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Engineering Aesthetics and Aesthetic Ergonomics:

Theoretical Foundations and A Dual-Process Research Methodology

Yili Liu, Ph.D.

Department of Industrial and Operations Engineering, University of Michigan,

Ann Arbor, MI 48109-2117, U.S.A.

Abstract

Although industrial and product designers are keenly aware of the importance of design aesthetics, they make aesthetic design decisions largely on the basis of their intuitive judgments and "educated guesses". Whilst ergonomics and human factors researchers have made great contributions to the safety, productivity, ease-of-use, and comfort of human-machine-environment systems, aesthetics is largely ignored as a topic of systematic scientific research in human factors and ergonomics. This article discusses the need for incorporating the aesthetics dimension in ergonomics and proposes the establishment of a new scientific and engineering discipline that we can call "engineering aesthetics". This discipline addresses two major questions: How do we use engineering and scientific methods to study aesthetics concepts in general and design aesthetics in particular? How do we incorporate engineering and scientific methods in the aesthetic design and evaluation process? This article identifies two special features that distinguish aesthetic appraisal of products and system designs from aesthetic appreciation of art, and lays out a theoretical foundation as well as a dual-process research methodology for "engineering aesthetics". Sample applications of this methodology are also described.

Keywords engineering aesthetics, aesthetic ergonomics, aesthetic human factors, a dual-process research methodology

1. Introduction

While aesthetics and appearance have always played a role in product and system design, this role will dramatically increase in the 21st century as the society and market become more sophisticated and the manufacturing technologies become further developed. To compete and succeed in the marketplace, manufacturers will have to look beyond reliability and physical quality, and pay more and more attention to the aesthetics and subjective quality of their products. In the more established technology sectors, product reliability is a “given” to the customers and is often regarded as a basic qualifying “ticket” to enter the market place. Other features and metrics, such as usability and aesthetics often separate the winners and losers.

Although industrial and product designers are keenly aware of the importance of design aesthetics, they rely largely on their “educated guesses,” “talents,” or “gut-feelings” in making design decisions (Noblet, 1993). Some of them also consult trend analyzer’s “hunches” and predictions. There is an obvious lack of systematic, scientific, and engineering methods to help them make aesthetic design decisions and conduct aesthetic evaluations. There is also an obvious lack of a scientific and theoretical foundation or framework to organize, communicate, and explain related ideas and concepts.

As a scientific discipline that devotes itself to the study of human-machine-environment systems, human factors and ergonomics has long established its goals of enhancing the safety, comfort, productivity, and ease-of-use of products and systems (Wickens, Gordon, Liu, 1998) and has made great strides toward achieving these goals. Although there have been calls for the expansion of the research scope of human factors to include emotional aspects of design and there have been some endeavors toward that direction (Jordan, 1998; Nagamachi, 1995), aesthetics has not generally been regarded as one of the central topics of human factors research.

In a closely related discipline, "consumer behavior" has long been one of the central topics of marketing research, where design and product aesthetics are examined from the perspective of how they may influence people's purchasing decisions and their preferences or behavior as buyers and consumers of market products (Holbrook and Huber, 1979; Sewall, 1978). Results of marketing research are extremely useful for product design, advertising, and marketing, but there are major limitations in its current scope of research: Because of its main focus on "marketing", it does not offer a comprehensive view of the design of human-machine-environment systems, many of which are not designed for "marketing" or "consumption" (Liu, 2000a). Examples of these systems abound and include hospitals, schools, and military and public service systems.

This article argues that it is time that we add aesthetics as an important dimension to human factors research. Furthermore, because design decisions may have ethical implications, it is also important to incorporate the ethics dimension explicitly and systematically in human factors research and practice. This argument can be further supported by a brief examination of three fundamental human pursuits.

As shown in Figure 1, ancient philosophers believe that all human pursuits can be classified into three fundamental categories: pursuit of truth, pursuit of beauty, and pursuit of the good and right. Corresponding to this trinity of fundamental pursuits there appears to be three types of judgments: the cognitive (or scientific), the aesthetic, and the moral, which are the topics of study in three main branches of philosophy: metaphysics, aesthetics, and ethics. Metaphysics addresses the issue of truth—the true and fundamental nature of the universe and existence (what truly exist). Aesthetics addresses the issue of beauty and related notions (e.g., tragedy, sublimity). Ethics addresses the issue of what is a good (or bad) thing and what is a right (or wrong) action. As some philosophers put it, “Truth, beauty, and the good may be the traditional staples of philosophy (Honderich, 1995, p. 14)”.

Insert Figure 1 about here

The foundation for traditional human factors is mainly that of metaphysics and the pursuit of truth, and traditional human factors issues can be organized along three dimensions: the arousing quality dimension, the dimension of information processing demands, and the dimension of psychosomatic soundness. A broader view of ergonomics should be based on all three pursuits, and should include an aesthetics dimension and an ethics dimension. We may use the term "aesthetic ergonomics" or "aesthetic human factors" to describe an ergonomic approach that systematically incorporates all the five dimensions (the aesthetics and the ethics dimensions, together with the three traditional dimensions). These five dimensions together offer a structured and comprehensive view of the diverse range of human-machine-environment systems and products, can help identify ignored important research areas, explain the demise of old work systems and products, and predict the possible emergence of new work systems and products. For example, these five dimensions help us realize that aesthetic ergonomics is not just about tangible products made to sell or consume; it is also about intangible systems, jobs, and environments. Aesthetic ergonomics is not just about design for pleasure; it is about displeasing situations as well.

As an illustration, the aesthetic dimension is shown in Figure 2 with the dimension of "psychosomatic soundness". Future workplace and products should not only be safe, but rejuvenating, as shown in Quadrant 1 (top-right quadrant) of Figure 2. Some products and activities can have negative psychosomatic consequences, although they may be pleasurable, as shown in Quadrant 4 (bottom-right quadrant), such as reckless thrills and additive behaviors. Similarly, not all healthful situations are pleasing or attractive to the experiencing person-- Physical rehab or drug rehabilitation programs can be extremely painful but healthful to the patient during the treatment process, as shown in Quadrant 2 (top-left quadrant). Quadrant 3 (bottom-left quadrant) shows displeasing and harmful situations that can be called stressful or even dangerous. But when the aesthetics and the ethics dimensions are examined together, certain dangerous/displeasing situations have high ethical values such as the jobs of prison guards, policemen, and firefighters. We often use words like "brave" and "heroic" to describe them.

Insert Figure 2 about here

In this article, I focus on the aesthetics dimension and emphasize the need to establish a research discipline that devotes itself to the systematic study of aesthetics in human-machine-systems, and we may call this discipline "engineering aesthetics". I discuss the theoretical foundations for this discipline and propose a comprehensive and rigorous dual-process research methodology for "engineering aesthetics".

2. Engineering aesthetics

The scientific discipline “engineering aesthetics” should address two major questions: 1) how can we use engineering and scientific methods to study aesthetic concepts in system and product design? 2) How do we incorporate engineering and scientific methods in the aesthetic design and evaluation process (beyond designer’s intuitions and trend analyzer’s “hunches”)?

As discussed later in this article, philosophers and art critics have been debating about the nature of beauty and other aesthetic concepts for a long time. Although these debates may offer important insights into aesthetic questions and provide useful perspectives from which we can examine aesthetic concepts, these debates are not, and they were not meant to be, scientific studies. Similarly, industrial designers in various fields of design have developed a large base of design heuristics, success stories, and winning strategies. They are extremely valuable “food for thoughts”. They may serve as a rich soil for the growth of the discipline of “engineering aesthetics,” and will in return benefit from the fruits of the discipline. However, designers’ heuristics are not, and they were not meant to be, scientific and engineering statements or findings.

In daily life, the word “aesthetics” is used widely in diverse contexts ranging from cosmetics and beauty salons to the appreciation of enjoyable objects and fine arts. However, currently in academic settings and scholarly discourse, the use of the term “aesthetics” is primarily centered around the theory of art and the criticism of the arts (Honderich, 1995). Encouragingly, a number of empirical studies of aesthetic concepts have appeared that can be found both inside and outside of the domain of arts (e.g., Hekkert and van Wieringen, 1996; Langlois and Roggman, 1990). Both the philosophical discussions and the empirical studies agree that aesthetic responses and appraisals are not limited to beauty judgments.

Rather, there is a whole range of aesthetic notions such as the sublime, the beautiful, the pretty, the humorous, the comic, the "cool," the fashionable, the funky, the ugly, and the tragic (Devereaux, 1997; Honderich, 1995). Further, aesthetic experiences and responses are multi-dimensional in the sense that overall aesthetic response is the joint outcome of a multitude of factors. The issues of debate among philosophers, art critics, and designers are what these factors are and how they contribute to aesthetic response, either positively or negatively. The goal of engineering aesthetics is to employ scientific, engineering, and mathematical methods to systematically identify and quantify the roles of aesthetic factors in system design.

In addition to the multidimensional nature of aesthetic experience, I would like to point out that aesthetic appraisals of products and work systems possess two special features: First, they tend to be multi-modal; and second, they tend to be interactive. These two features distinguish aesthetic appraisal of products and work systems from aesthetic appreciation of arts, and pose special and fascinating challenges to engineering aesthetics. Let me discuss the two features below.

First, aesthetic appraisal of product and system design tends to be multi-modal in the sense that more than one sensory modality is likely to be involved in the process. While fine art appreciation is primarily visual, aesthetic appreciation of a product or work system may involve the interplay between a person's visual, auditory, olfactory, tactile, haptic, and even proprioceptive systems. For example, the visual appearance and the surface texture of a perfume bottle are often as important as the perfume itself in a consumer's aesthetic evaluation of the perfume. Similarly, when making aesthetic appraisals of a potato chip, consumers examine with their eyes and feel with their fingers the shape, the contour, and the thickness of the chip. They smell with their noses and taste with their tongue the flavor of the chip, feel with their teeth and jaw the biting pressure, and hear with their ears the cracking sound of breaking the chip. A winning brand will have to please the consumer along all the modalities.

Second, aesthetic appraisal of a product or system may be not only multi-dimensional and multi-modal, but interactive as well. In other words, the consumer as an appraiser may not be a passive examiner of the appraised object. The appraiser may actively interact with the object, test its reactions, and communicate with the appraised, which may or may not "communicate back." For example, before purchasing a new car, we not only look and feel the car in a parking lot, but always test drive it to see how it responses in various driving situations and whether it offers us the "driving excitement." In a classroom or lecture hall, students and audience consider a speaker "engaging" if the speaker is not merely an object to look at and listen to, but a live person with whom they can interact in interesting ways.

Clearly, engineering aesthetics must develop theories and research methods to address all the three characteristics. In Figure 3, I propose a framework for representing the multi-dimensional, multi-modal, and interactive nature of aesthetic appraisal of art work, products and work systems. As illustrated in Figure 3, the overall aesthetic evaluation as a psychological response (Ψ_{AE}) is an integration of responses along various specific psychological dimensions, Ψj, j=1,...m, each of which is based on several physical or environmental dimensions, Φi, i=1, ..., n. Further, aesthetic evaluation is not a passive process. Individual characteristics of the perceiver, such as income level, age, gender, cultural background may influence how the perceiver selects and responds to the information from the environment/object, as shown by the arrows at the top of Figure 3, pointing from the individual to the environment/object and to the mapping processes between the Φ's and the Ψ's.

Figure 3 is not only a conceptual model of the processes involved in aesthetic evaluation; it also shows the various mathematical/statistical/experimental methods that can be used to examine these processes. For example, as discussed later in this article, content analysis and interaction analysis can be used to identify a list of the physical/environmental/task dimensions, Φi's, that may be relevant. Unidimensional scaling, multidimensional scaling methods, as well as methods such as factor analysis and cluster analysis can be used further to examine the relative importance of and the structural relationship among each of these dimensions in affecting the various psychological dimensions, Ψj's. In other words, how do the Φi's map onto the Ψj's? Conjoint analysis can be used to answer the following questions: How do the Ψj's combine to form the overall impression of Ψ_{AE}? What are the relative importance of each dimension in forming the overall impression of Ψ_{AE}? The hypothesized causal flows or relations in the model can be examined with causal modeling methods. Psychophysical and psychological experiments can be used to study the absolute and relative thresholds of the perceivers in aesthetic judgments and to establish related psychophysical magnitude functions. Later in this article I propose a dual-process research methodology and describe in detail the use of these methods for engineering aesthetics research. But first, let me briefly discuss the theoretical foundations for engineering aesthetics.

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insert figure 3 about here

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3. Theoretical Foundations

3.1. Philosophical theories

Although most philosophers agree that not all aesthetic judgments are about art, the philosophy of aesthetics is largely a philosophy of art. Discussions of aesthetic issues of art and beauty can be traced back to ancient Greek philosophy, but Kant's Critique of Judgment (Kant, 1790/1952) was generally regarded as the foundational work that established aesthetics as a distinct discipline within philosophy. The topics discussed by Kant such as the analysis of the beautiful and the sublime, the logic of aesthetic judgments, and the moral function of the aesthetic are still among the central issues of aesthetics today.

Philosophers in the school of aestheticism believe that aesthetic judgment or aesthetic attitude is a distinct judgment that exists "for its own sake," and is independent of any utilitarian, instrumental, cognitive, emotional, or moral judgments (Kant, 1790/1952; Bell,). But other philosophers such as instrumentalists believe that aesthetic objects are judged to possess aesthetic value because they are a means or instruments to some ends. They question whether we can and whether we should have a purely aesthetic judgment (Schiller, 1795/1967).

Some philosophers adopt an analytic view of aesthetics and attempt to identify the invariant elemental ingredients and compositional structure of aesthetic judgments, while some others examine aesthetics from a historical or sociological perspective to investigate the historical, social, and cultural factors that influence taste and aesthetic value. Some philosophers believe that aesthetics must engage itself with the philosophy of mind and metaphysics in order to achieve a deeper understanding of the relationship between the aesthetic value of an artwork, the mind of the artist, and the notions of intention, belief, and emotion. Some philosophers seek and embrace "an ethical turn" of aesthetics and make strong arguments about the moral function of art, the moral responsibilities of the artist, and the moral limits of aesthetic appreciation (Cooper, 1997; Honderich, 1995; Ross, 1994; Korsmeyer, 1998).

3.2. Psychophysical theories (also called formal or compositional theories)

While most psychologists date the birth of psychology as a scientific discipline in 1879, the year when Wilhelm Wundt established the first experimental psychology laboratory at the University of Leipzig, no one argues that the forerunner of experimental psychology was Fechner and his work in psychophysics. In fact, some psychologists choose to celebrate 1860, the year of publication of Fechner's Elements of Psychophysics, as the birth of psychology from the intellectual incubator of philosophy (Fechner, 1860).

Fechner developed experimental techniques and measuring methods for investigating the quantitative relationships between psychological responses and physical stimuli. Along with his research on sensory thresholds, psychometric functions, and psychophysical laws, he pioneered the experimental study of aesthetics (Fechner, 1876). His research approach is characterized by systematic manipulations of the dimensions of simple visual stimuli such as rectangles and ellipses with the research goal of discovering relationships between aesthetic response and the manipulated dimensions. Another goal of this research approach is to understand aesthetic responses to more complex objects such as real artwork through "synthesizing" research findings with more primitive pictorial elements. The research focus is mainly on identifying the basic pictorial features and compositional patterns that please or displease the senses. This "bottom-up" approach continues in the branch of modern experimental aesthetics that focuses on analyzing essential aesthetic features of stimuli such as shape, color, complexity, order, rhythm, novelty, and prototypicality that may affect an individual's aesthetic response (Austin and Sleight, 1951; Birkhoff, 1933; Boselie and Leeuwenberg, 1985; Eysenck, 1941; Farnsworth, 1932; Granger, 1955; Martindale and Moore, 1988; Schiffman, 1966).

A major criticism of this "bottom-up" approach is that aesthetic response to complex aesthetic objects such as an artwork is not simply the "sum" of the aesthetic responses to its components. The "top-down" approach attempts to understand aesthetic response as a whole. Real works of art or photographic images of nature are often employed as stimuli (Berlyne, 1971, 1974, 1975; O'Hare and Gordon, 1977). However, this approach encounters a major criticism that its lack of systematic control of the stimulus variables and dimensions renders its findings different to interpret. A more recent approach attempts to deal with both criticisms by employing stimuli that are based on systematic manipulations of realistic images along well-defined dimensions (Boselie, 1992; Nodine et al., 1993; Hekkert and van Wieringen, 1996).

3.3. Cognitive (Symbolic or association) and social theories

Many researchers in aesthetics and psychology believe that human aesthetic responses are influenced not only by the form or the apparent surface attributes, but also by the content or the symbolic meaning of the stimuli. Different individuals may have different aesthetic responses to the same object or stimuli because they carry different symbolic or connotative meanings to the individuals and evoke different memories or mental associations.

Research methods and results from cognitive psychology, sociology, and anthropology are borrowed to study the role of symbolic meaning, the stimulus features that carry symbolic meaning, and the acquisition of symbolic meaning for different individuals. Research methods and results from social and personality psychology are also employed to examine the role of personality, race, gender, and cultural backgrounds in aesthetic response (Adams and Crossman, 1978; Cunningham et al., 1995; Franzoi and Herzog, 1987; Jackson, 1992).

3.4. Ecological theories

According to the ecological approach to perception pioneered by Gibson (1977), there exists a direct relationship between animals and environment, and the animals (including humans) pick up relevant information in the ambient array directly. The ambient array refers to the ambient light with some sort of structure or arrangement, such as a pattern, a texture, or a configuration. The information in the ambient array is always relational in the sense that it always specifies the dimensions of the environment on the scale of the perceiver and the habitat it occupies. The information available to the perceiver is always veridical and complete in specifying the environment.

The central concept of ecological psychology is the concept of affordances introduced by Gibson, who states, "The affordance of anything is a specific combination of its substance and its surfaces taken with reference to an animal" (Gibson, 1977, p. 67). The affordance of anything is what it "offers the animal, what it provides or furnishes, either for good or ill" (Gibson, 1979, p.127).

The ecological approach to perception and the concept of affordances have been employed mainly in studies of motion perception, environmental support for action, and "usability" of objects. For example, in motion perception, according to Gibson, information for motion perception is contained in the ambient optic array that surrounds the perceiver. The flow patterns of the optic array, called optic flows, provide information for persisting or invariant structures of the environmental layout; they also provide information for the location and action of the perceiver with respect to the environment he moves in (Gibson, 1977). In action, experimental evidence showed that individuals make judgments of "usability" of objects according to their own action capabilities. They made judgments about whether a staircase affords climbing according to a constant proportion of their leg length with respect to the riser height and tread depth. Similarly, they judged the "sittability" of chairs and the "passability" of walkways with body-scaled information (Michaels and Carello, 1981; Turvey, Shaw, and Mace, 1978).

It is not clear how the concept of affordances can be fruitfully employed in the study of aesthetics. A chair's affordance may provide information to an individual about whether and how it affords or supports sitting. It is not clear how this affordance can please or displease the senses and elicit the aesthetic responses from the sitter. Is the concept of "affordances" alone sufficient to explain aesthetic responses? Do we need concepts such as "aesthetances, pleasantances, or excitances?" These questions need to be addressed in aesthetics research for those who adopt the ecological approach.

3.5. Natural and Sexual Selection Theories

Natural selection theories of aesthetic response essentially adopt a Darwinian approach to aesthetic theorizing, in that aesthetic responses are explained in terms of evolutionary adaptation and survival. For example, Appleton (1975) suggests that the kind of landscapes that are most pleasing to humans once would have provided us a "refuge" from potential danger or a "prospect" for exploration of surrounding environments (Appleton, 1975). Langlois and Roggman (1990) suggests that cross-cultural preferences for attractive faces may be explained by evolutionary processes that favor symmetrical, average, and prototypical facial features (Langlois and Roggman, 1990).

It has been suggested that symmetric faces may reveal a higher level of ability to resist parasites. Many adult male facial and body features that are now regarded as attractive once would also have supported him to be a stronger hunter. Many adult female facial and body features that are considered attractive may also reveal higher fertility levels that are critical for reproductive success (Buss, 1999; Buss and Barnes, 1986).

While natural selection theories focus on the survival of the species or the individual, sexual selection theories explain aesthetic response from the perspective of sexual desire and mating opportunity. Many exhibitional or decorative features of animals enhance their mating opportunities (such as the beautiful plumage of birds and the musky odors of some animals in mating season), although these features are not necessarily beneficial and may be harmful to individual survival (such as the peacock's tail and some deers' large antler) (Buss, 1985; Johnston and Franklin, 1993)

4. A Dual-Process Research and Evaluation Methodology

As illustrated in Figure 3, aesthetic appraisal or evaluation of products and systems is multidimensional, multimodal, and interactive. The theories and research approaches described above either focus on one aspect or dimension of aesthetic response or are qualitative in nature. To achieve a comprehensive, rigorous, and quantitative understanding of aesthetic responses in a design context, we need to ask two sets of questions. The first set is "top-down": what is the conceptual and mathematical structure of the aesthetic constructs in question? What are the major psychological and physical dimensions involved? How do we measure and scale these dimensions (ordinal, interval, or ratio scale)? How are the dimensions related to each other and what is the relative importance of each dimension? What type of multidimensional evaluation scale can be developed to measure the aesthetic construct with adequate validity and reliability?

The second set of questions is "bottom-up:" how sensitive are the perceivers in detecting small variations in aesthetic variables? What are their absolute and relative thresholds in detection? What are their abilities to perceive and judge values, changes, and variations in design parameters? What are their preferences of the levels of values of aesthetic variables?

The two sets of questions can be addressed by two types of research methods, as shown in the dual-process engineering aesthetics research methodology proposed by Liu (2000b). This dual-process methodology consists of two parallel but closely related lines of research (Figure 4). The first process (shown on the left side of Figure 4) is called "multidimensional construct analysis or multivariate psychometric analysis", whose goal is to establish a "global", "top-down", and quantitative view of the critical dimensions involved in a specific aesthetic response process. The second process (shown on the right side of Figure 4) is called “psychophysical analysis”, whose objective is to establish a “local”, "bottom-up", and quantitative view of the individual’s perceptual abilities in making fine aesthetic distinctions along selected dimensions. It identifies how keen the perceivers’ senses are in detecting variations along critical aesthetic dimensions and how their preference levels change as a function of specific design parameters or aesthetic variables.

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insert Figure 4 about here

Let us use aesthetic judgments of coffee taste as a concrete illustration. The top-down process asks questions such as: What attributes affect a person's judgment of coffee taste-- coffee temperature? cup shape? cup size? milk/sugar concentration? How important is each attribute and how do they relate to each other? The bottom-up process asks questions such as: Suppose we know coffee temperature is important, then how sensitive are the coffee drinkers in judging variations in coffee temperature? Suppose the most preferred temperature is 85 degree Fahrenheit, selling coffee at exactly 85 degree can be very costly for a coffeehouse. So we need a "local", psychophysical study to establish the difference threshold of coffee temperature judgment. If the study reveals that a person cannot tell the difference between coffee of 85 degrees and those between 82 and 88 degrees, then it is much more economical to run a coffeehouse with this knowledge. Similarly, if the "global" process reveals that a flat and smooth surface is one of the important issues for certain products, then we need to use the "local" process to examine how flat and smooth the surface has to be in order to be perceived as flat and smooth. This "local" process can help make products not only more aesthetic, but also more economical (reduction of production cost) and more ethical (reduction of natural resource consumption and pollution, and better environmental protection).

The "top-down" process shares the same types of psychometric questions with research areas such as attitude measurement in psychology (Dunn-Rankin, 1983) and mental workload measurement in human factors (Hart and Wickens, 1990). The "bottom-up" process employs psychophysical concepts such as the concept of just noticeable difference (jnd), which has been studied in sensation and perception research (Gescheider, 1983) and in some areas of human factors (Helander, Little, and Drury, 2000). The example discussed above illustrates that engineering aesthetic issues need to be examined from both the psychometric and the psychophysics perspectives.

4.1. Multidimensional construct analysis or multivariate psychometric analysis

The specific objective of this line of research is to develop a comprehensive and quantitative understanding of the multidimensional conceptual structures of the aesthetic constructs in a specific domain of aesthetic evaluation. For some domains of research and application, this process may also be used to develop a multidimensional evaluation scale for the aesthetic constructs in question.

As shown on the left side of Figure 4, the first stage after literature review consists of at least three major types of analysis: content analysis, interaction pattern analysis, and marketing and other data analysis. In content analysis, researchers use well defined procedures to analyze selected texts with the aim of obtaining useful insights into a research question and make valid inferences about their substantive problems. The texts analyzed can come from a variety of sources, including formal or informal open-ended interviews and surveys, related magazines and other publications, and historical archival materials. Historical materials are particularly valuable and must be used if the researchers need to analyze trends and patterns of change in time. Interaction analysis refers to the process in which researchers use systematic methods to measure how the individual interacts with the object, such as the individual's eye movement pattern in examining the object, the hand movement pattern in touching or manipulating the object, and various facial expressions in interacting with the object. Marketing and other data sources provide information about customer's comments, patterns of purchasing and refund, demographic data, and so on. These data can help researchers achieve a preliminary understanding of the many factors involved and prepare a set of specific questions to be used in the next stage—formal or structured interviews.

In the structured interview stage, researchers use the set of questions prepared on the basis of Stage 1 to delve more deeply into the aesthetic judgment space in the individual's minds, while continue to raise open-ended questions. As shown in Figure 4, researchers may need to go through several rounds of iteration between Stage 1 and Stage 2 before they are ready to construct scales and questionnaires.

In Stage 3 researchers should use unidimensional scaling methods and survey methods to construct subjective rating scales. Unidimensional scaling methods such as Thurstone's comparative judgment, Green's successive intervals, Likert's summated ratings, item analysis methods, and Steven's direct ratio scaling methods can be compared and selected for the specific purpose of the research (Dunn-Rankin, 1983). The quantitative data in Stage 1 and Stage 2 mainly come in the form of frequency of occurrence of certain words or frequency of eye fixation at certain locations. Frequency of usage is regarded as an indication of importance. In Stage 3, the main quantitative data come from subjective ratings on well-constructed unidimensional scales.

In Stage 4 subjective rating data collected in Stage 3 and other relevant data such as interaction pattern data and marketing data collected in Stage 1 are analyzed with multivariate statistical data reduction methods such as cluster analysis, factor analysis, multidimensional scaling, and individual differences scaling (Dunn-Rankin, 1983). These methods will help reveal the hidden structure of the multivariate data set and uncover the underlying structure of the investigated construct. Conjoint analysis can be used to answer the following questions: How do the various psychological dimensions combine to form the overall aesthetic impression and judgment? What is the relative importance of each dimension in forming the overall aesthetic judgment (Louviere, 1988). The hypothesized causal flows or relations between various variables and dimensions can be examined with causal modeling methods such as path analysis (Asher, 1983).

Interpretation of the results of Stage 4 requires substantive and theoretical considerations as well as statistical ones. In fact, interpretability, ease of comprehension and communication, theoretical and substantive supports often play a central role in choosing among alternative explanations of data. Due to the nature of the research questions involved, this line of research tends to be highly iterative, explorative, from more open-ended at the beginning to more "structured" at the latter phase. This iterative nature is illustrated with bi-directional arrows between various stages on the left side of Figure 4.

4.2. Psychophysical Experiments

The specific objectives of this line of research, shown on the right side of Figure 4, are to use psychophysical methods (Gescheider, 1985) to investigate quantitatively an individual's perceptual abilities in making fine aesthetic distinctions along selected dimensions. It identifies how keen the perceivers' senses are in detecting variations along critical aesthetic dimensions and their preferences levels for specific design parameters or aesthetic variables. The major research questions are: What are the perceiver's abilities to perceive and judge values, changes and variations in aesthetic variables or design parameters? What are their patterns of preferences? More specifically, what are their absolute and relative sensory thresholds? What is the quantitative relation between an individual's response (preference or ability to perceive or judge) and changes in specific aesthetic variables (often called "psychophysical magnitude functions)?"

Well-controlled single or multi-factor psychophysical experiments should be used in this line of research. Psychophysical methods of constant stimuli, method of limits, method of adjustment, and the direct ratio scaling methods should be compared and selected for use in these experiments. Other methods of sensory and percetual reseach such as signal detection theory can also be used as appropriate. The results of psychophysical experiments may offer insight into the issues of scale development and data pattern interpretation conducted along the first line of research as well.

4.3. Some main differences between the dual-process methodology and Kensei engineering methods

Kansei Engineering (Nagamachi, 1995) is a very valuable method for considering consumer preferences in product evaluation and development and has been applied in a variety of application domains. It is thus important to discuss the relationship between the dual-process engineering aesthetics methodology discussed here and Kansei Engineering.

In short, there are at least three main differences between the two approaches. First, Kansei Engineering mainly focuses on the first research process described here--the global process. It is clear from the discussions above that from the engineering, economical, and ethical perspectives, it is important to integrate the global psychometric research process and the local psychophysical research process. Second, in Kansei engineering, the researchers/designers usually are the ones to propose the initial list of product attributes, which is then ranked or rated by the subjects. The data are then subjected to factor analysis. In the methodology proposed here, the researchers do not propose the initial list. The list is constructed on several basis, one of which is a detailed "content analysis" of carefully elicited texts from the subjects. Third, in addition to data reduction using factor analysis and other data reduction methods, other important questions such as how subjects integrate information to form an overall impression and what causal relations exist are also addressed here with methods such as conjoint analysis and causal modeling. The dual-process methodology is a more comprehensive methodology that includes Kansei Engineering as a special case.

5. Sample applications of the dual-process methodology

This dual-process engineering aesthetics research methodology is currently being applied by the present author and his students in aesthetic evaluation of a diverse range of systems and products, including automobiles, cell-phones, stadiums, churches, cosmetic products, workplaces, residential areas, and instructional technology. In the remainder of the article, I use a "job attractiveness" study as an example to illustrate briefly the application of this methodology. This example also helps emphasize that aesthetic evaluations are not limited to tangible products.

The objective of the "job attractiveness" study was to evaluate how college students evaluate the attractiveness of a job. This information is important for job designers and company recruiter who wish to attract high quality college graduates. Applying the dual process methodology, we examined this question with both multidimensional construct analysis (the top-down process) and psychophysical analysis (the bottom-up process).

For reasons described above, we did not start the research by asking the researchers to propose an initial list of potential job attributes. Rather, to identify as completely as possible the potential job attributes that college students may consider in their aesthetic evaluation of a job's attractiveness, we started the "top-down" process with "content analysis," as specified in the first box on the left side of Figure 5. Thirty-three college students were asked to write down in five minutes ten to fifteen job attributes that they consider important in evaluating how attractive a job is. Two days later, under no time pressure, the same students were asked to write down twenty to thirty attributes. Content analysis was conducted on the obtained sixty-six lists, which resulted in a list of 57 items shown in Table 1.

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insert Table 1 about here

To understand how important each of the 57 items is to each person, a researcher may be enticed to ask each person to simply rank order the 57 items. But anyone who has tried to rank order more than 10 items would have realized that it is difficult or impossible to rank order a long list. Another commonly used method is to ask subjects to rate each item on a numerical scale, but this rating method tends to be not very useful either, because subjects tend to rate all or many items very important, which would not help reveal the relative importance of each item. To deal with these shortcomings of simple ranking or rating methods, we adopted a unidimensional scaling method called Balance Incomplete Blocked (BIB) ranking method, which allows a researcher to obtain scale measurements based on blocked rankings (Dunn-Rankin and King, 1969; Gulliksen and Tucker, 1961). More specifically in our study, the 57 items were grouped into 57 groups (blocks), each containing 8 items. The subject's task was to rank order 8 items at a time. Thirty University of Michigan students were asked to perform BIB rankings on the 57 items. Using the corresponding data analysis method for BIB rankings, for each of the thirty subjects, we obtained both the overall rankings and the interval scale measurements of the relative importance of the 57 items in the subject's evaluation of a job's attractiveness. The top- and the bottom- ranked job attributes and their interval scale measures of importance are shown in table 2 for male and female students separately.

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insert Table 2 about here

The 57 interval scale measurements from the 30 subjects form a 30 × 57 data matrix, which is often called a "profile data" matrix. This matrix was analyzed with factor analysis, cluster analysis, and multidimensional scaling methods to "reveal the hidden structure" of the construct of "job attractiveness". The analysis showed that there appears to be nine factors or dimensions underlying the 57 variables: direct personal benefits, extra "perks" and bonuses, autonomy at work, mobility at work, work matching self-interest, location of company, relationship with family and friends, company style/feature, company social climate.

As discussed earlier, according to the dual-process methodology, we must not only identify the important factors and examine their relative importance, but also study these factors at a local, psychophysical level. In the context of job attractiveness, we can use "starting salary" as an example. The top-down process has established the relative importance of starting salary on the minds of college students and has revealed how starting salary can be regarded as a component of a factor called "economic factor." The top-down process also reveals how "starting salary" relates to the other 56 items through cluster analysis and multidimensional scaling. But from the "bottom-up" perspective, we also need to know how sensitive college students are in judging differences in starting salaries, particularly when they consider starting salary together with a few other items such as vacation time. We also need to know how college students' job attractiveness responses change quantitatively as a function of starting salary, with or without considering some other items simultaneously.

Figure 5 shows how a ratio scale measurement of job attractiveness changes as a function of starting salary, based on the same 30 college students, using a ratio scale measurement method called the magnitude scaling method (Gescheider, 1985).

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insert Figure 5 about here

To study how college students integrate considerations of various aspects of a job to form an overall impression of job attractiveness (see the right side of Figure 3: how the Ψj's combine to form Ψ_{AE}?), a series of "conjoint analysis" is being conducted with college students. For example, to examine how college student integrate considerations of job variety/enjoyability, starting salary, job security, job respectability, and job advancement potential, each student would be presented with eighteen "job description bundles" generated according to the design specifications of conjoint analysis (Table 3). Their task is to rank order the "job bundles" according to the overall desirability of each bundle. The "part-worth utilities or part-worth desirabilities" of the various job attributes can then be calculated with the conjoint analysis methods (Louviere, 1988).

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insert Table 3 about here

To understand why some students consider certain job attributes highly important, while other students may consider them unimportant (see the top section of Figure 3: how Ψ affects the perception and judgment of the Φ's?), we are currently evaluating a causal model of job attractiveness judgment using causal modeling methods (Asher, 1983).

6. Conclusion

This article discussed the theoretical foundations of engineering aesthetics and proposed a model of the multidimensional, multi-modal, and interactive characteristics of engineering aesthetic appraisals (Figure 3) as well as a dual-process research methodology (Figure 4). Further, it is shown that the various processes involved in aesthetic judgments shown in Figure 3 can be studied comprehensively, systematically, and rigorously with the proposed dual-process methodology.

A potential benefit of this methodology is that it offers a systematic, step-by-step process to follow, which may help a research team to plann and coordinate its research activities. It also helps a researcher to think more comprehensively so that important issues are less likely to be omitted than if the researcher conducted an aesthetic evaluation in a more ad-hoc way. Another potential benefit of the methodology is that it helps researchers to achieve a quantitative understanding of the aesthetic issues involved. The job attractiveness study briefly described above only serves as a preliminary but concrete illustration of this point, although it does not demonstrate the full value of the proposed methodology.

The proposed methodology is an integration of a large number of existing methods that have been developed and applied in diverse areas. Researchers with prior experience of using these methods will find little difficulty in applying this methodology. It offers an integrated framework for applying existing methods to a new problem, but each of the methods is not new. Further developments of any of these methods will at the same time strengthen this integrated methodology for engineering aesthetics evaluation.

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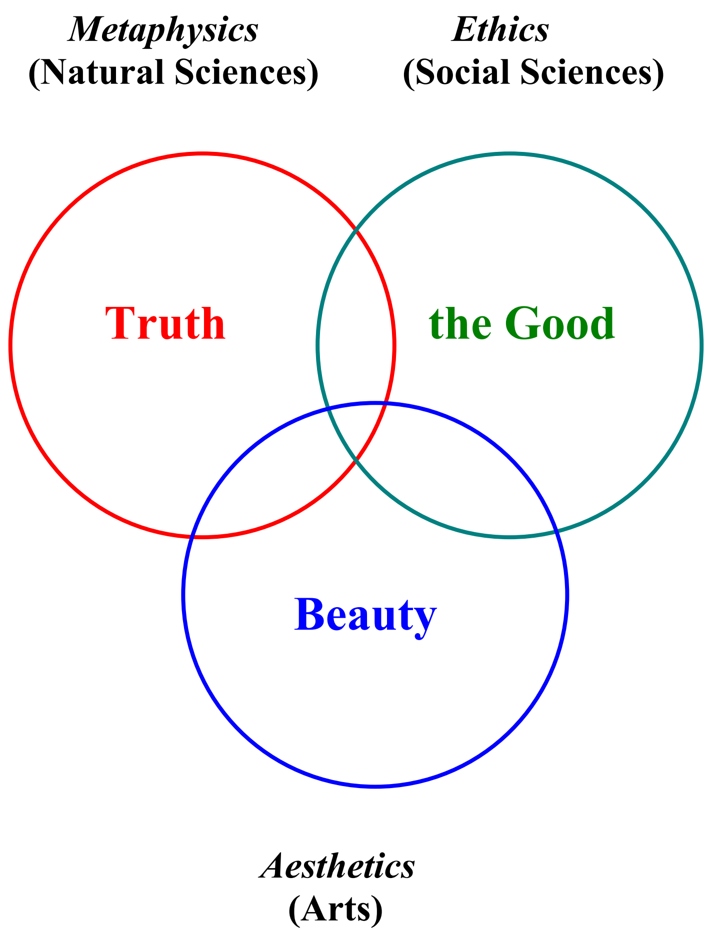

Figure 1: The three fundamental human pursuits are shown in three circles. The three corresponding branches of philosophy are shown in italics, and the three corresponding fields of modern disciplines are shown in parenthesis. The foundation for traditional human factors is mainly the upper-left circle, while aesthetic ergonomics should be based on a comprehensive view of all the three circles (from Liu, 2000a, c).

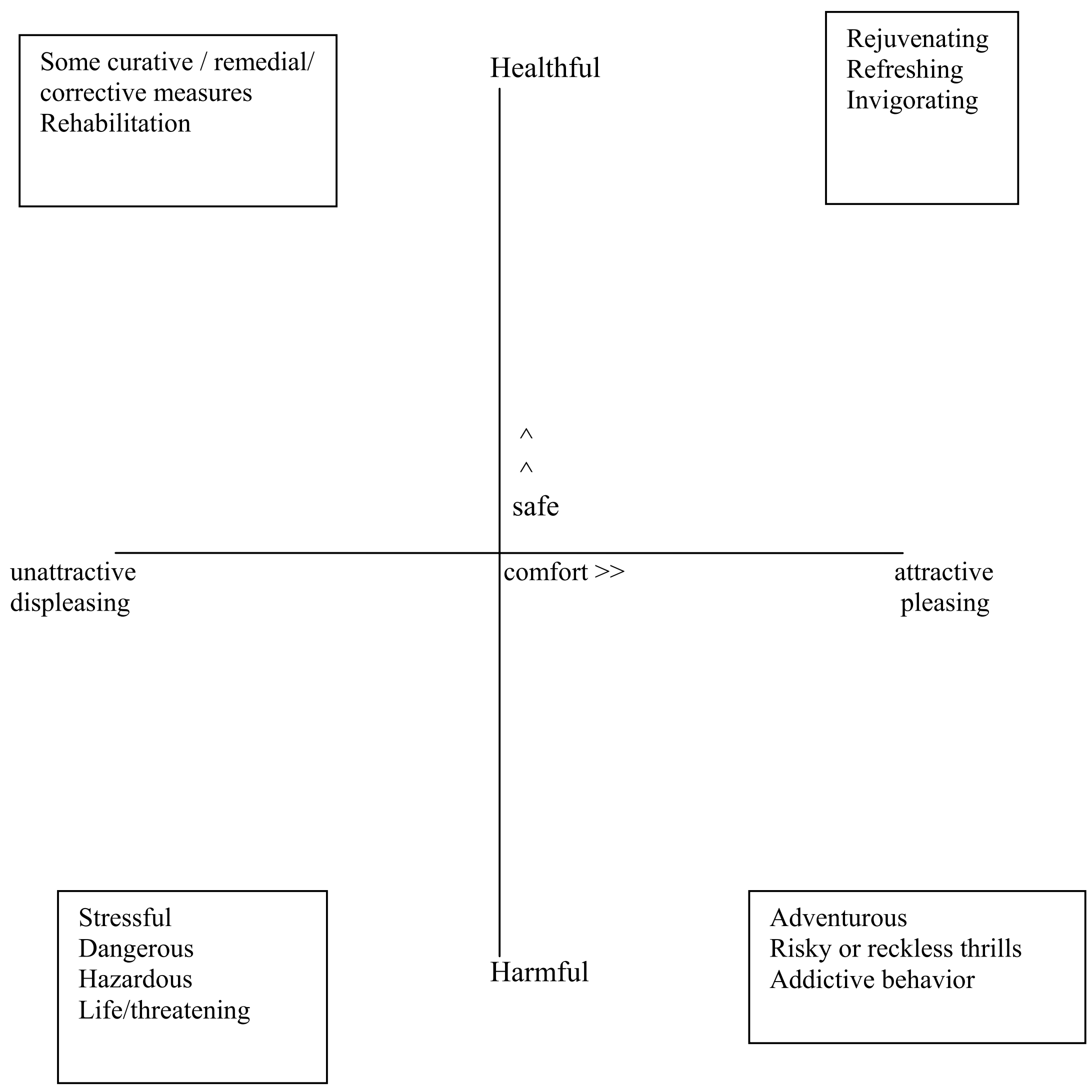

Figure 2: The two-dimensional space defined by the aesthetics dimension and the dimension of psychosomatic soundness. Other two dimensional spaces for job/product/system classification can be found in Liu (2000a).

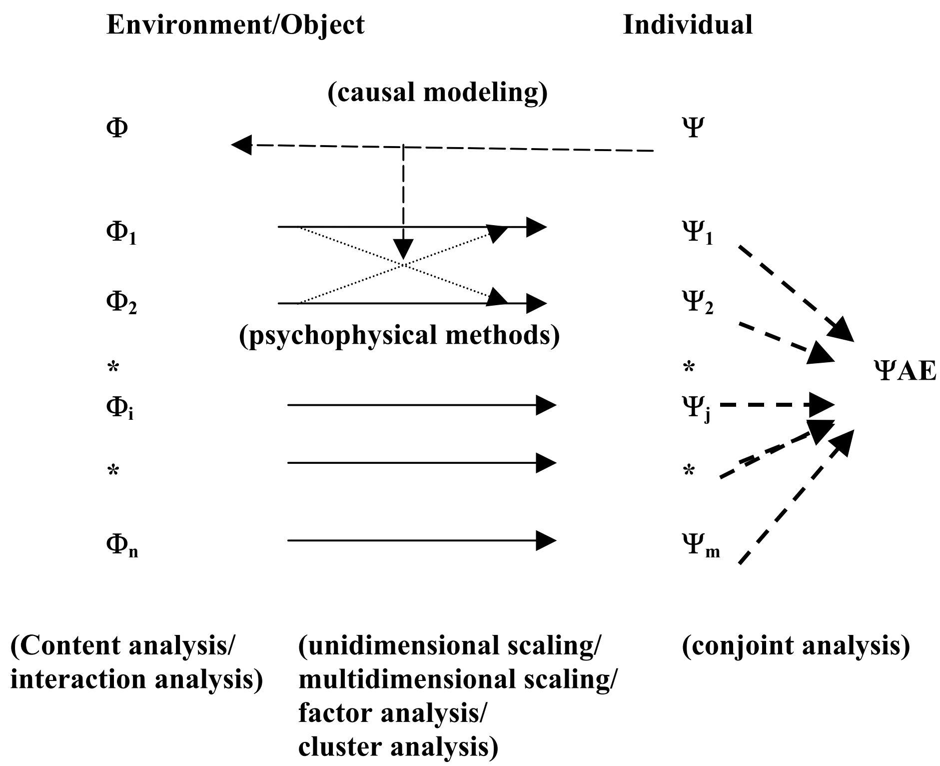

Figure 3: A model of the multidimensional, multi-modal, and interactive characteristics of aesthetic evaluation of products, systems, and environments. Selected major research methods for each component of the model are shown in parenthesis correspondingly.

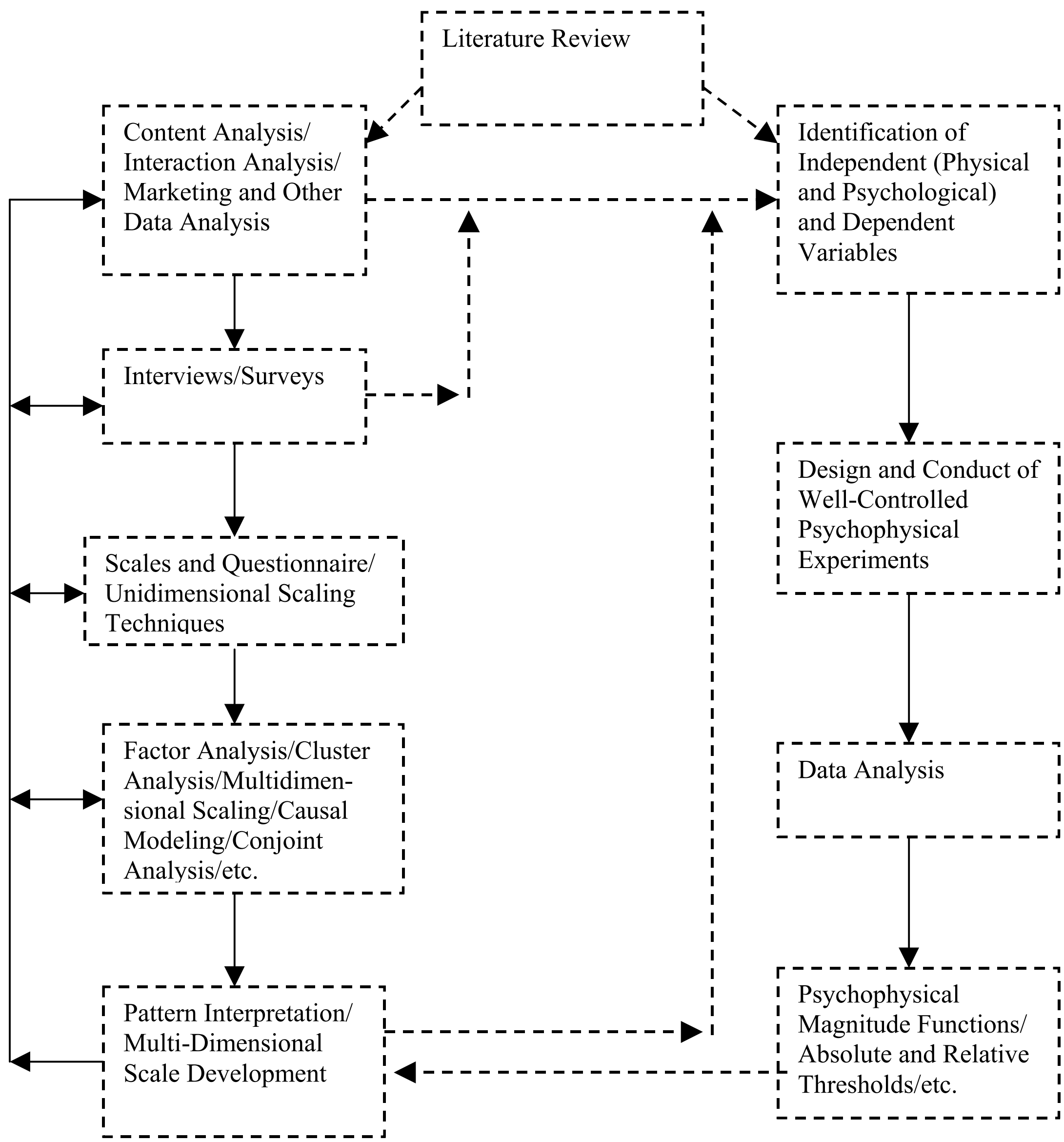

Figure 4: A Dual-Process Methodology for Engineering Aesthetic Research and Evaluation (From Liu, 2000b, 2001b). The first process ("top-down" process, shown on the left side) is called “multidimensional construct analysis or multivariate psychometric analysis,” whose goal is to establish a “global” and quantitative view of the critical dimensions involved in a specific aesthetic response. The second process ("bottom-up" process, shown on the right side) is called “psychophysical analysis,” whose objective is to establish a “local” and quantitative view of an individual’s perceptual abilities and characteristics in making fine aesthetic distinctions along selected dimensions. It identifies how keen the perceivers’ senses are in detecting variations along critical aesthetic dimensions and how their preference levels vary with changes in specific design parameters or aesthetic variables.

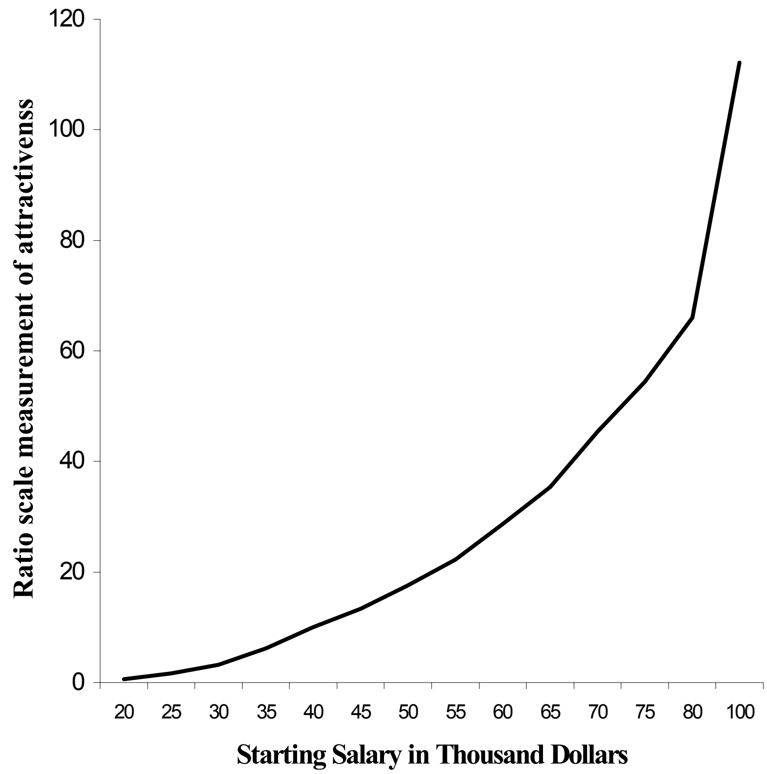

Figure 5: Ratio scale measurement of job attractiveness as a function of starting salary (30 college students) (from Liu, 2001a)

Table 1: A list of 57 items related to job attractiveness.

This list is the result of a content analysis of 66 texts. The list is the basis for BIB-rankings, which produced interval-scale measures of the importance of each item. These measures can be further analyzed with cluster analysis, multidimensional scaling, and factor analysis to reveal the hidden structure of job attractiveness evaluation.

1	vacation time	2	flexibility of work time
3	less work time	4	size of company
5	signing bonus	6	mean age of co-workers
7	cost of living	8	advancement opportunity
9	company culture/mission	10	Money/salary
11	friendly co-workers	12	nice geographical location
13	job variety/enjoyment	14	extracurricular activities offered
15	travel opportunity	16	high-tech or low-tech
17	big city nearby	18	distance to work
19	job independence/autonomy	20	future schooling opportunity
21	retirement/dental/medical benefit	22	challenging work
23	company car	24	rotational program
25	type of industry/products/service	26	corporate social atmosphere
27	company history/stability/health	28	paid vacations
29	company reputation	30	ability to move to other companies
31	well-respected job status/position/title	32	stock options
33	family values within company	34	local school system
35	good boss	36	perks/discount on products/services
37	in a nice city	38	international experience offered
39	free company gym	40	3-day weekend/4-day workweek
41	smart coworkers	42	amount of team work involved
43	child care programs/facilities in company	44	office has windows
45	mentorship/job help offered	46	work-at-home opportunity
47	job security	48	good-looking coworkers
49	easy to move around within company	50	dress code (formal or casual)
51	aesthetic office interior design	52	closeness to friends/family
53	job matching my skills or undergrad major	54	office/building amenities
55	turn-over rate	56	workforce diversity
57	personal office space size		

Table 2: The top- and the bottom- ranked job attributes and their interval scale measures of importance

Average response from male students | Average response from female students

rank	job attribute	interval scale		rank	job attribute	interval scale
1	money/salary	48.9	*	1	job variety/enjoyment	49.8
2	job variety/enjoyment	46.6	*	2	money/salary	42.8
3	advancement opportunity	45.1	*	3	well-respected job status/title	41.1
4	in a nice city	40.1	*	4	company history/stability	41.0
5	good boss	39.5	*	5	advancement opportunity	39.5
*	*** ***	***	*	*	*** ***	***
53	free company gym	12.6	*	53	child-care programs/facilities	12.8
54	local school system	12.6	*	54	free company gym	11.9
55	aesthetic office interior design	11.4	*	55	company car	10.6
56	child-care programs/facilities	9.4	*	56	dress-code (formal or casual)	10.6
57	office has windows	9.1	*	57	good-looking co-workers	3.1

Table 3: Eighteen "Job Description Bundles" Generated according to Conjoint Analysis Specifications for Obtaining the "Part-worth Utilities" of the Job Attributes

Job Bundle #	Job variety/ enjoyability	Starting Salary	Job Security	Job Respectability	Advancement Potential
1	high	40K	low	average	average
2	high	55K	medium	average	high
3	high	70K	high	high	average
4	medium	40K	medium	high	high
5	medium	55K	high	average	average
6	medium	70K	low	average	average
7	low	40K	high	average	high
8	low	55K	low	high	average
9	low	70K	medium	average	average
10	high	40K	high	high	average
11	high	55K	low	average	high
12	high	70K	medium	average	average
13	medium	40K	low	average	average
14	medium	55K	medium	high	average
15	medium	70K	high	average	high
16	low	40K	medium	average	average
17	low	55K	high	average	average
18	low	70K	low	high	high