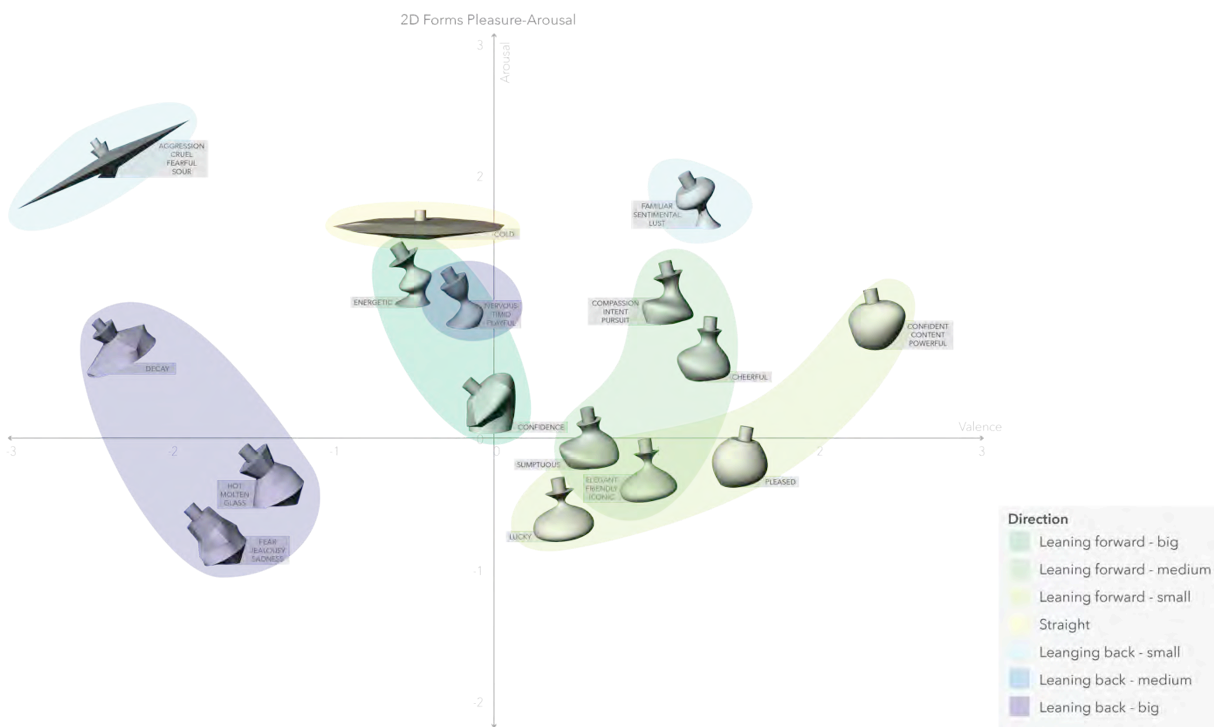
Direction-based rhythm design elements (i.e. the distribution of volume) for the designs created by the participants, and their own valence-arousal interpretation



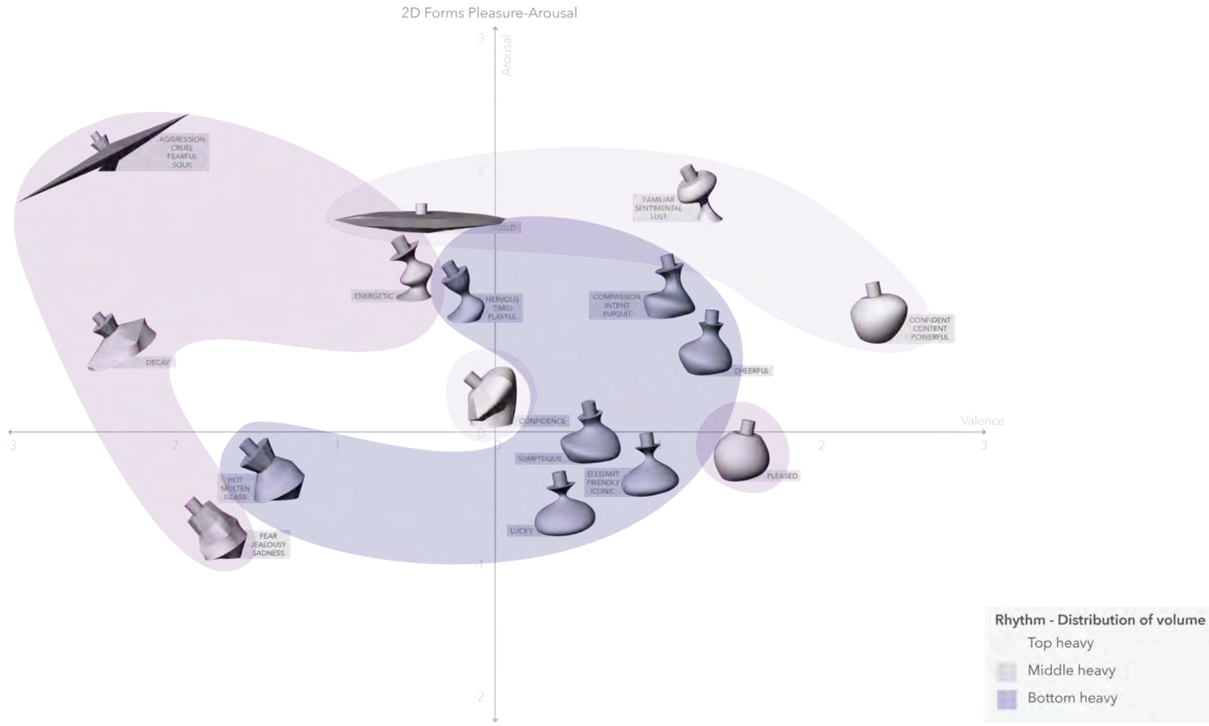
Direction-based form design elements (i.e. the aspect ratio) for the designs created by the participants, and their own valence-arousal interpretation



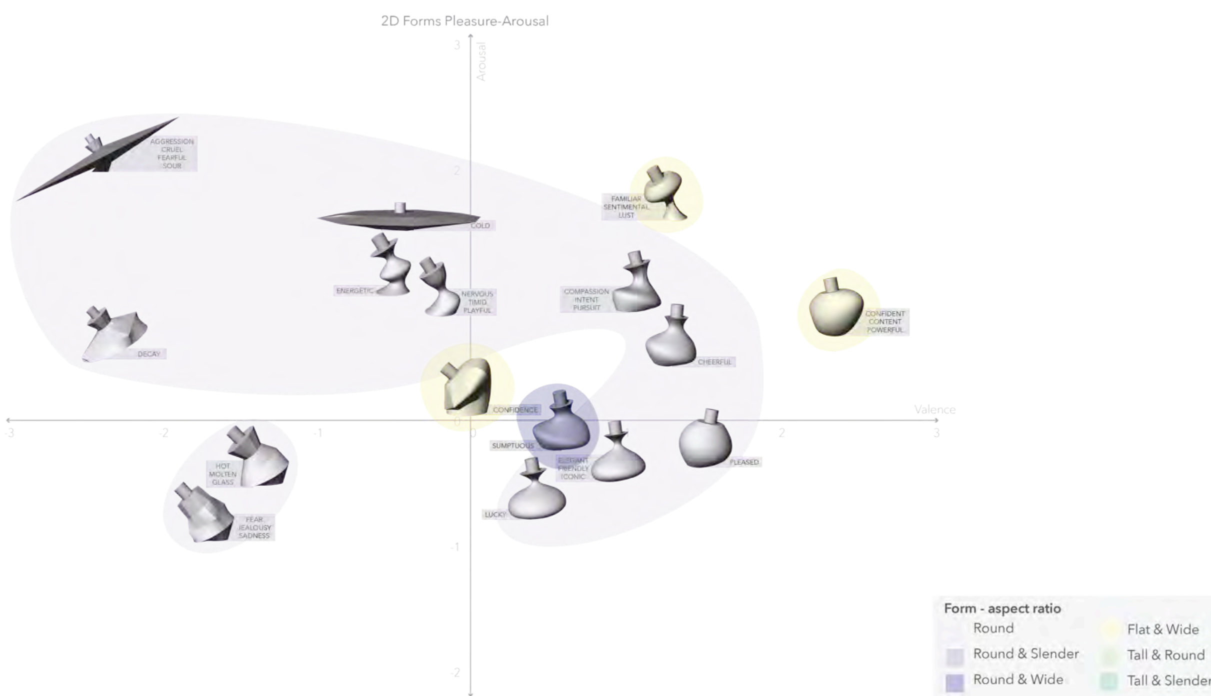
Form and rhythm design elements for the designs created by the participants, plotted using the animated test object response valence-arousal values



Directional design elements for the designs created by the participants, plotted using the animated test object response valence-arousal values



Direction-based rhythm design elements (i.e. the distribution of volume) for the designs created by the participants, plotted using the animated test object response valence-arousal values



Direction-based form design elements (i.e. the aspect ratio) for the designs created by the participants, plotted using the animated test object response valence-arousal values