Product performance assessment

Paul A. Rodgers

School of Electronics and Computer Science

PRODUCT PERFORMANCE ASSESSMENT

PAUL A. RODGERS

UNIVERSITY OF WESTMINISTER

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PAUL A. RODGERS

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School of Electronic and Manufacturing Systems Engineering,
Faculty of Engineering and Science,
University of Westminster,
115 New Cavendish Street,
London W1M 8JS

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Dedicated to my Mother and Late Father, Betty and Charlie Rodgers

Abstract

This thesis describes a formal methodology for defining and assessing product performance and its implementation in a prototype computer system. The methodology is based on abstract descriptions of the operations that are conducted within the design process. It is, consequently, extremely generic and creates a bridge between physical product performance and actual user requirements.

The methodology is based on defining product attributes in terms of observable parameters of the product in use. Defining an attribute in this way inherently reflects its required interaction with the user and consequently can truly be said to be in "user terms".

A product will have a range of attributes and a performance indicator is proposed, such that the attributes are combined in a way that reflects their relative importance to the user. At the conceptual stage of the design process, when the actual product does not exist, and only some abstract representation is available, it is vitally important to be able to model or simulate and hence evaluate the product attributes. This area of design has often been associated with non algorithmic design procedures, because of its intangible nature.

In this thesis the attribute methodology has been used to implement a prototype Computer Aided Design Evaluation Tool (CADET), which has been used and tested with an existing product range.

The methodology being abstractly defined supports a wide range of product attributes. It also gives an indication of how the correspondingly wide range of existing analysis software could be integrated into a powerful single Computer Aided Design system.

This work has resulted in the publication of two papers in refereed Journals and the presentation of eight other papers at refereed International Conferences. A list of the publications is included in the Appendices.

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Glossary

Attribute: An attribute is an observation or measurement taken of a physical product in use. An attribute is a variable whose name expressed in user terms reflects a common understanding of the observation. A product will have a range of different attributes which contribute to the product's performance.

Product Performance: Product Performance is a combination of the product's different individual attributes reflecting the relative importance of each attribute.

Representation: A representation is a description of a physical product. The representation generally contains definitions of shapes, materials and finishes. (If we have a representation of a product rather than a physical product we have to predict the product's attributes in use as there is no physical product to observe).

Model: A model of the product in use is used to predict attributes from a representation. The model is based on the relevant physical, psychological or sociological knowledge that apply to the product in use.

Product Characteristics: The information about the product required by the model are the characteristics of the product. Characteristics are inherent properties of the product, independent of use, and can be determined purely from the representation. Examples include mass, colour, dimensional information (height, breadth etc.).

Extraction: Extraction is the process of determining product characteristics from representations. For example the product characteristic *mass* can be found by multiplying the *density* of the material defined in the representation with *volume* for which standard procedures exist for calculating it from a given geometry also contained within the representation.

Designer: The person **using** the prototype Computer Aided Design Evaluation Tool (CADET).

User: The person using the product.

C1: Actual context.

F1: Actual form (e.g. product, artifact, such as a kettle).

E1: Actual ensemble entity comprising the actual form **F1** and its actual context **C1**.

M1: Actual measure of fit or performance.

I: Instructions which define the physical actions (**S**) on the physical form.

S: Signal that comprises both power and information that is sufficient to cause the required effect.

Com1: Operator that combines the actual form and its actual context to produce the ensemble entity **E1**.

Obs1: Operator that observes the ensemble **E1** to determine the actual measure of fit or performance **M1**.

Inv1: Operator that determines the entity **I** which is a plan of actions (instructions) to be taken to eliminate the misfits **M1**.

E1 ← Cra (S): Function which changes the actual ensemble **E1** to eliminate the misfits.

Act: Operator which takes the plan of action(s) **I** and converts it into a signal **S**.

Man: Operator which takes the signal **S** and processes the signal, via tools or machinery, into an actual form.

C2: Mental picture of the context.

F2: A complete and unambiguous description of the form, for example a BS 308 drawing.

E2: Mental picture of the ensemble, comprising both the mental picture of the form **F2** and its context **C2**.

M2: Mental picture of **M1**.

Exp: Operator that takes the actual context **C1** and produces a mental picture of the context **C2**. The operator **Exp** is physically a process of research, investigation and exploration to define the mental picture of context from the actual context.

Com2: Operator that combines **F2** and the mental picture of the context **C2** to produce the ensemble entity **E2**.

Obs2: Operator that observes the mental picture of the ensemble **E2** to determine the mental picture of the measure of fit **M2**.

Inv2: Operator that produces drawings of the form **F2** based on the mental picture of the measure of fit **M2**.

Pla: Operation of manufacturing planning which determines the manufacturing instructions **I** from the complete description of the form **F2**.

C3: Formal picture of the mental picture of the context.

F3: Concept representation, for example sketches, annotated drawings, diagrams, etc.

E3: Formal picture of the mental picture of the ensemble of **F3** and **C3**.

M3: Measure of fit within the formal picture.

For: Operator that constructs the formal picture of the context **C3** from the mental picture of the context **C2**.

Com3: Operator that combines the formal picture of form **F3** and context **C3** to produce the formal picture of the ensemble **E3**.

Obs3: Operator that observes the formal picture of ensemble **E3** to determine the measure of fit **M3**.

Inv3: Operator that produces the concept representation of form **F3** from the formal picture of the measure of fit **M3**.

Emb: Operator that takes the concept representation **F3** (e.g. annotated sketch) and embodies and details it to produce a complete description of the form **F2** (e.g. BS 308 drawing).

$\Re$: Set of real numbers.

Com3(C3,)•Obs3: Composite operator which determines formal picture of the measure of fit **M3** from **F3** (concept representation).

Emb•Pla•Act•Man: Composite operator that physically realises the actual form **F1** from the conceptual representation **F3**.

Oba: Attribute definition function.

Mes: Relationship between actual and represented form.

Ext: Operator for extracting relevant characteristics from a product representation.

Mod: Operator used in simulating **Oba**.

Cob: Combination function for combining attributes reflecting their relative importance.

$A = \{a : S(a)\}$: Open sentence.

$a \in A$: Element **a** is a member of **A**.

$Oba \mid E1 \rightarrow A$: Function that observes a single attribute.

$A = A_1 \times A_2 \times \ldots A_n$: Product set.

$Oba_1, Oba_2, \ldots Oba_n$: List of observation functions for each attribute.

$a = <a_1, a_2, \ldots a_n>$
$\quad = <Oba_1(E1),\ Oba_2(E1), \ldots Oba_n(E1)>$: A n-tuple of attributes.

$Mes \mid F1 \rightarrow F2$: Function which describes the relationship between an actual form **F 1** and its representation **F 2**.

$Mes \mid F1 \rightarrow F3$: Function which describes the relationship between an actual form **F 1** and its representation **F 3**.

$Cob \mid A \rightarrow M3$: Combination function which defines the relative weight of each attribute within the overall product performance.

$M1 \leftarrow Obs1(E1)$: Function which determines the actual misfit **M1**.

Exp•For: Composite operator which defines the attributes.

$\mathbf{Ch = \{ch : S(ch)\}}$: Open sentence.

$\mathbf{ch} \in \mathbf{Ch}$: Element **ch** is a member of **Ch**.

$\mathbf{Ch = Ch_1 \times Ch_2 \times \ldots Ch_n}$: Product set.

$\mathbf{Ch = \langle ch_1, ch_2, \ldots ch_n \rangle}$: A n-tuple of characteristics.

$\mathbf{Ext \mid F3 \rightarrow Ch}$: Function which determines the product characteristics from the representation **F3**.

$\mathbf{Mod \mid Ch \rightarrow A}$: Function which takes the product characteristics and predicts the attributes.

$$v = \frac{Fl^3}{3EI}$$

: Formula for calculating the end-point deflection of an end-loaded cantilever.

$$\mathbf{I = \frac{bd^3 - hk^3}{12}}$$

: Formula for calculating the second moment of area.

$\mathbf{Cob(a) = \sum_{1 \leq i \leq 6} w_i a_i}$: Linear weighted combination function where w_i is the relative weighting of attributes a_i.

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Chapter 1.0.0

Introduction

1.0.0 Introduction

The aims of this study were to develop methodologies for product performance assessment and to implement and test them in an interactive or rule-based system. This has been achieved, and the results provide a basis for further research and development, to yield new design practice tools, that will support and sustain the global manufacturing capacity that is of vital importance to a country's economic viability. As the 21st Century approaches, opportunities for creating new wealth will multiply, as will the number of contenders. For example Naser (1990) suggests that demand for products and services will explode worldwide, with an anticipated 60 percent growth of the global car market in the next 20 years coming from the Pacific Rim alone.

Human beings have always designed things. One of the most elementary traits of human beings is that they make a wide range of artifacts and tools to suit their own needs. As those needs alter, and as artifact users' reflect on the currently-available artifacts, so refinements are made to the artifacts, and completely new kinds of artifacts and tools are created and manufactured (Cross 1994).

In the past twenty years or so, however, there has been a significant cultural change towards manufactured goods in that product designers and manufacturers have passed through the period in which it was a challenge to manufacture an artifact to one in which the challenge is to "Design and Manufacture' a product that satisfies user needs, wants or desires" (JIDPO 1990). The global market place for products is changing faster now than ever before in terms of political, economical, biological and technological advances. As a consequence, designers cannot simply allow their products and procedures to evolve slowly. The priority for designers is to design solutions to problems, better and faster than before.

In an attempt to address increasing global competition, greater financial constraints, and expanding customer demand of newer products and systems, etc. many manufacturers have turned to Computer Integrated Manufacturing (CIM) techniques (Ranky 1986). CIM working practices have been developed to provide designers and manufacturers with, for example up-to-date information; systems for controlling and analysing large amounts of business and technical data; generating concepts; designing and evaluating products/components; determining manufacturing capacity, scheduling, fabrication processes; analysing system disturbances and economic factors, etc. (see Figure 1.0.0a).

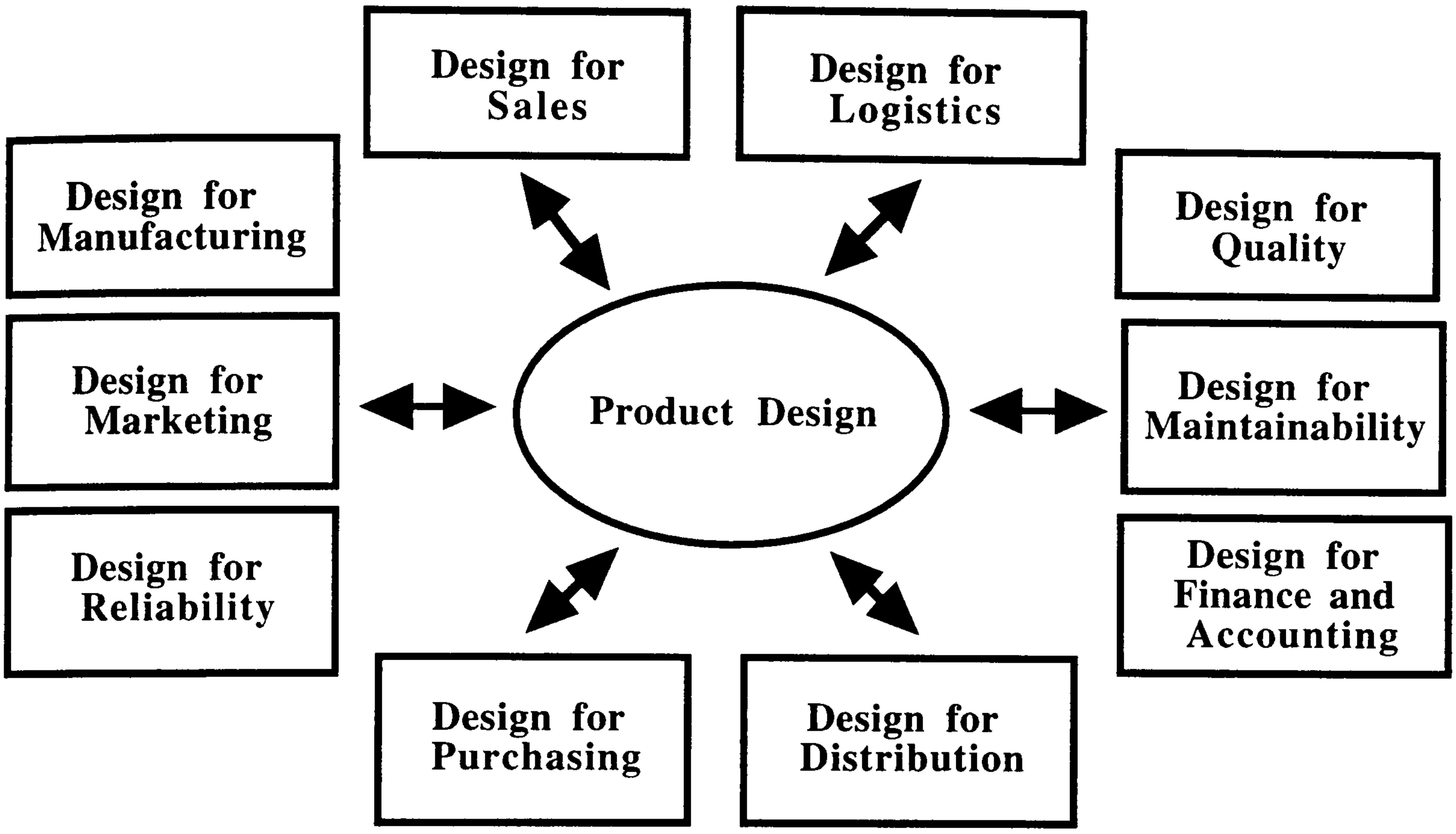


Figure 1.0.0a: Product Design in a Computer Integrated Manufacturing (CIM) Environment

The aim of CIM is to make the design and manufacture process more efficient; increase product reliability; decrease production costs; and increase human participation in the designing and manufacturing activities (Dowlatshahi 1993).

The advent of the computer and associated technologies has gone some way to alleviate the problem of storing and manipulating large amounts of information to solve typical design problems, that was highlighted by Alexander (1964) as a design constraint. Now large amounts of data can be stored on even the smallest Personal Computer (PC). The Computer Aided Design Evaluation Tool (CADET) described here facilitates storage and retrieval of design information, for example ergonomic data, colour data, materials data, etc. Furthermore, the CADET system will enable evolutionary development, so that the designer will be able to make optimum decisions based on the information and knowledge within the system.

The focus for designers is undoubtedly on serving the needs of the users of their designs. However, as Pirkl (1992) has noted there have been recent signs of a broadening gap between what design should do and what it is doing. He proposes that many examples of mass-produced products are, in fact, one-off *objet d'art* conceived as personal aesthetic expressions that undervalue the needs of users. Today the quality of many products reaches such a high standard that it becomes very difficult to evaluate their inter quality differences. Product users' judge manufactured goods not on a good-bad criterion, but on like-dislike preferences. For example Akita (1991), suggests that beauty and user-friendliness is more important than the sense of high technology within high-tech products, such as cameras, personal computers, and audio-visual equipment etc. Moreover Sipek (1993), goes as far to state that product designers have forgotten that their designed artifacts are made for people to use.

The microchip revolution has turned the economics of electronic-based product design on its head. For example the cost of adding features on say a microwave oven or a video cassette recorder no longer restricts the number of features a designer can place within a machine. This advance has had a negative effect, though, as many users do not understand the features that have been built into the products. Nussbaum (1991), cites the example of a Japanese office equipment manufacturer, who discovered that nearly 95% of its fax customers did not use the key features that they had deliberately built into their machine as they found them too complicated to use.

Potential users range widely, from the very young to the very old, men to women, healthy people to hospital patients, amateurs to professionals and so on. Therefore equipment should be designed to be adaptable, or in some cases specific to different peoples needs, in the most satisfying and efficient way for their personal use. This means a shift in emphasis for the designer in that a design proposal has to be evaluated at the concept stage of the design process, prior to detailed design, when s/he does not have a physical artifact, and no definite knowledge of how the market will respond to it, but simply a representation of it, for example; a design drawing or a 3-D prototype model.

This challenge presents a new requirement to the work of design in that there is a need to create a methodology to evaluate designs more accurately and earlier in the design process (conceptual stage) that ideally has some universal characteristics. It is unlikely that there is a first law of design analogous to the first law of thermodynamics, but nonetheless there is a need for a procedure with a quantifiable result to guide the designer towards his goal of satisfying the needs, wants or desires of the user.

This thesis presents a methodology for product performance assessment, which has been stimulated by the work of Alexander (1964). Alexander's main endeavour was proposing a method that would help unravel complicated design problems. He expressed:

"Today more and more design problems are reaching insoluble levels of complexity. This is true not only of moon bases, factories, and radio receivers, whose complexity is internal, but even of villages and teakettles. In spite of their superficial simplicity, even these problems have a background of needs and activities which is becoming too complex to grasp intuitively."

In order to consider Alexander's approach it is appropriate to record that he was an architect who was motivated to resolve issues of complexity by creating a design process or methodology that enabled complex design questions to be rationalised into a series of sub-systems. For this work, Alexander's key philosophical contribution was to introduce a formalisation of design problems based on a set of "misfit" variables (e.g. "the kettle must pour cleanly", "the kettle must be able to withstand the temperature of boiling water", etc.). His approach stemmed from Architectural practice in that he decomposed the problem space by creating a diagrammatic language in which he sought to represent complex entities, through an organisational pattern. Almost ten years after his book, *Notes on the Synthesis of Form*, was published, Alexander suggested in his preface to the Second Edition that the major contribution of this work was the idea of representing complex structures through a series of diagrams or patterns. Alexander stated:

"The idea that it is possible to create such abstract relationships one at a time, and to create designs which are whole by fusing these relationships - this amazingly simple idea is, for me, the most important discovery of the book."

In effect Alexander introduced a formal design language, whose development is a major element of this thesis.

These basic ideas have been developed into a broad framework that represents the design process and which has been implemented into a Computer Aided Design Evaluation Tool (CADET), that has been described in (Rodgers et al 1993) and (Rodgers et al 1994) and is presented in Chapter 6.0.0.

The thesis comprises six chapters. Chapter 2.0.0 is entitled "The Design Activity" and looks at what is actually meant by the term 'design'. This chapter also focuses on the distinctions between the many fields of design, in particular the subtle nuances between the likes of 'Industrial Design', 'Engineering Design', and 'Product Design'. The second part of the chapter is named "The Design Process" and describes a typical model of the design process.

Chapter 3.0.0 is entitled a "Review of Design Models". This chapter commences with a definition of "design methodology" and describes a few reasons for their development. The chapter concentrates on a selection of five major works on design models over the last 30 years, namely: Alexander (1964), Archer (1965), French (1985), Pahl and Beitz (1988), and Pugh (1990). The reason for the selection of these 5 design models is that they contain key features of the development of design methods, and also because they are the most widely cited works within design literature. Finally the chapter reviews critically a selection of procedures aimed at predicting product performance assessment at the early stages of product development.

Chapter 4.0.0 comprises one of the three major contributions (i.e. a formal definition of product performance assessment) of the thesis, the other two being Chapter 5.0.0 (i.e. the abstract design language) and Chapter 6.0.0 (i.e. the generic computer architecture). This chapter (4.0.0) describes a a formal definition of product performance assessment. The definition is concerned with using product performance assessment at the conceptual stage of the design process, to both assess the potential performance of a product proposal, and rationalise and make apparent the predominately intuitive decisions taken by the designer at this stage. The proposed procedure of product performance assessment is based on a formal model of the design process developed from that of Alexander (1964).

Chapter 5.0.0 is entitled a "Methodology for Product Performance Assessment at the Conceptual Stage of the Design Process". This chapter describes the abstract language for design assessment, by illustrating its use in three disparate design domains. The chapter commences with a look at an existing design tool for measuring the quality of product performance, namely Quality Function Deployment (QFD). The thesis goes on to define the deficiencies in that method, or more specifically the deficiencies in the concept selection stage of the method developed by Pugh (1990). The second part of this chapter begins with a definition of assessment, followed by the method of attribute prediction. The method of attribute prediction is illustrated by three attribute examples: (i) cantilever desk, (ii) toothbrush performance, and (iii) visual categorisation.

The emphasis of this chapter, Chapter 6.0.0 - "Computer Aided Evaluation of Product Performance Assessment", is on an explanation of the Computer Aided Design Evaluation Tool (CADET), the CADET system suggests a generic architecture that can be used as a framework for integrating other CAD systems. The chapter commences with a short summary of expert system tools and computer systems that have been developed to provide support to designers throughout various stages of the design process. Next, a description of the computer implementation of the assessment method which has been written in *FLEX* - an expert system toolkit fully integrated into a PROLOG environment is given. The final section of this chapter includes preliminary test results of the CADET system on three typical examples of product design (toothbrush, cellular phone, shaver).

The final chapter, Chapter 7.0.0, presents the conclusions and recommendations for future work.

Chapter 2.0.0

The Design Activity

2.0.0 The Design Activity

Before one can look in-depth at systematic methods for designers and designing, one must first understand what is meant by terms such as: "design", "designing" and "designer". The dictionary definitions offers us the following meanings[1]:

design

substantive

I.1. A plan or scheme conceived in the mind of something to be done; the preliminary conception of an idea that is to be carried into effect by action; a project.

2. Purpose, aim, intention.

3. Contrivance in accordance with a preconceived plan; adaptation of means to ends; prearranged purpose.

II.1. A preliminary sketch for a work of art; the plan of a building, or part of it, or of a piece of decorative work, after which the structure or texture is to be completed; a delineation, pattern.

2. The combination of details which go to make up a work of art; artistic idea as executed; a piece of decorative work.

design

verb

I.1. To mark out; to indicate.

II.1. To plan, plan out.

III.1. To make the preliminary sketch of; to make the plans and drawings necessary for the construction of.

2. To plan and execute; to fashion with artistic skill.

3. To draw, sketch; to form or fashion a work of art.

designing

verbal substantive

Marking out; planning, etc.

[1] The Shorter Oxford English Dictionary (1973), Oxford University Press: Oxford

designing

adjective

That designs, plans, etc.

designer

1. One who designs or plans.

2. One who makes an artistic design or plan of construction; one who makes designs or patterns for the manufacturer or constructor.

Although helpful, the above meanings as they stand are inadequate. The word "design" is commonly used as both a verb and a noun which can sometimes lead to confusion. Potter (1989) highlights further the problem of finding a suitable definition:

"The difficulty becomes acute if the word 'design' is used without reference to any specific context - used, for instance, as a blanket term to cover every situation in which adaptation of means to ends is preceded by an abstract of intent - though designing is thus usefully distinguished from 'making' or from spontaneous activity."

Some excellent definitions and descriptions of design and the act of designing are as follows:

"Decision making, in the face of uncertainty, with high penalties for error", (Asimow, 1962).

"Finding the right physical components of a physical structure", (Alexander, 1964).

"Design is the preparation of a prescription for some artifact or system in the light of all the relevant functional/constructional, economic, marketing, ergonomic and aesthetic requirements", (Archer, 1965).

"...the effect of designing is to initiate change in man-made things", (Jones, 1980).

"Design is the systematic activity necessary, from the identification of the market/user need, to the selling of the successful product to satisfy that need", (Pugh, 1990).

"Design is really the translation of broad ideas and technological concepts into reality", (Marzano, 1994).

From these definitions, one can declare that a designer is someone who formulates a plan, drawing, or model for a finished artifact, system or environment in **advance** of its realisation.

If the subject matter is a machine, the designer may be an engineer. If the subject matter is a washing machine, the designer may be a product designer. But if the subject is washing detergent, the designer may be an industrial chemist. Therefore, it can be seen that design can embrace most products, systems and employ any **creative skill** (Archer, 1974).

The definition of design employed here is based on Simon (1988). He stated that design is the **process** by which the **decisions** are taken to move the world from its **current situation** to a **preferred one**. The preferred situation must be **perceived** to be an **improvement** on the existing situation by or for **those with the power to actually enact the decisions**.

For example manufacturers have the power to enact the decisions and choose to, based on their perception of the improvement it makes to them, i.e. there is no absolute definition of improvement, it is only relative to the producer.

Creativity is a broad concept that is related to, generating, almost anything new in the way of an idea, a formulation, a model, a theory, or an aesthetic or practical product. Generally, a working definition of creativity is defined as:

An idea, theory, artifact, etc. that should not be one that could be arrived at by a logical routine, or mechanical process, but that should still provide a good solution to the problems in the situation. Creativity is an intuitive process, but is still rational if not necessarily rationalised. In design, intuition plays two parts:

(i) first, in identifying the problem,

and

(ii) second, in finding a solution.

The distinction between these two parts is not always clear, for example an individual resting on a table with a uneven leg may take the action of placing a book under the shorter leg to steady the table. In other words, the action of identifying the problem (wobbly table), and rectifying the problem (placement of book), is carried out intuitively and simultaneously.

Creativity is evident, in that element of designing, when the designer conceives of new solutions for systems or products, but creativity also extends to the work of artists, scientists, philosophers, writers and musicians.

Therefore, design involves formulating a realistic plan or drawing in **advance** of physical realisation of something which is potentially of use or value. In design, however, there are three inter linking criteria:

"(i) there can be no solution without a problem.

(ii) and no problem without constraints.

(iii) and no constraints without a pressure or need." (Archer 1965 : 4)

Potter (1989) suggests that it is convenient to group the gamut of design practice into three simple categories, though he acknowledges that the distinctions are in no way absolute, nor are they always so described:

(i) the design of artifacts,

(ii) the design of spaces,

and

(iii) the design of communication and messages.

This thesis will concern itself with the activity of product design practice. Product design obviously falls within the design of artifacts. For the purposes of this thesis, the following terms will apply. Product design falls within the design of those artifacts whose form directly responds to the user. This will include the design of three-dimensional products such as jewellery, furniture, domestic appliances and the "user elements" of technically complex products such as machine tools, medical and scientific equipment etc.

On the other hand, engineering design is concerned with solving well defined, if complex, problems often requiring specialists and is less concerned than product design with the original formulation of the problem. Another strong characteristic of both engineering and product design practice is that the designer will rarely be the end-user (i.e. the product designer is not seeking to solve his/her own problems), and also that the end result is rarely realised by the designer.

At this point one may draw a distinction between the activity of arts and crafts and the activity of product design. Potter (1989), states that the designer works with and for other people; ultimately the same may be said of the fine artist, however in the real working situation, designer's decisions are subject to more constraints. The fine artist is less dependent on discussion, agreement, letters, visits; communication activities that bring meaning to a design problem. Fine artists generally work directly with their chosen medium. On the other hand, the designer has to proceed through many stages before a firm proposal can emerge. The proposal may then be realised in a scale model - arguably the nearest thing to the realisation of the designer's ideas.

The design process results only in the decisions, but the perceived benefit must be judged by those with the power to produce the product. **This is the ultimate level of product performance assessment**. For example manufacturers have the power to enact the decisions and choose to, based on their perception of the improvement it makes to them, i.e. there is no absolute definition of improvement, it is only relative to the producer.

This definition excludes naturally created objects such as lakes which satisfy some human need, want, or desire and includes obvious consumer products such as refrigerators and washing machines. It does not include any living organism produced by selective breeding or genetic engineering which are called designoid objects whose characteristics are influenced and guided rather than being completely defined by the designer (Sofer 1991). Even so not all such products are the result of what will be described as product design. The activity of product design cannot be distinguished purely by examination of the result. Poster prints of the Mona Lisa are a clear consumer product. It is doubtful however if Leonardo Da Vinci considered its panting an exercise in product design. Consequently product design must be approached in terms of both the process as well as the result.

Product design definition problems exist not only because of the historic separation of Art from Science, but also because of that human tendency unwittingly to group technically simple products (where sensuous qualities are paramount) with technically sophisticated products (where function and safety are paramount), and look for a simple definition to cover both (Potter 1989).

Definitions of the terms "product design" and "engineering design" remain elusive, and for this reason The Carter Report on *Industrial Design Education in the United Kingdom* (1977) chose to focus attention upon what designers do, rather than to formulate simplistic and potentially misleading definitions. The Carter Report (1977) describes the relationship between industrial design and engineering design as follows (in this context Carters use of "Industrial Design" is equated to "Product Design"):

> *3.2.1 The skills embodied within the practice of industrial design frequently overlap those of related disciplines - not only architecture and graphic design, but also ergonomics and engineering design. Since it is the purpose of this report to study those aspects of industrial design that relate to engineering design, it is important to establish a clear understanding of the sources of the design contribution to the extent to which any overlap occurs.*
>
> *3.2.2 No tidy picture emerges. In practice, the overlap varies according to the nature of the project, and the contribution of different designers is affected by their individual talents, personalities, skills, and experience, and by the composition of the development team. On some projects it is almost impossible to distinguish between the work of the industrial and engineering designers. This blurring of the lines of demarcation and overlapping of design skills is a significant factor in the development of design practice. The total design activity can best*

be described as a 'design spectrum' and individual designers, be they industrial or engineering, will find themselves working in that part of the spectrum which best suits their abilities and the project upon which they are engaged, whatever their formal qualifications.

3.2.3 The spectrum spans products such as cutlery and lighting fittings at one end, to computer terminals and machine tools at the other. In another sense the spectrum spans a range of design factors from aesthetics and ergonomics to mechanics and electronics. In addition, the designer's approach to a problem may extend from a subjective reaction to a consumer mood on the one hand to an objective satisfaction of a performance requirement on the other.

The diagram below (The Design Spectrum - Figure 2.0.0a) gives an approximate indication of the relationship between industrial and engineering design disciplines appropriate to the development of various types of product. It can be seen that the industrial designer will himself design products with a small to medium engineering complexity where aesthetic, ergonomic, and other human and social factors are important. He will collaborate with engineering designers on these aspects of more technologically complex products.

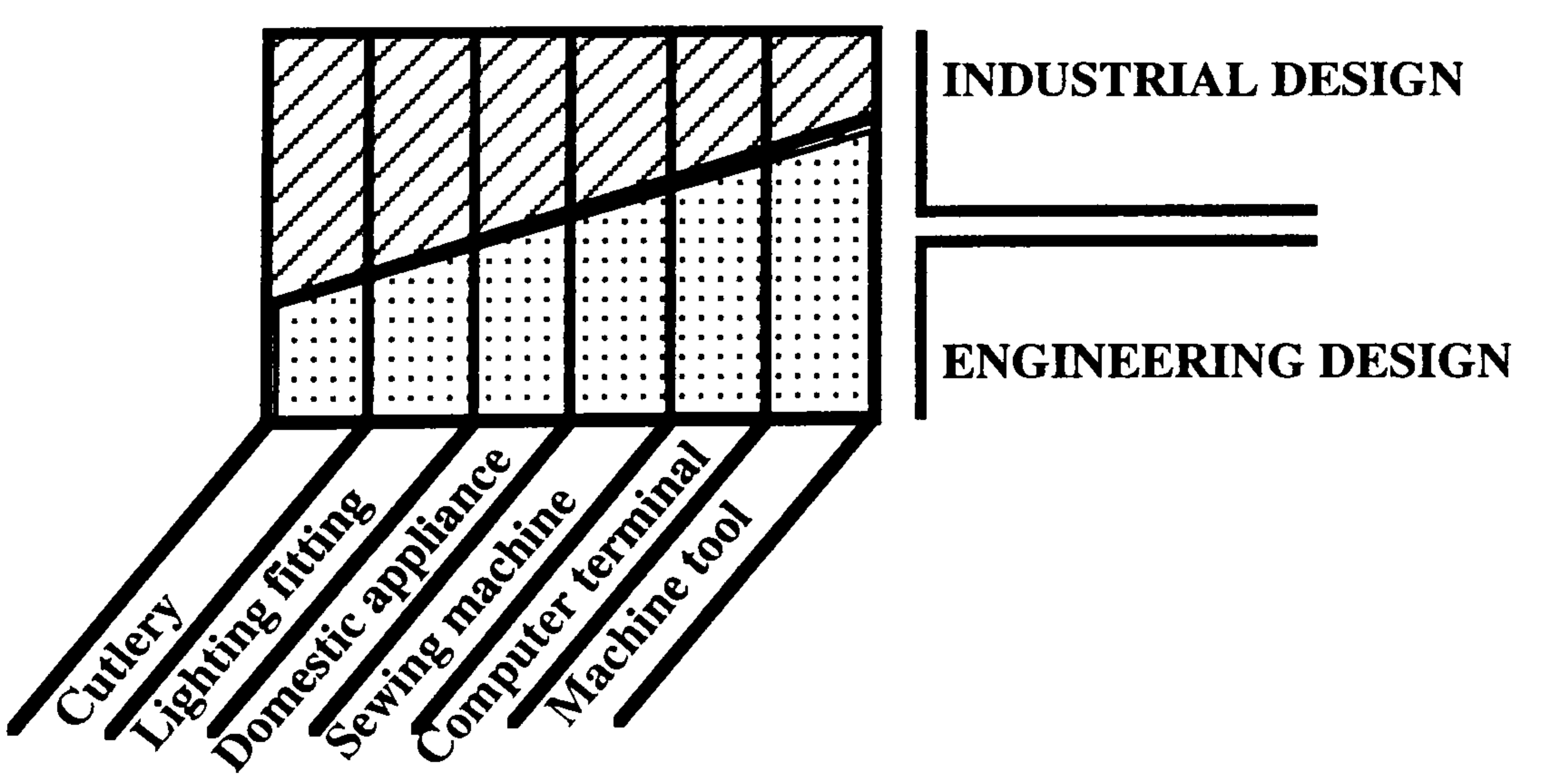


Figure 2.0.0a: The Design Spectrum

3.2.4 Good relations between the industrial designer and the engineering designer are vital when they are collaborating on any project. It is essential that each type of designer accepts the value of others contribution and that both fully understand the benefits that can accrue from the establishment of a creative working atmosphere.

3.2.5 Industrial design and engineering design are at present distinct disciplines arising from different educational systems. Each discipline has much to learn from the other; this is a process that can be advanced by the teaching of both, side by side, in universities and colleges of higher education. In the long term it may be that a type of engineering designer will emerge who will be qualified to absorb some of the present functions of the industrial designer. Conversely, it is possible that a new type of industrial designer with enhanced engineering skills may emerge, thus redrawing the lines of demarcation, but not fundamentally affecting the concept of the 'design spectrum'. The committee does not believe, however, that at this stage the two design disciplines should be amalgamated.

3.2.6 There is a large area of common ground in the practice of the two disciplines, including information assembly and analysis, creative identification of problems and the production of solutions, conservation of resources, economy of expression and a desire to produce a solution that is correct, satisfying and elegant. A vital requirement for practitioners in both disciplines is that they should be able to work as part of a design team, to adjust their design proposals to accommodate the recommendations of other specialists within the team, and above all to know when to call upon the expertise of specialists in *related disciplines such as marketing, ergonomics, materials technology, graphics, electronics, hydraulics or optics.*

3.2.7 The ability of a particular designer, whether an engineering designer or an industrial designer, may lead him to undertake duties and responsibilities in industry beyond the scope of his immediate discipline. Initially, a young engineering designer will be primarily concerned with technical performance while the industrial designer will be concerned with aesthetics and human values. As time goes by both may develop management skills and familiarity with other disciplines and so change the directions of their careers.

Although the Carter Report was written nearly twenty years ago, the propositions remain sound today. For instance the Report acknowledges that there exists much overlap of "Product Design" and "Engineering Design" subject areas, and that this overlap will vary from project to project. The committee were of the opinion that the best description of the total design activity was that of a "Design Spectrum" (see Figure 2.0.0a), which spans from the objective to subjective. Even though the Carter committee did not believe that "Product Design" and "Engineering Design" should be amalgamated at this stage (1977), they conceded that in the long term there may emerge a type of graduate who will possess skills/ abilities in both "Product Design" and "Engineering Design".

Without doubt there is no generally accepted definition of the distinction between the two subject areas of engineering design and product design. In fact this difficulty was one of the themes of a recent conference on engineering education[2], and the subject of several papers, including Billett (1994), and Marinissen (1994). The assessment methodology developed within this research programme, and discussed later in Chapter 4.0.0, is intended to be applicable to any field of study within the Carter Report's Design Spectrum shown in Figure 2.0.0a (i.e. from aesthetics and ergonomics to materials to engineering science, etc.). This

[2] Second International Symposium on Product Development in Engineering Education, University of Limerick, Ireland, 28-31 October 1994

approach encompasses distinct subject areas commonly found in most Universities today, for example Industrial Design, Engineering Design, Electronic Design, Product Design, Architectural Design, etc. The methodology reported within this thesis can be applied to assess the suitability of any product that may fall within this broad Spectrum. Later in Chapter 5.0.0, (Section 5.3.1) the thesis discusses the use of the assessment methodology on three different product examples.

2.1.0 The Design Process

Design has been defined here as a process. In future the phrase "Design Process" only relates to the design of products. This section examines, in greater detail, the activities involved within that process. In its most general form a product is an entity which has been deliberately and completely created to meet some human need, want, or desire. Chisnall (1975) points out that there are two general categories of human needs:
(i) biogenic,
and
(ii) psychogenic.

The former refers to the basic physiological needs related to bodily wants, while the latter, also described as emotional or psychological needs, are concerned with social, cultural and aesthetic needs. Maslow (1943) and Asch (1952) suggest that there is a hierarchy of basic human needs (see Figure 2.1.0a). An individual who lacks food, safety, love, esteem, etc. would probably seek food more strongly than anything else.

The most prepotent of all needs is therefore physiological needs. Next in the hierarchy of basic needs is safety needs, for example individuals strive for safety in employment, finance, etc. The need for safety is an active mobiliser in times of emergency, for example war, disease, natural catastrophes, and so on. If physiological and safety needs are satisfied, love and affection, and belongingness needs become the focus of attainment. Human beings desire for self-esteem and desire for the esteem of others. Individuals desire personal strength, adequacy, confidence, and desire for a reputation and recognition by others. If all the above basic needs are met, man/ woman still strives for more. A musician must write music - an artist must paint to be ultimately happy.

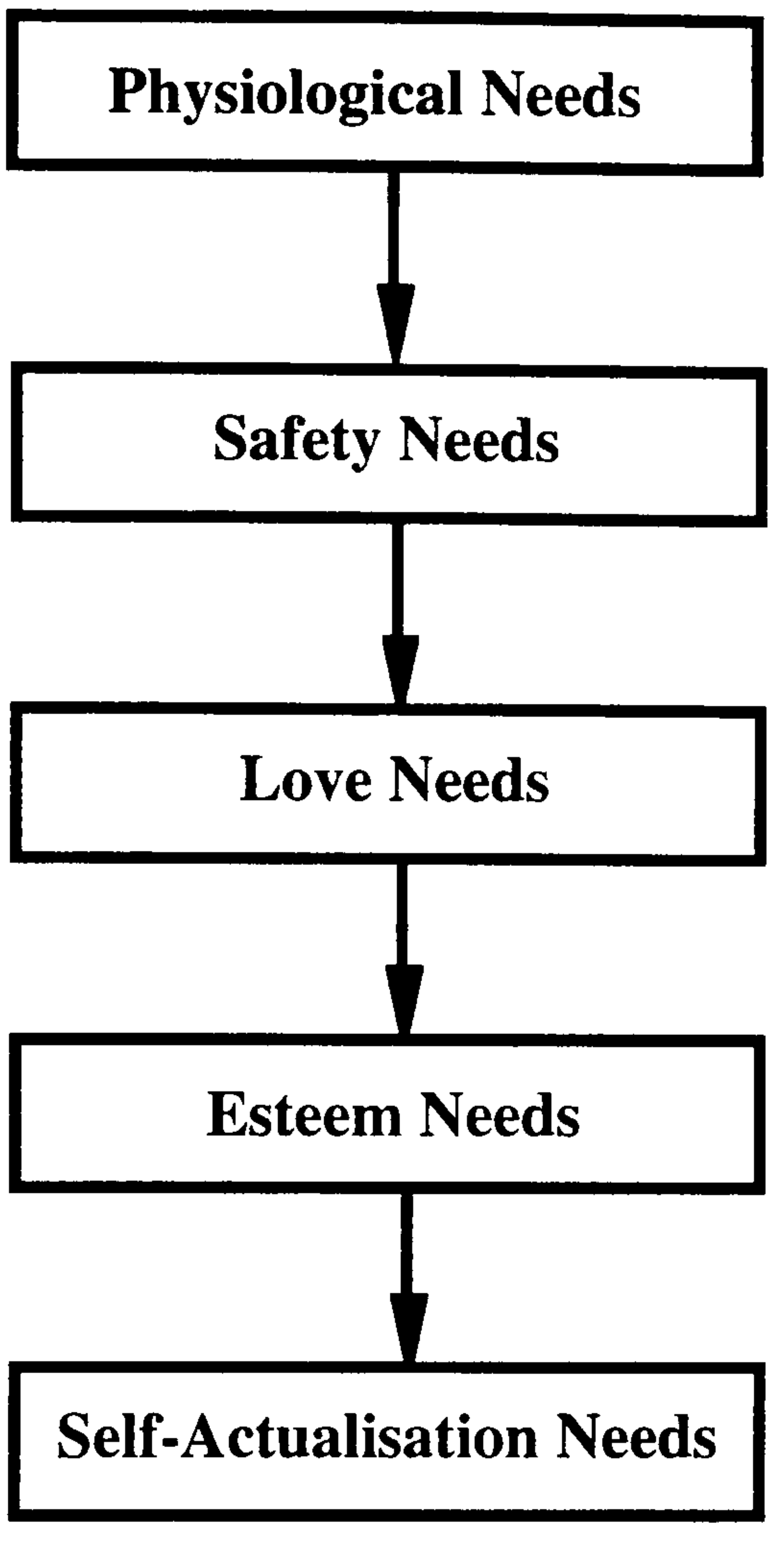


Figure 2.1.0a: Hierarchy of Basic Human Needs (Maslow 1943)

Maslow (1943) states that the most prepotent need will monopolise human consciousness and this will usually lead to the less prepotent needs being minimised, forgotten, or denied. However, when a need is fairly well met, the next prepotent ('higher') need emerges, in turn to dominate the conscious life.

The following five figures (2.1.0b to 2.1.0f inclusive) paint a common picture of the design process. This simple picture of the process of design depicts the activities that are traditionally involved.

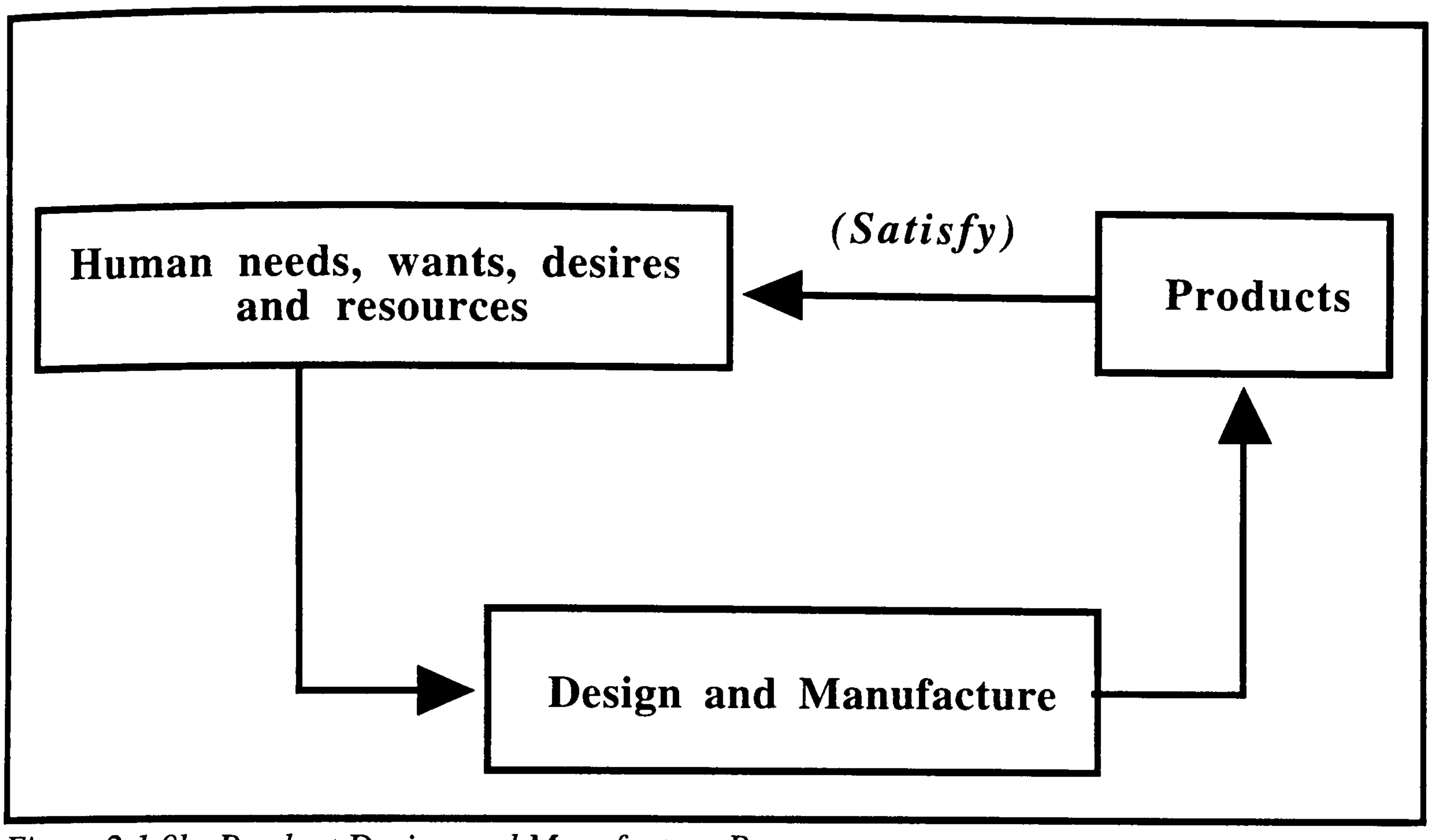


Figure 2.1.0b: Product Design and Manufacture Process

Figuratively in Figure 2.1.0b above, the design and manufacture process is represented as a process which generates real world products to meet real world needs, wants, and desires. An important characteristic of product design and manufacture is that it is an intellectual activity of taking the decisions aimed at influencing events in the real world.

A successful product is one that individuals select in preference to other equivalent products with respect to both its ability to meet their needs, wants, or desires and with respect to the resources exchanged for it. Moreover, MacKenzie (1991), points out that a successful product is one that performs its function successfully; is easy to use; is safe; offers good value for money; and looks attractive.

Design and Manufacture

Within the activity of product design, the design and manufacture process from Figure 2.1.0b can be clearly delineated into two separate activities of design followed by manufacture (Figure 2.1.0c). This is not to say that the design process is not influenced by manufacturing considerations or that the manufacture of test pieces and prototypes is not part of the design process, but that the result of the design process is not the designed artifact but a representation or definition of the designed artifact.

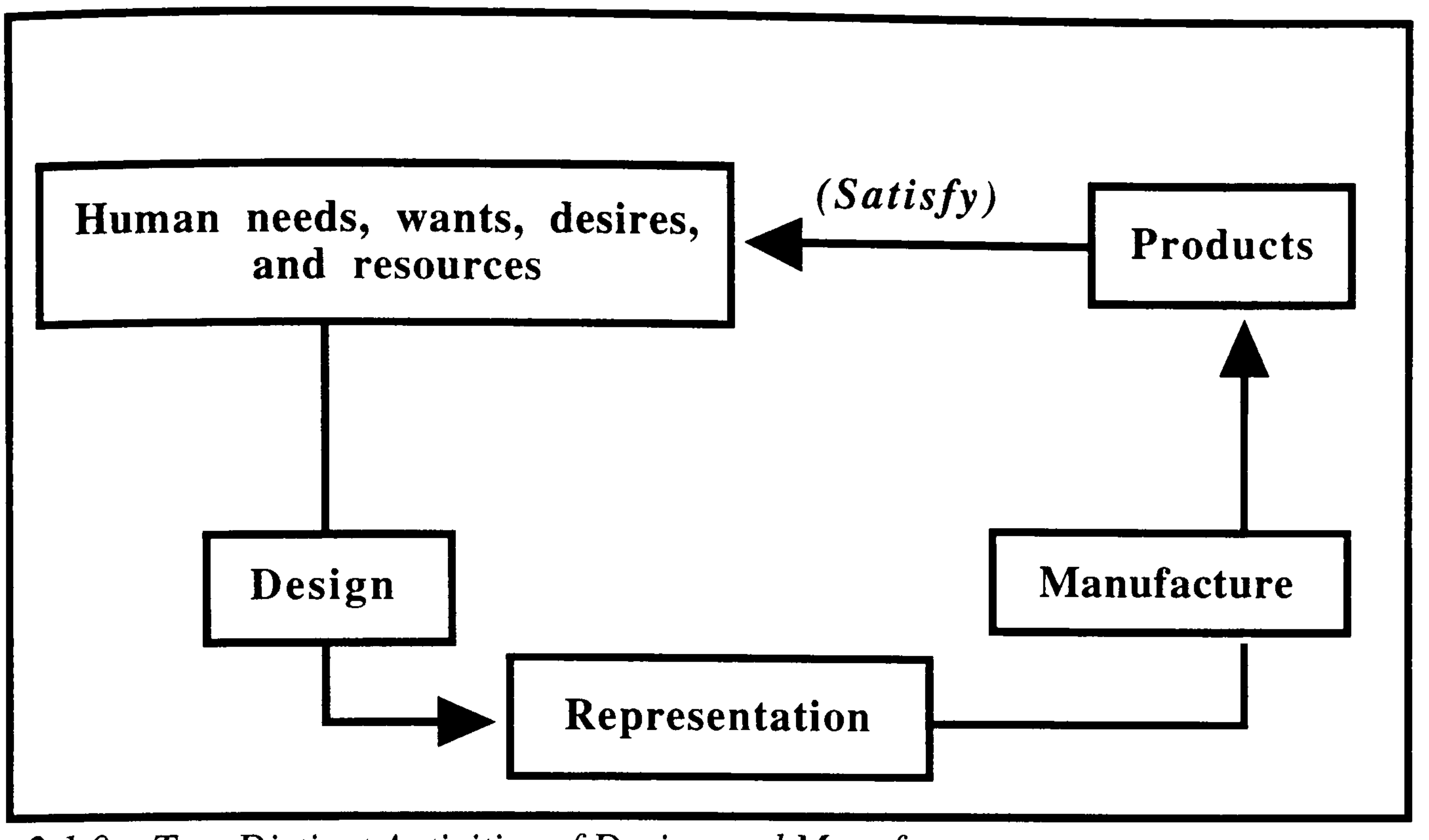


Figure 2.1.0c: Two Distinct Activities of Design and Manufacture

Manufacture is the process of realising the artifact from the definition. Design is, in practice, an indeterminate process in that there is no unique result to most problems and it is unlikely that two designers will produce the same solutions to the same problems. This implies that no universal method is available for synthesising design solutions to solve design problems. (This does not mean that a universal method does not exist just that we do not know it). Manufacture however is a determinate process in that the result is predetermined. In the same way as arts and crafts does not enhance an idea but simply realises it. This is a further distinction between the activity of arts and crafts and the activity of product design, where in many cases within arts and crafts practice the definition of the result and the production of the result can occur simultaneously.

The artifact definition which is the result of the design process is a **representation** of a real (as yet not existing) artifact. Representation is a key concept in understanding the design process. It may take on a variety of forms such as: presentation drawings, physical models, layouts, etc. during the design process and is the basic medium for communicating and reasoning about objects which exist (or will exist) in the real world.

Describing how a product functions in the real world requires a way of describing how a product interacts with its user(s) and its environment. It is not easy to describe rather abstract concepts such as human needs, wants, and desires so instead one considers the requirements a product should have to satisfy those needs, wants, and desires (Figure 2.1.0d).

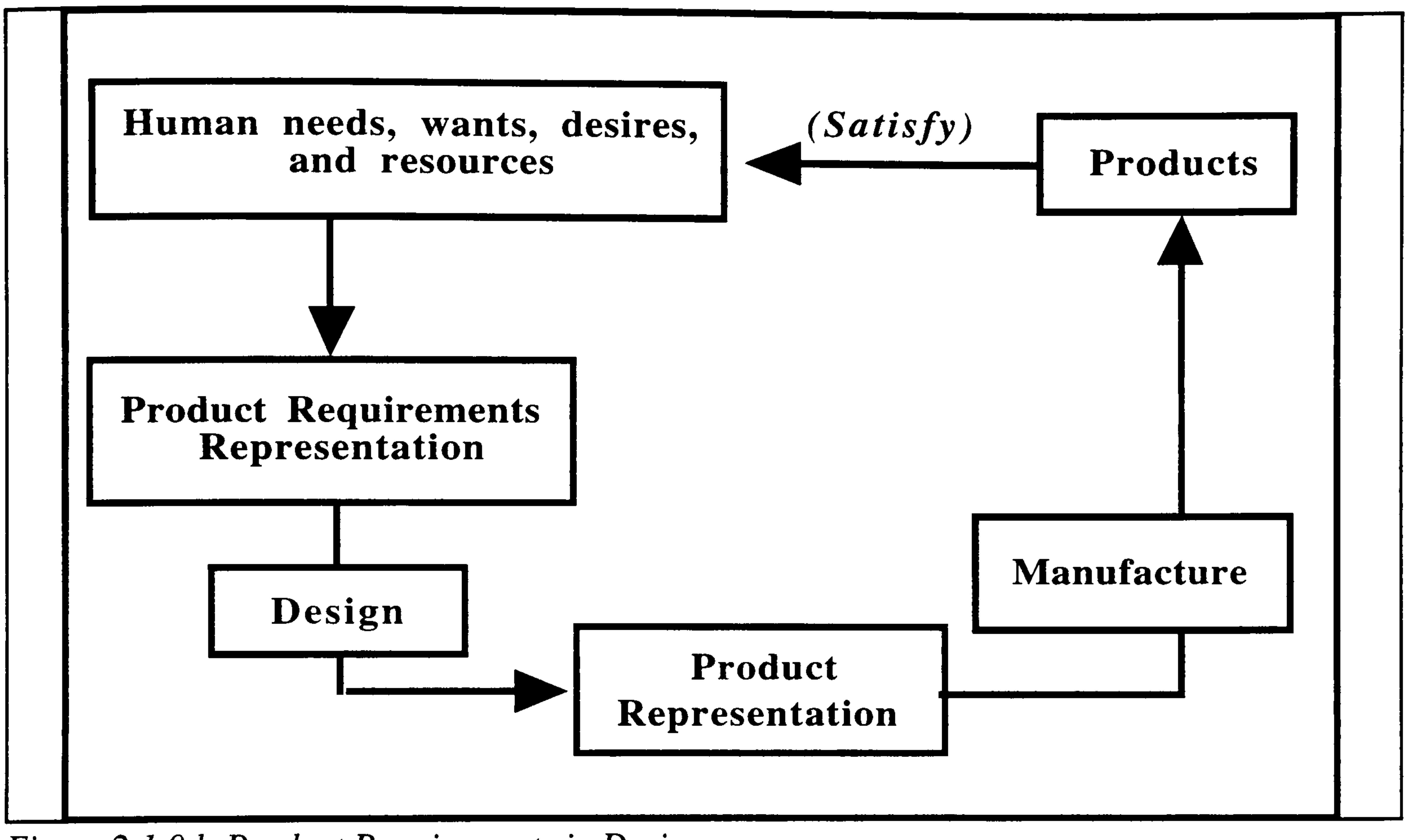


Figure 2.1.0d: Product Requirements in Design

The activity of product design is concerned with determining a product with particular properties which (it is believed) will satisfy those particular needs, wants, and desires.

The activity of product design aims at determining a product that meets the range of product requirements as effectively as possible. Whilst each requirement may be considered in isolation by the user they cannot be provided independently by the designer. The nature of materials and their processing imposes constraints and improving one requirement may well degrade another. The problems imposed by one requirement cannot be dealt with in isolation to the others necessitating the simultaneous solution of many problems in the hope of achieving the optimum combination in the final product. "Optimisation" is too strong a word. Alexander (1964 : 99) asserts:

"A design problem is not an optimisation problem."

March and Simon (1958) recommended using the term "satisficing", as opposed to "optimisation", as a more accurate explanation of what one actually does in terms of making complex decisions.

Synthesis and Analysis

Two essential elements that help define the complex creative act of solving design problems are the act of synthesis and the act of analysis. Synthesis is the bringing together of intuition and knowledge to form ideas that may be the solution to the design problem. Analysis is the process of breaking down solutions to see if they do in fact solve the problem. Crudely the design process can be considered as an iterative procedure of synthesising new ideas, and analysing them with respect to the initial problem, modifying, and reanalysing until an optimal or at least satisfactory solution is found (Figure 2.1.0e).

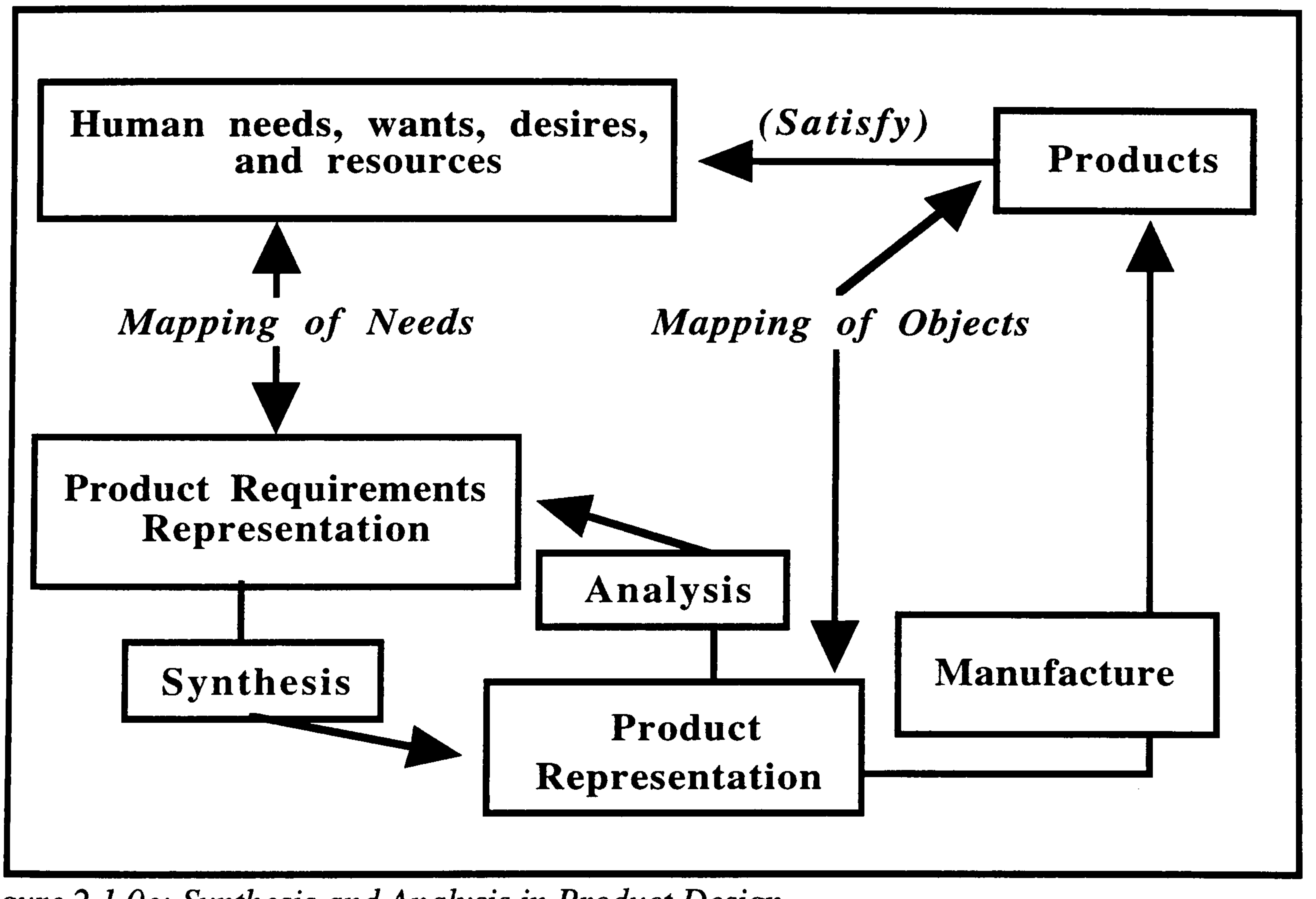


Figure 2.1.0e: Synthesis and Analysis in Product Design

Manufacturing

The manufacturing process does not produce products directly. The manufacturing process determines instructions for manufacturing plant and equipment to transform existing materials into the designed product (Figure 2.1.0f). This imposes constraints of practicality and cost on potential design solutions.

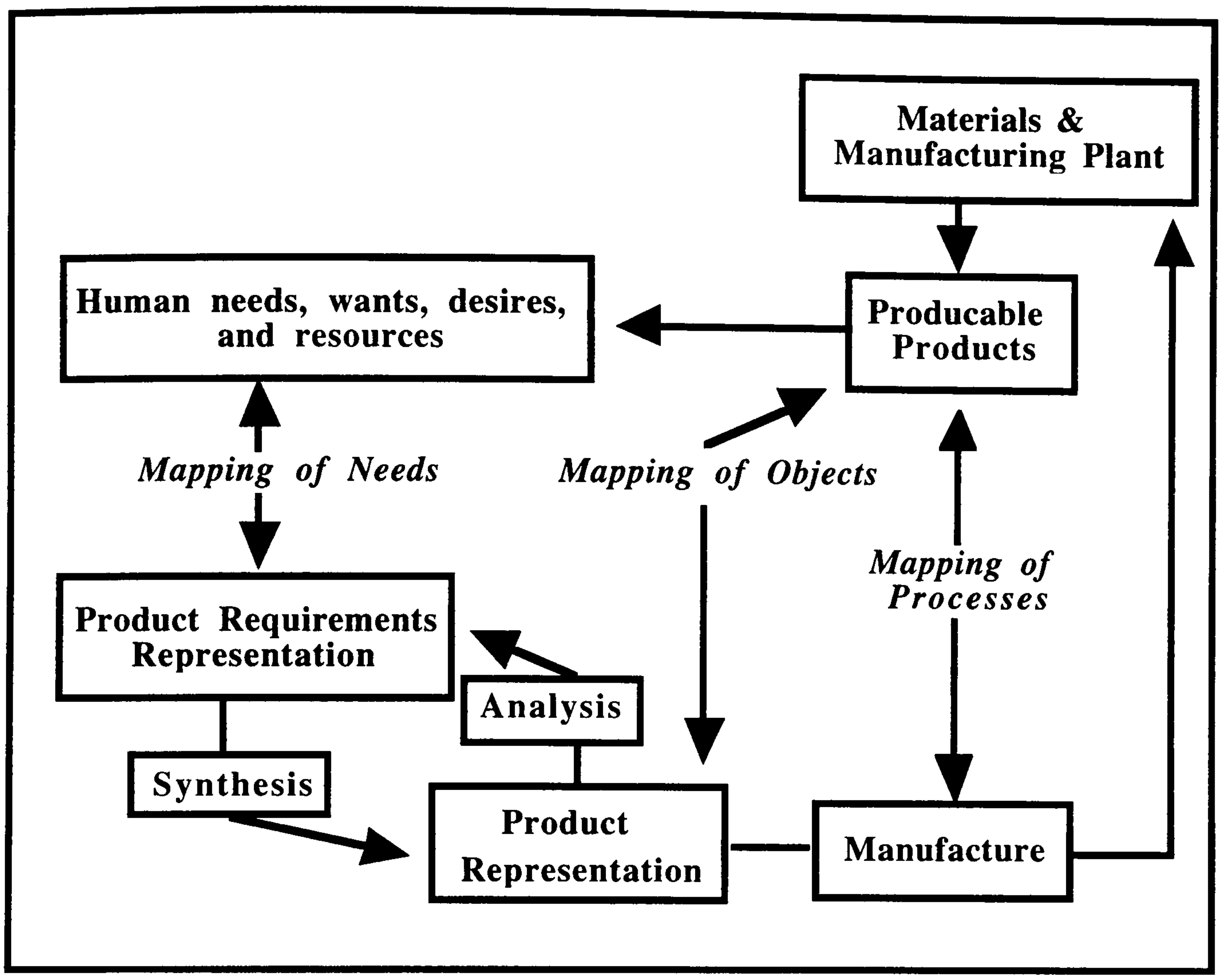


Figure 2.1.0f: The Manufacturing Process

The constraints of practical and economical production are applicable to any form of design, but the nature of the employed materials and their processing is another, although less potent, way of characterising design activities. Product design, in particular, does not deal exclusively with raw materials. The designer must also utilise existing products such as motors, electronic components, etc.

Figures 2.1.0b to 2.1.0f illustrate an overview of the design process. This rather simplistic view illustrates succinctly the activities that are commonly involved within the design process. The next chapter, (Chapter 3.0.0), reviews several different models of the design process, developed by eminent design thinkers such as Alexander (1964), Archer (1965), French (1985), and Pugh (1990) and how they have led to working design tools or methodologies that have been adopted in design practice.

Chapter 3.0.0

Review of Design Models

3.0.0 Review of Design Models

Designing is one of the most significant human acts. However, given that designing has been happening for nearly 5000 years our understanding of what is involved in designing is still remarkably ineffectual. There is a continuous need for designers to produce new, cost-effective, high-quality products in an increasingly less amount of time. It is in this context that this chapter begins with a definition of "design methodology" and highlights a number of reasons for their development. The distinction between descriptive models and prescriptive models of the design process is also discussed in this chapter.

The next section of this chapter concentrates on a selection of five major works on design models that have been developed over the last 30 years, namely: Alexander (1964), Archer (1965), French (1985), Pahl and Beitz (1988), and Pugh (1990). The reason for the selection of these 5 design models is that they contain key features of the development of design methods, and also because they are the most widely cited works within design literature. The final part of this chapter reviews a selection of existing methods for predicting product performance at the early stages (conceptual stage) of the product design process and establishes the platform on which the developments in design methods that are presented in this thesis are based.

It will be very clear to the reader that the results of this thesis are stimulated by the considerable intellectual contribution in Design by the authors referred to above. The thesis is also, in part, stimulated by work in Software Engineering, which has analogous conceptual design problems and it is in the specific area of functional descriptions of the design process that ideas of Software Modelling have been utilised. New insights can often be gained through the study of problems in quite different areas, and by mapping those insights onto established practice. It is in this interface area, between the concepts originally developed in Software Engineering and Design, that a new approach to design methodology is presented in this thesis.

3.1.0 Design Methodology

In an attempt to alleviate some of the problems that may be encountered by designers or design teams during various stages of the design process, numerous design methods and models have been developed. For instance several design methods have been formulated to be utilised in specific areas, these include Horak and Wormley (1981) passenger vehicle rail trucks' design method, Hodes and Akagi (1986) method for developing design criteria for a general purpose mechanical input device (*mouse*), Opferman and Yacobellis (1986) design method for specifying quality levels for communications hardware and software components, Orpwood (1990) who proposed a method for designing equipment for disabled people, and Hearn et al (1992) in their formulation of a design method for conceptual ship design.

There have been tendencies throughout the design fraternity to shy away from the word "model" and "methodology". Amongst many designers there is resistance towards anything resembling a "design methodology". Perhaps part of this skepticism is due to the ambiguity of the word "methodology". In the sense of "a methodology" it can mean a particular, prescribed, rigid approach, of which design practitioners are generally legitimately distrustful. The sense in which "a methodology" is used within this thesis is to mean the general study of method. Anyone who contemplates on how they practice their particular art or science, and anyone who teaches others to practice, must draw on methodology. Cross (Ed., 1984) states:

*"Design methodology, then is the study of the principles, practices and procedures of design in a rather broad and general sense. Its central concern is with how designing both **is** and **might be** conducted. This concern therefore includes the study of how designers work and think; the establishment of appropriate structures for the design process; the development and application of new design methods, techniques, and procedures; and reflection on the nature and extent of design knowledge and its application to design problems."*

Many of these models of the design process simply describe the activities involved within design (*descriptive models*), whilst others strive to prescribe a more appropriate method of working (*prescriptive models*).

Descriptive models of the design process generally stress the importance of creating a concept solution early in the process indicating the 'solution focused' nature of design reasoning. The initial solution to the problem is then exposed to analysis, evaluation, refinement and development. The descriptive model of the design process is heuristic, that is it relies mainly on the designer using his or her knowledge, intuition, and experiences in making the right decisions (Cross, 1994).

Prescriptive models of the design process attempt to improve designers methods of working. Cross (1994), suggests prescriptive models offer a more algorithmic, or systematic procedure for the designer to follow. In other words, the intention of adopting this procedure is to establish a sound understanding of the design problem, and proceed through the design process in a logical manner, making rational choices sensibly and intelligently. In this work a prescriptive model of the design process is called a "Design Methodology".

Cross (1994), suggests that although there may be many different models of the design process, they all have one thing in common - the need to improve on traditional methods of working in design. There are several reasons for this interest in developing new design methodologies, strategies and procedures, these are:

(i) The fact that the design problems designers have to solve nowadays have become extremely complex. Demands such as those concerning materials and manufacturing processes' information is now so vast that it is well beyond the grasp of the individual designer to keep up to date (Alexander 1964).

(ii) Costs and investments involved in design projects are now so great, for example in setting-up of plant and machinery, purchase of raw materials, etc. that there are now greater pressures on the designer or design team to get it right first time before the project proceeds into the later stages of the design process, such as the production stages. Figure 3.1.0a graphically illustrates the alteration costs and possible reduction costs involved in various stages of design projects generally carried out nowadays (Cross 1994).

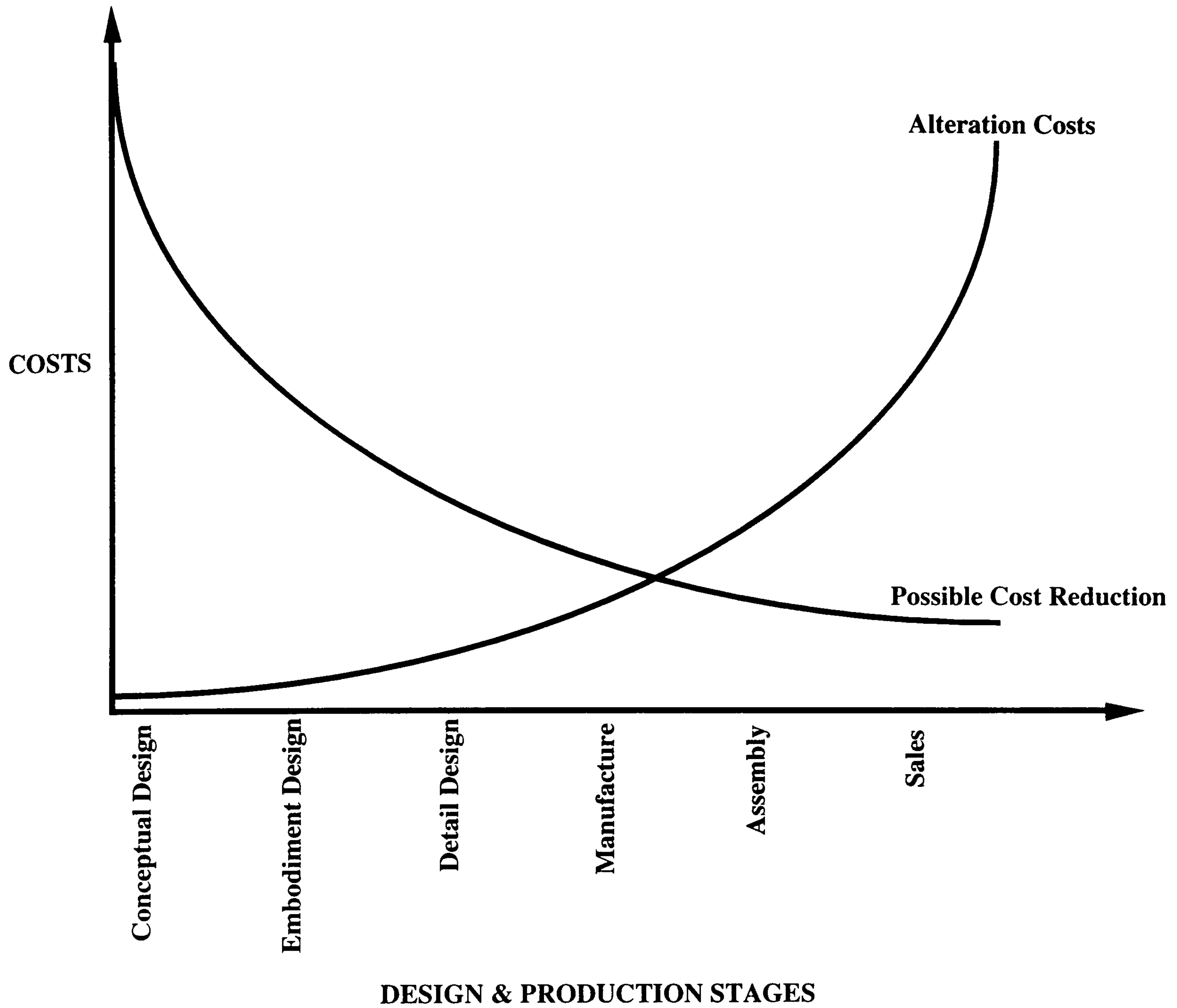


Figure 3.1.0a: Alteration and Possible Cost Reductions at Various Stages of the Design Process (Urban and Hauser 1993)

(iii) The fact that the needs, wants, desires of the user are perceived as having far more relevance nowadays, subsequently adding to the demands placed on designers (Heskett, 1992).

3.1.1 Design Models

It was noted in the introduction to this chapter that Design has been an integral component of human development over the last 5000 years, but this thesis will limit its discussion to a selection of five of the most widely cited design models that have been developed during the last 30 years. The design models that will be discussed are those of:

(i) Alexander (1964),

(ii) Archer (1965),

(iii) French (1985),

(iv) Pahl and Beitz (1988),

(v) Pugh (1990).

Alexander (1964)

Alexander presented a descriptive model of the design process from which followed a prescriptive model. Alexander's work will be discussed further in Chapter 4.0.0, but Alexander's propositions reflect his architectural experiences in that he describes the design process as having advanced through two well defined phases, but he proposes the need of a third one. The phases are as follows:

(i) Phase 1 (The Unselfconscious culture):

In this phase form-making and using are closely integrated and cannot be separated; the problem remains static; novices learn from gradual exposure to the craft in question, by imitating and correcting mistakes. There is a lack of understanding of theoretical background in this phase. Alexander suggests that this culture represents those generally found within "primitive societies".

(ii) Phase 2 (The Selfconscious culture):

In this phase form-making and using have become distinct; the problem may suddenly change; the novice learns on the basis of general principles (i.e. they can be taught). In the unselfconscious culture, form is shaped by the interaction between the actual context's demands and the actual inadequacies of the form. Form making is learned informally, through imitation and correction, while in the selfconscious culture, form making is generally taught academically, according to explicit rules.

(iii) Phase 3 (Formalisation):

Alexander argues, the selfconscious culture can be improved by introducing logical structures to represent design problems which retain only the abstract structural features of the form. He states that:

"A logical picture is easier to criticise than a vague picture since the assumptions it is based on

are brought out into the open. Its increased precision gives us the chance to sharpen our conception of what the design process involves." (Alexander 1964 : 8)

The primary rationale behind Alexander's approach was his observation of the increasing distance between designer and user in architectural design. Alexander suggested bridging this gap by using formal models, diagrams or graphical representations to make these mental pictures communicable, discussable and open to criticism. Alexander's specific objective was to create a conceptual framework that could be used to describe a way of representing design problems in a functional manner which would make them easier to solve. His approach is based on the idea that every design problem begins with an effort to achieve "fit" between two entities:
(i) the **form** in question,
and
(ii) its **context**.

Alexander asserts that the ultimate objective of design is form. The form is the solution to the problem, while the context defines the problem (i.e. the requirements to be met). The form is any part of the world over which the designer has control and can shape. The context is that part of the world which puts demands on the form, anything in the world that makes demands of the form is context.

Alexander refers to a formal statement of the design problem as a set of "misfits" (requirements), and the solution to this problem will be a form that successfully satisfies all of these misfits. Alexander illustrates his approach with the example of an Indian Village. He identified a total of 141 "misfits" in the life and work of the village, (i.e. all potential problems and weaknesses imaginable in farming, cattle-raising, housing, water supply, etc.). From considering the relative interdependency of the misfit variables, Alexander uses formal mathematical techniques to decompose the problem into a series of relatively independent sub-problems, which may then be handled as separate design problems dealing with various facets of, in this case, Indian village life. This approach is relatively controversial and some of the shortcomings of Alexander's approach can be attributed to a view of design problems as having a mechanistic character (Lawson 1990).

The importance of Alexander's work lies in his argument that design (process as well as product) can be improved by introducing formal methods and techniques, whereas the generally held view at the time was that design cannot profit from formal procedures, as it is an intuitive and individual activity.

Archer (1965)

Archer initiated a great deal of subsequent design research in the field of design methods and models by pointing out the positive aspects of systematic methods. He listed three excellent reasons for using these systematic methods that still hold true for most of todays design problems. The reasons he stated were:

"Systematic methods are extremely useful.... ",

(i) "when the consequences of being wrong are grave",

(ii) "when the probability of being wrong is high (e.g. due to lack of prior experience)", and

(iii) "when the number of interacting variables is so great that the break-even point of man-hour cost versus machine-hour cost is passed (e.g. in the design of industrial plant or large hospitals)." (Archer 1965 : 6)

In todays terms, with the advent of data base technology and sophisticated CAD modelling and visualisation packages, the concern raised in Archer's point (iii) is now less of a problem than it was. The prescriptive model of the design process proposed by Archer (1965) is illustrated in Figure 3.1.1a.

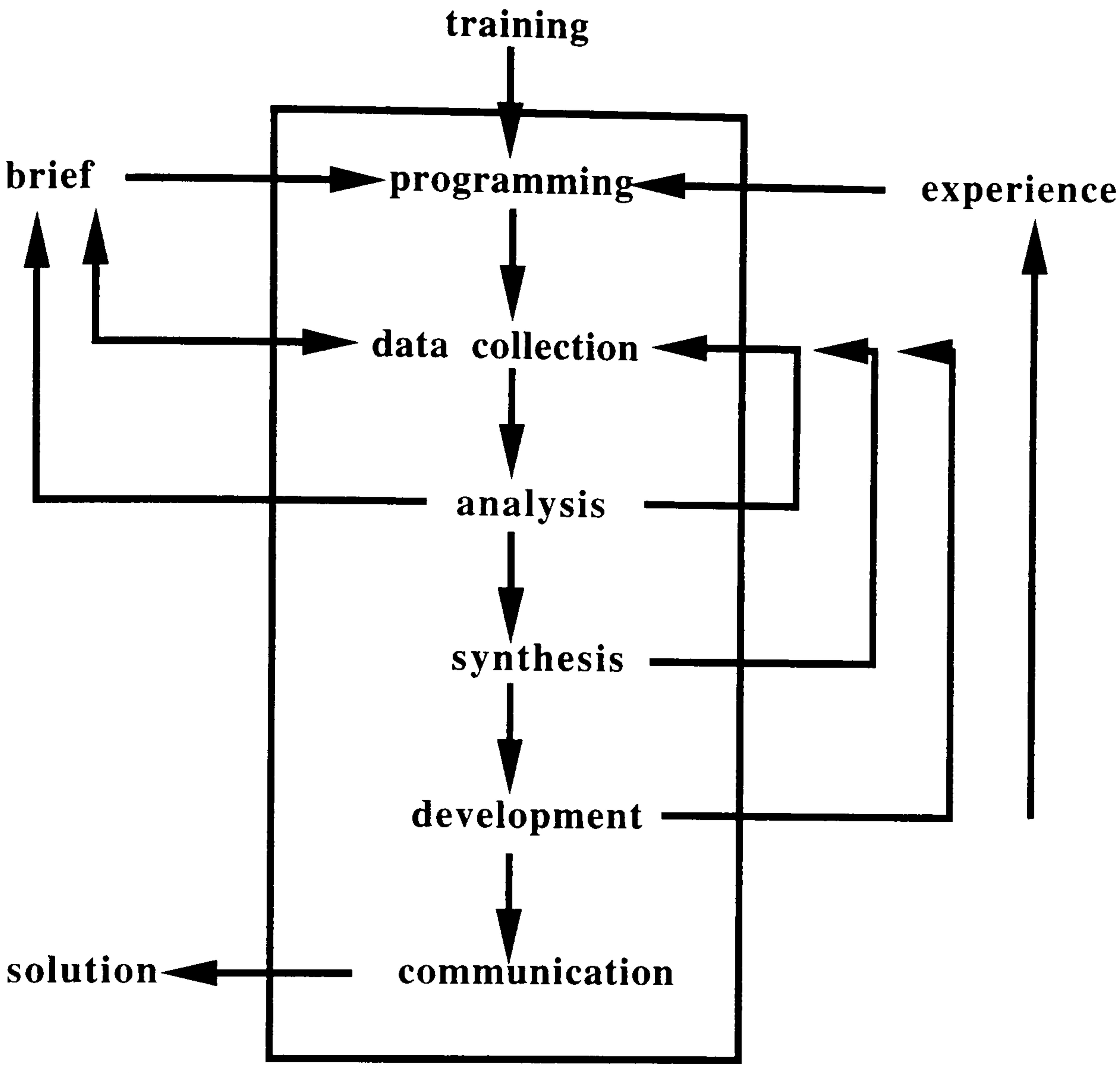


Figure 3.1.1a: Archer's (1965) Model of the Design Process

Archer's model of the design process includes connections between the designer's training, collection of data, etc. In practice, Archer asserts that various stages of the process are overlapping and this results in frequent feedback loops to earlier stages. Archer distinguished six types of activity intrinsic to this process as:

(i) Analytical phase:

* Programming: establish crucial issues; propose a course of action.

* Data collection: collect, classify and store data.

(ii) Creative phase:

* Analysis: identify sub-problems; prepare performance (or design) specifications; reappraise proposed programme and estimate.

* Synthesis: prepare outline design proposals.

* Development: develop prototype design(s); prepare and execute validation studies.

(iii) Executive phase:

* Communication: prepare manufacturing documentation.

Archer viewed the design process as a "creative sandwich", with the creative act in the middle of two slices of objective and systematic analysis.

French (1985)

An example of a descriptive model of the design process is found in French (1985). Figure 3.1.1b illustrates French's descriptive model of the design process. French points out that the circles represent stages reached, whilst the rectangles represent work in progress.

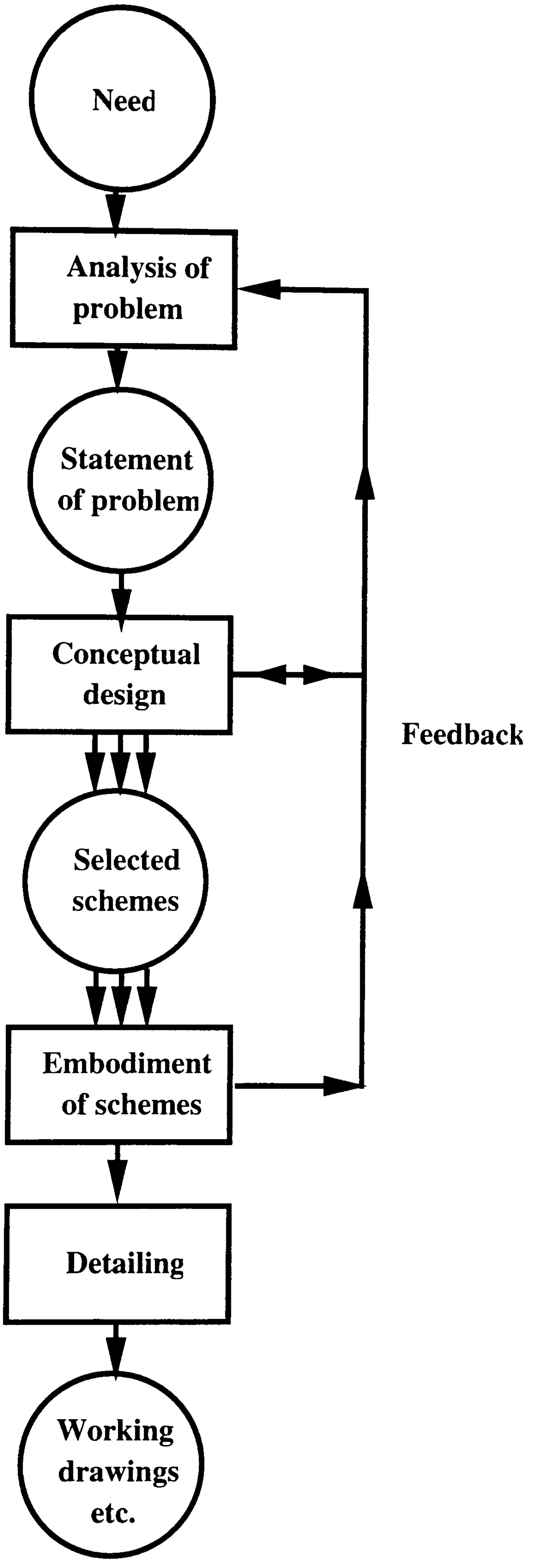


Figure 3.1.1b: The French (1985) Model of the Design Process

French suggests that the process generally begins with a "need", followed by an "analysis of the problem". He suggests that the analysis of the problem is an important part of the overall process. The output from this stage of the design activity is a statement of the problem, and this can have three elements:

(i) a statement of the design problem proper,

(ii) limitations placed upon the solution, e.g. codes of practice, statutory requirements, customers' standards, date of completion, etc.

(iii) the criterion of excellence to be worked to (French 1985).

The French model next proceeds through the activities of:

(i) Conceptual design. This stage takes the statement of the problem and generates solutions to it in the form of schemes.

(ii) Embodiment of schemes. In this stage greater detail is added to the schemes, and if there is more than one scheme then a final choice is made on which scheme to proceed with. The result of this activity is normally a set of general assembly drawings.

(iii) Detailing. The last phase in which a number of final decisions concerning detail and quality are made.

Pahl and Beitz (1988)

Pahl and Beitz suggest that the intention of using their procedure is to establish a sound understanding of the design problem, and proceed through the design process in a logical manner. The main stages of the Pahl and Beitz model are:

(i) Clarification of the task.

(ii) Conceptual design.

(iii) Embodiment design.

(iv) Detail design.

Figure 3.1.1c illustrates each stage of the Pahl and Beitz process. Pahl and Beitz suggest that at each stage, the designer must decide whether the next step can be made or whether previous steps must be repeated. Moreover, they stress that by continuing to the end of the process without detecting that a serious mistake has been made must be avoided at all costs.

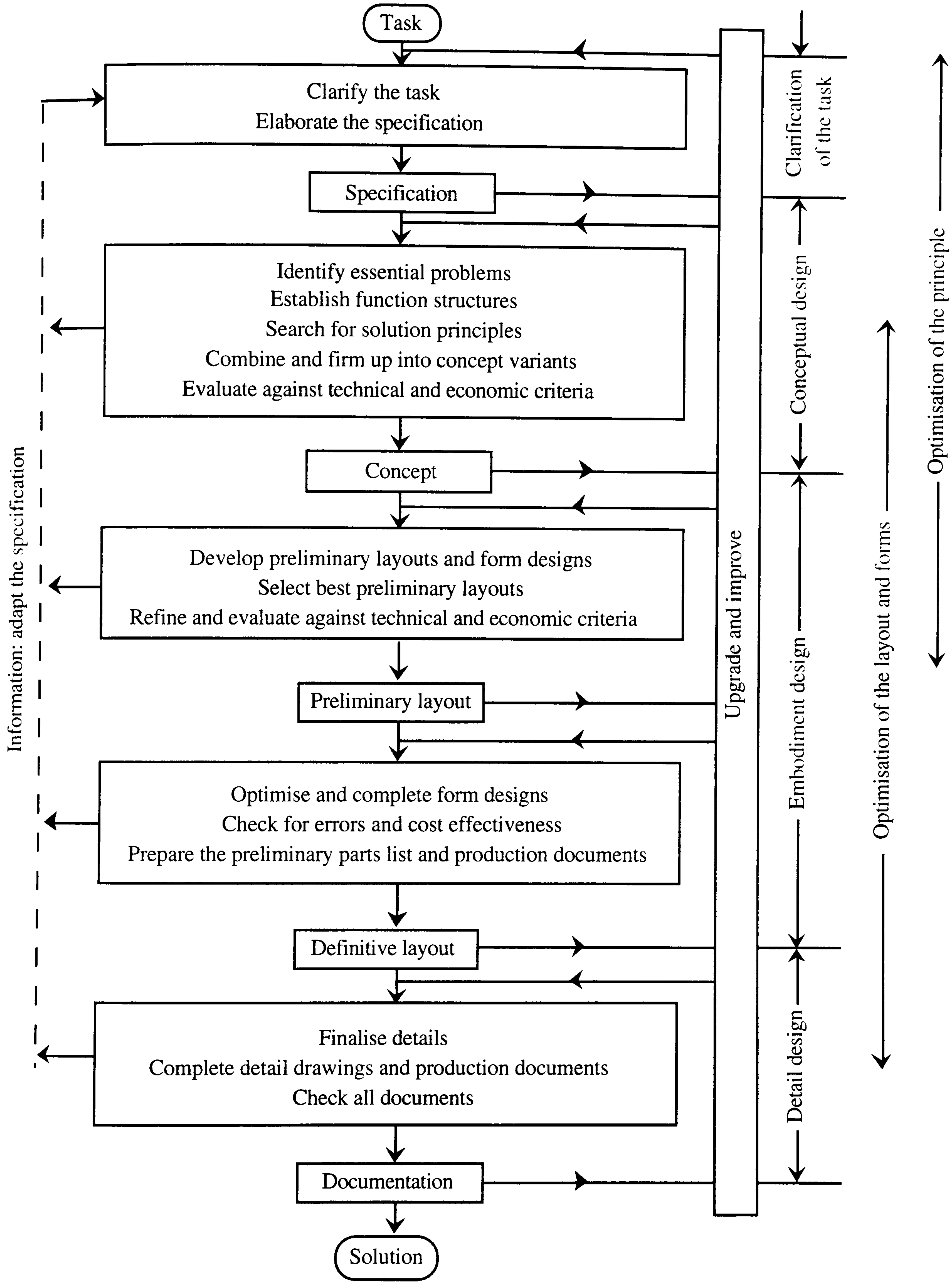


Figure 3.1.1c: Flow of Work During the Design Process (Pahl & Beitz 1988)

The above figure may seem over elaborate and many designers may object to following this type of rigid procedure on the grounds that it would be excessively time consuming to use in practice. However, Pahl and Beitz reassuringly state that:

* most of the steps have to be taken in any case, albeit unconsciously, in which case unforeseen consequences may arise;

* the deliberate step-by-step procedure, on the other hand, ensures that nothing essential has been overlooked or ignored, and is therefore indispensable in the case of original designs;

* in the case of adaptive designs, it is possible to resort to time-tested approaches and to reserve the step-by-step procedure for specially promising cases;

* if the designer is expected to produce better results, then he or she must be given the extra time the systematic approach demands; and

* scheduling becomes more accurate if the step-by-step method is followed rigorously.

Pugh (1990)

Pugh's approach to design problems in general is to take a "Total Design" view. The total design activity begins with the identification of the market/ user need, and proceeds through to the the selling of the product to satisfy that need - an activity that Pugh states:

"encompasses product, process, people and organisation".

Pugh suggests that total design may be thought of as having a central core of activities, all of which are necessary for any particular realm of design (e.g. Industrial Design, Graphic Design, Software Design). Briefly, as shown in Figure 3.1.1d, the design core consists of market/ user need identification, product design specification or PDS, concept design, detail design, manufacture, and selling. Typically, any existing product will have proceeded from an identification of a market/ user need through to sales. The main design flow is iterative in nature. Pugh suggests that through all the stages in the design core, activity is operated iteratively, yet upon later inspection, the stages represented in Figure 3.1.1d will have been gone through sequentially.

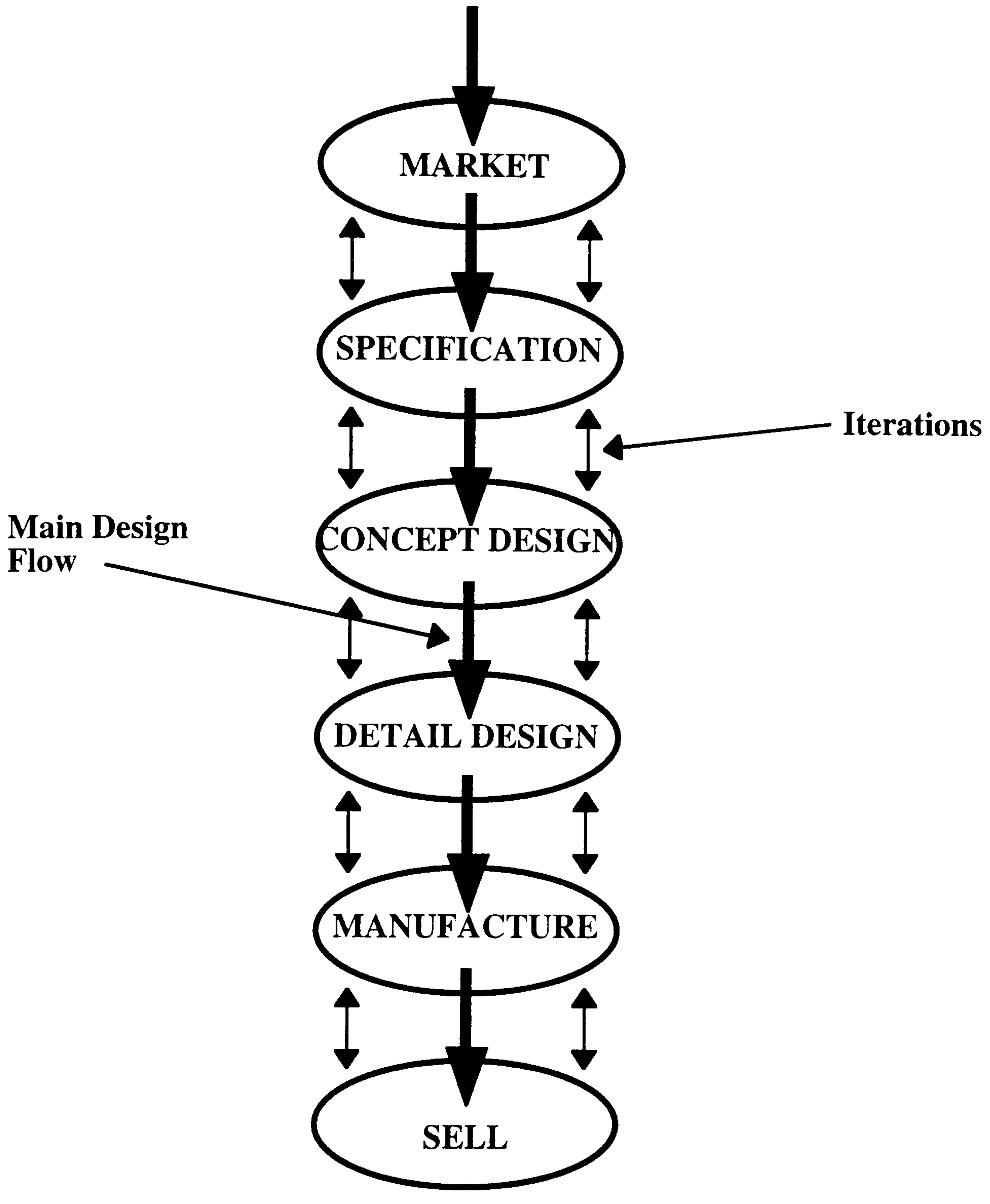


Figure 3.1.1d: Total Design Core (Pugh 1990)

Comparisons

A selection of the more noteworthy models of the design process, developed by eminent design thinkers (i.e. Alexander, Archer, French, Pahl and Beitz, and Pugh), has been discussed. Each of the models examined will have its own particular strengths and weaknesses and one model may be more appropriate than another in a certain situation.

ALEXANDER (1964)	Analytic Phase: requirement	set of requirements	Synthetic Phase: diagram, tree of diagrams		Realisation of Program	Form
ARCHER (1965)	Brief, data collection, training	Analysis	Synthesis	Development	Solution	
FRENCH (1985)	Need	Analysis & statement of problem	Concept design	Selected scheme, embodiment, detailing	Working drawings	
PAHL & BEITZ (1988)	Task, specification	Identify essential problems	Concept	Preliminary layout, definitive layout	Solution	
PUGH (1990)	Market/user need	Product design specification	Concept design	Detail design	Manufacture	Sell

Figure 3.1.1e: Comparison of Design Model Terminology

However, upon closer inspection of the figure above (3.1.1e) it is possible to draw conclusions which suggest that there is very little difference in the approaches adopted in the models depicted earlier, the major difference being the terminology applied. The five models described reflect the overview of the previous chapter (Section 2.1.0 The Design Process).

3.1.2 Product Performance Assessment in the Early Stages of Design

Although implicit within the aforementioned design models, the process of testing or evaluating candidate design solutions against the initial problem statement or specification is not explicit. Product performance assessment at the concept stage is concerned with both rationalising and evaluating the suitability of a concept in solving the original problem.

Rigorous concept selection holds the key to better overall product quality (Andersson 1994). In spite of what design techniques or methods we might apply during later design phases, they can only partially (indeed, sometimes never) compensate for a poor concept solution.

This has lead to a fundamental shift, during recent years, in the design process which has been observed by many authors within the product design and manufacturing community. For example Ertas and Jones (1993) draw attention to the fact that this change has been brought about as a result of the following factors:

(i) the limited economic life of many consumer and high technology products,
(ii) the pressures on both designers and manufacturers to reduce the development time for products,
(iii) the need to improve product quality, and
(iv) the need for improved communication techniques between design engineering and manufacturing.

The significance of product design is well documented in Jo, Parsaei and Sullivan in (Parsaei and Sullivan 1993 : 3-23). They illustrate this significance by citing the following statistics:

"...product design accounts for only 5% of total product cost, 70% of the cost is influenced by the design" (Boothroyd 1988)

"...40% of all quality problems can be traced to poor design" (Dixon and Duffey 1988)

"80 to 90% of the total life-cycle cost of a product is determined during the design phase" (Gatenby and Foo 1990).

Recent advances in Computer-Aided Design/Computer-Aided Manufacture are aimed at addressing these issues and others. Many manufacturers now utilise CAD/CAM technologies and encourage individual tasks within design and manufacturing engineering to be performed concurrently rather than sequentially. Consequently these manufacturers are reducing product development time significantly.

Ertas and Jones emphasise that a successful design must take account of many factors, for example they suggest:

"A fully interactive process will give designers instant feedback on essential elements such as strength, aesthetics, manufacturability, and cost, leading to development of optimum designs that can be quickly manufactured using automated NC programs." (Ertas and Jones 1993 : 30)

This "complete view" of product design is a central feature of the methodology developed in this work (see Attribute Spectrum - Figure 4.2.1a). At present, however, with the odd exception, CAD/CAM cannot be applied for the whole process of product design engineering (Krottmaier 1993).

Definitions of conceptual design vary from one author to another, however the majority would agree with the claim made by French (1985) when he stated:

"It is the phase... where there is the most scope for striking improvements... and where the most important decisions are taken." (French 1985 : 23)

It is widely acknowledged that the concept stage of the design process contains three main stages, namely:
(i) clarification/ definition of the project objectives;
(ii) generation of concept proposals that attempt to meet the objectives (synthesis); and
(iii) evaluation of the concept designs against the objectives (analysis), and selection of a suitable proposal.

Some existing methods of identifying product performance requirements and assessing design solutions to them are outlined below.

King (1989)

King's book is dedicated entirely to the Quality Function Deployment (QFD) procedure. This technique is not only aimed at improving the product, including process and production planning, but it also implies a management approach that incorporates the quality concepts of W. Edwards Deming amongst others. The QFD system provides a method for translating customer needs, wants, or desires into appropriate engineering requirements, which can then be implemented throughout the design and manufacturing stages.

The first stage of the QFD procedure is to identify the customer(s). The objective of this stage is to translate customer requirements into a technical description of what is required of the product. In other words, the emphasis is to "listen to the voice of the customer". Significantly, the customer requirements should be stated in the customers' own terms, for example "easy to clean", "looks attractive", etc.

The second stage is to determine the relative importance of requirements. A weighting factor must be assigned to each requirement that describes their relative importance. To determine importance, a pair wise comparison (Ullman 1992 : 122) or weighted objectives method (Cross 1994 : 123), or utility theory (Thurston and Locascio 1993) can be used.

Stage three is translating customer requirements into measurable engineering requirements or characteristics. Setting measurable targets for each engineering requirement of the design facilitates measurement of actual samples of competing products which in turn provides a basis for establishing target values for the engineering characteristics.

This stage contains three elements:
(i) first, the customer requirements must be translated into engineering requirements, for example "easy to attach" can be measured by the number of steps needed to attach, the time needed to attach, the number of parts needed, and the number of standard tools needed (Ullman 1992 : 123);
(ii) second, every effort must be made to ensure each engineering requirement is measurable; and
(iii) thirdly, the relative importance of each engineering characteristic to each customer attribute is assigned a **qualitative** weighting.

The final stage is competition benchmarking where each competing product is compared with the customer requirements. Some of the comparisons will be directly measurable, however others will be subjective and customer opinion may be required.

A visualisation of the QFD technique is the "House of Quality" matrix, illustrated in Figure 3.1.2a. The horizontal rows contain two customer requirements, (i.e. "easy to open and close door", and "isolation"). The columns comprise the engineering characteristics (e.g. energy to close door, peak closing force, etc.) which are expected to be met by the new product. Once the customer requirements have been translated into a technical description (i.e. 'stays open on a hill', 'doesn't leak in rain', etc.), the relationships between the engineering characteristics (columns) and customer requirements (rows) must be defined (i.e. strong positive, medium positive, etc.). This process usually involves both the marketing and the engineering personnel (Hauser and Clausing 1988). The design team interprets the customer requirements through discussion and by clarifying the relationships between the customer requirements and the engineering characteristics, the design team establishes a common understanding of the project goals.

The relationships between engineering characteristics and customer requirements will vary in levels of importance, therefore the design team usually works through the matrix examining where a relationship occurs, and deciding on the relative importance of that relationship. The strengths of the relationships are usually indicated by either symbols or numbers.

The customer perceptions, at the right of the house, illustrates how customers rate competing products against their stated needs. This information comes in useful for identifying which characteristics of existing products must be improved. Targets and objective measures, near the base of the house, helps in both competitive benchmarking for each of the engineering characteristics (i.e. ft-lb, lb/ft, psi, etc.) and facilitates performance comparisons between competing products. Targets can be set for the measurable parameters of the engineering characteristics, (e.g. ft-lb, lb/ft, psi, etc.), in order to achieve the customer requirements or improve the existing product.

The correlation matrix, the *roof* of the "House of Quality", illustrates the inter relationships between engineering characteristics. Decisions can be made, by the design team, as to whether these interactions are negative or positive. After following this method, the design and marketing teams will have acquired a significant **understanding** of customer perceptions, competing products performance, and how the engineering characteristics relate to the customer requirements. However, there is no formal or computable relationship between the customer attributes and engineering characteristics.

Subsequent steps are needed, however, to transform the customer requirements into the proper product, the correct production process plan, and the correct process parameters to realise the product. To determine these specifications, the targets of the first house are inserted on the rows of a second house for parts deployment. The design team then proceeds to write specifications for the components and/or subsystems which will meet the demands of the overall product. This technique of translating the 'targets' of the previous house into the 'needs' of the subsequent house continues for a third, process planning house, and a fourth, production planning house. These houses define the major process operations and the production control parameters, respectively (King 1989).

The four linked houses of quality illustrate the format for 'deploying' the customer requirements, from planning to production, and provide the total structure for quality function deployment (QFD).

Although the QFD method described by King (1989) is a comprehensive design tool, that is presently used in many major industries (e.g. BLACK & DECKER, TOYOTA, FORD MOTOR CO., RANK XEROX, DEC, etc.), it has the following shortcomings:

(i) There is no provision for justification of entries and therefore there is no corporate record of the decisions that led to the final design.

(ii) The QFD method of assessment is based on attainment of individual targets and therefore does not reflect the relative importance of each attribute, nor the significance of each characteristic to an attribute. In this technique, targets are set for the measurable parameters of the engineering characteristics, (e.g. ft-lb, lb/ft, psi, etc.), in order to achieve the customer requirements.

(iii) There is little indication, however, of how this system will be used for setting targets that reflect subjective or emotional customer attributes, for example "looks attractive".

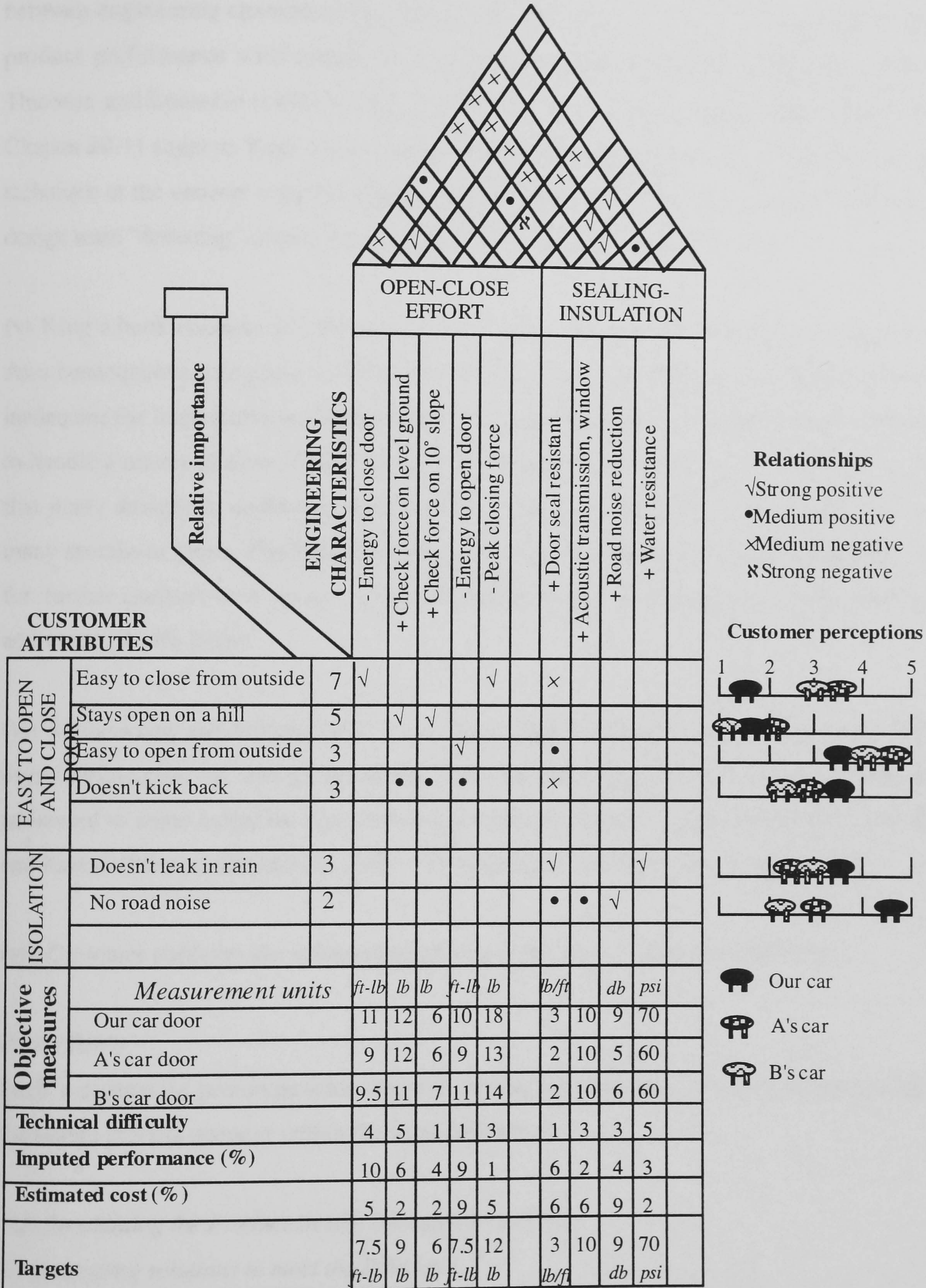


Figure 3.1.2a: "House of Quality" (from Cross 1994 : 103)

(iv) QFD is, predominately, a technique used for problem formulation. Because the relationship between engineering characteristics and customer attributes are only qualitatively described product performance with respect to customer attributes cannot be computed. However, Thurston and Locascio (1993) look to bridge this gap by using utility theory. King (1989 : Chapter 20-1) suggests Pugh's evaluation method should be used in conjunction with the QFD technique at the concept selection stage of the design process. Pugh's method is based on the design team "deducing" criteria for evaluation from the original specification.

(v) King's book contains 30 QFD matrices and charts that have to be filled out in paper form. As a consequence, this places several severe limitations on the QFD system. Paper forms are inadequate for large numbers of requirements and specifications (e.g. users cannot be expected to handle a matrix of over 10,000 cells). Also the paper forms offer no provision for the fact that many designers, engineers, and customers may be involved in a project that may span many months or years. Furthermore, there is no way to automate the search for specific items for further analysis or a review to ensure each customer requirement has been adequately addressed (Wolfe 1994).

(vi) Ramaswamy and Ulrich (1992) have the coupling between design variables as a "gross oversimplification" of design problems. The computer implementation problem has been addressed to some extent by Thurston and Locascio in (Parsaei and Sullivan 1993 : 207-230) and Kim in (Parsaei and Sullivan 1993 : 413-425) and is described later in this chapter.

(vii) Customer attributes are written descriptively rather than as objective measures.

Pugh (1990)

Pugh's method for prototype selection, (e.g. product, system, etc.), at the conceptual stage of the design process operates within the same framework.

"(1) formulating the Product Design Specification (PDS),

(2) generating solutions to meet the PDS, and

(3) evaluating these solutions to select the one that is most suited to matching the PDS." (Pugh 1990 : 68)

Pugh attaches considerable importance to the PDS and outlines, in some detail, its constituent elements and methods of their establishment. Evaluation, however, is not directly based on the specification but on criteria "deduced" from it by the design team.

Pugh does not appear to distinguish between functional requirements of the product and user requirements. He does not indicate how functional requirements are related to customer/ user requirements in the way that QFD does.

Pugh recognises that the PDS may change over the design process and anticipates this. The end solution is a consistent pair of design and PDS, not a design consistent to an initial specification.

The Pugh method is intended to assist designers in the early stages of the design process. Pugh proposes a simple non-mathematical matrix for his method of evaluating concept proposals against criteria established by members of the design team. The method uses one part of the matrix to express the criteria for selection, derived from unambiguous statements of performance - functional and otherwise, that is the Product Design Specification (PDS) on the vertical axis, and the horizontal axis is used to express the concept design proposals (see Figure 3.1.2b below). In terms of this work each product attribute, in users' terms, is comparable to an element of Pugh's PDS criteria.

Criteria \ Concept	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Ease of achieving 105-125 DbA		S	-		+	-	+	+	-	-	-	-	S	+
Ease of achieving 2000-5000 Hz		S	S		+	S	S	+	S	-	-	-	S	+
Resistance to corrosion, erosion and water		-	-		S	-	-	S	-	+	-	-	-	S
Resistance to vibration, shock and acceleration	D	S	-	N O	S	-	S	-	-	S	-	-	-	-
Resistance to temperature	A T	S	-	T	S	-	-	-	S	S	-	-	S	S
Response time	U	S	-	E	+	-	-	-	-	S	-	-	-	-
Complexity: number of stages	M	-	+	V A	S	+	+	-	-	-	+	+	-	-
Power consumption		-	-	L	+	-	-	+	-	-	-	-	S	+
Ease of maintenance		S	+	U	+	+	+	-	-	S	+	+	S	-
Weight		-	-	A T	+	-	-	-	S	-	-	-	-	+
Size		-	-	E	S	-	-	-	-	-	-	-	-	-
Number of parts		S	S	D	+	S	S	-	-	+	-	-	S	-
Life in service		S	-		+	-	S	-	-	-	-	-	-	-
Manufacturing cost		-	S		-	+	+	-	-	S	-	-	-	-
Ease of installation		S	S		S	S	+	-	S	-	-	-	S	-
Shelf life		S	S		S	S	-	-	S	S	S	S	S	S
Σ+ Σ- ΣS		0 6 10	2 9 5		8 1 7	3 9 4	5 7 4	3 12 1	0 11 5	2 8 6	2 13 1	2 13 1	0 8 8	4 9 3

Figure 3.1.2b: Pugh Evaluation Matrix (from Pugh 1990 : 83)

Pugh's procedure for concept selection is carried out as follows:

(1) All concept solutions must conform to the PDS, i.e. all solutions must satisfy the same requirements and constraints.

(2) Having developed a number of possible solutions to the problem, they are produced in sketch form to the same level of detail for each one.

(3) The concept evaluation matrix can be established with the criteria derived from the PDS (usually not stated in product users' terms) along the vertical axis, and each concept design proposal on the horizontal axis.

(4) Ensure the criteria against which the solutions will be compared are chosen from the PDS. The criteria should be stated in terms which are unambiguous and understood by all involved.

(5) Select an existing product type as a datum with which all other concepts will be compared. If no competitive designs exist, the group should choose a datum which they believe intuitively to be the "best".

(6) Each concept and criteria combination is compared against the datum using the following symbols:

+ (plus): indicates better than, less than, less prone to, easier than, etc., relative to the datum.

- (minus): indicates worse than, more expensive than, more difficult than, more prone to, etc., relative to the datum.

S (same): indicates same as datum.

(7) An initial comparison of concepts is made using the above symbols. This results in a number of +'s, -'s and S's in relation to the datum. These scores are only for guidance at this stage and should not be summed algebraically.

(8) Assess the scores for the individual concepts. Certain concepts will exhibit strengths, while others will highlight weakness.

(9) If a pattern of one or more strong concepts does not emerge, change the datum and repeat the procedure. If a strong concept still does not emerge it means either that the criteria are ambiguous (this is usually the case) or that one or more concepts are subsets of the others (i.e. they are one and the same thing).

(10) If one concept continues to remain the strongest, change the datum and repeat. If the same concept continues to predominate, let this strong concept be the datum and redo the matrix.

(11) As strong and weak features of each concept emerge it is important to attempt to make modifications that will improve the situation. Often a new concept will emerge. If the effort to eliminate defects in a concept fails then it reinforces the view that it is a weak concept.

Pugh indicates that it may be necessary to carry out this procedure many times over before proceeding to the further stages of detailing and manufacture. Pugh points out that:

"...a single, typical matrix run may take anything up to a whole day to complete" (Pugh 1990 : 80).

An enlightening review of Pugh's method can be found in Bucciarelli (1994). In it he relates the conversation between several members of a design team working on a photo print processing machine project who have decided to use Pugh's method for concept selection. Bucciarelli's transcript of the meeting is almost five pages in length, and is referred to by the project manager of the design team as *"the disaster meeting"* (Bucciarelli 1994 : 156). The objective of this meeting, Bucciarelli reports, was firstly to establish a set of criteria and secondly to evaluate fourteen different concepts, against the agreed criteria with the intention of reducing the number of concepts to about two or three. The method, however, did not work. Bucciarelli proposes the most likely reasons being that the members of the design team could not agree on a set of criteria, and that the design team members' performance specifications were both in conflict with one another, and unclear (see point 4 of Pugh's method). Indeed Bucciarelli states:

"...the (Pugh) method does not allow for different views on the interpretation of those criteria. Rather, it presumes a single, coherent reading." (Bucciarelli 1994 : 157)

Pugh believes, however, that using his matrix-based method of concept evaluation will stimulate creative, unconstrained thinking due to its lack of rigorous structure. He goes on to add that his method lacks the inflexibility and false confidence that may be found by adopting numeric rating/weighting matrices. However, Pugh concedes that:

"Numerical rating and weighting is ***most useful*** *where strong product line precedent exists - and where the 'voice of the customer' has evolved through the PDS into a repeatable set of conditions, the relative merits of which have become firmly established and proven."* (Pugh 1990 : 93)

Pugh's method has four main shortcomings:
(i) he does not rate or weight individual criteria which means he treats each criteria with the

same value or worth,

(ii) the PDS is usually stated in objective and measurable terms of the product, not in terms of the product user,

(iii) it is enormously time consuming (a whole day for a simple, typical matrix), and

(iv) the practical problems described by Bucciarelli, that is the members of the design group found it almost impossible to agree on criteria and the specification of performance (PDS).

Suh (1990)

The main aim of Suh's axiomatic approach is to establish a scientific foundation for design. He expresses:

"Without scientific principles, the design field will never be systematized, and thus will remain a subject that is difficult to comprehend, codify, teach, and practice." (Suh 1990 : 46)

Suh's method is based on two axioms that attempt to govern good design. They are as follows:
(i) Axiom 1 - *The Independence Axiom* which aims to maintain the independence of FRs; and
(ii) Axiom 2 - *The Information Axiom* which aims to minimise the information content of the design (i.e. the 'best' design, relatively speaking, is the one that has minimum information content).

Suh's information axiom, reports Bahrami and Dagli in (Parsaei and Sullivan 1993 : 113-126), relates to an important virtue in design commonly recognised as "simplicity". In design terms, simple generally means the reduction of shapes, components, etc. without detrimental effect to the functional requirements or specifications of the design. "Simple design" also relates to ease of manufacturability, reduction of product cost, etc.

"A good design is one to which no more can be added, and at the same time, one from which nothing can be subtracted without causing an incomplete design." (Bahrami and Dagli 1993 : 122)

Suh, like Alexander (1964) and Cross (1994) amongst others, calls for a more "rational approach" to design than is practised at present. In other words an approach which is not based on intuition, gut feeling, etc. The purpose of Suh's book, he states, is to present a scientific approach to design. He asserts that his text is the first book that takes an axiomatic approach to design. Axioms are formal statements which are believed true until they or their consequences are in conflict with experience. The basic assumption of Suh's axiomatic approach to design is that there exists a fundamental set of principles that enables one to rank or compare candidate design solutions.

Design can be defined, Suh suggests, as the creation of solutions (products, systems, processes, etc.) that satisfy recognised needs through a mapping between the (FRs) functional requirements in the functional domain and the (DPs) design parameters of the physical domain, through the correct selection of DPs that aim to satisfy the FRs (see Figure 3.1.2c). FRs, for example "open bottles", "open cans", etc., are the designer's expression of the perceived functional needs for a product. Since the designer can arbitrarily define the FRs to meet a certain functional need, an acceptable set of FRs is not necessarily unique, nor is there a unique set of DPs that aim in turn to satisfy those FRs. Therefore, there can be an infinite number of feasible design solutions. Although he does not use the term, Suh's FRs are a specification. He, like Pugh, acknowledge that these may change over the design process, but also observes that the same problem may be defined with different FRs.

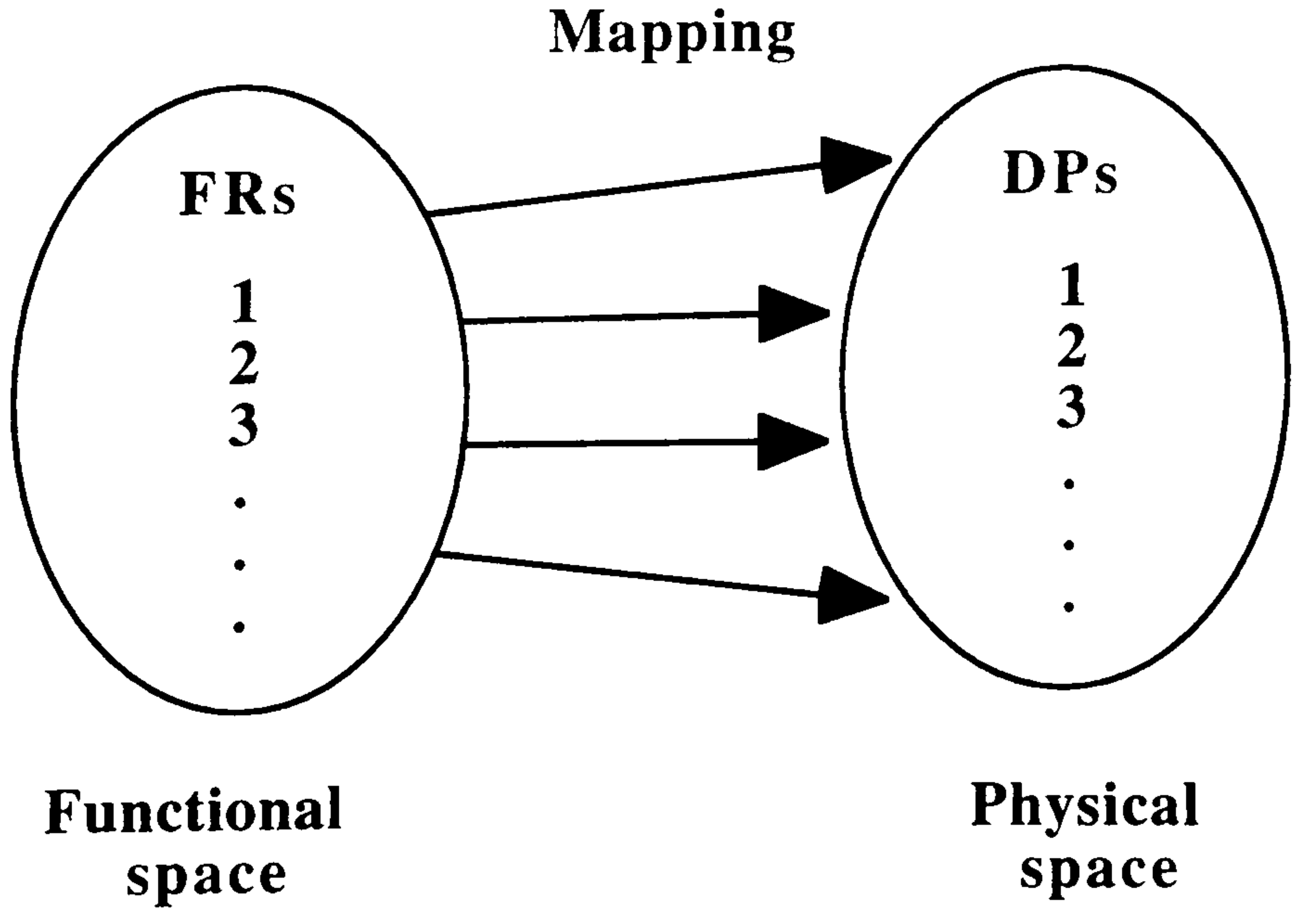


Figure 3.1.2c: Mapping process from the functional space to the physical space to satisfy the designer-specified FRs (from Suh 1990 : 26)

In many cases of design, however, the establishment of an acceptable bunch of FRs may require an iterative process. The preferable iteration cycle, Suh states, is at the conceptual stage of the design process. Once the conceptual design is accomplished, the expected performance of the realised concept can be compared against the original perceived needs of the product. If they differ, then an improved bunch of FRs can be generated without incurring great costs (Suh 1990).

There are two different approaches to this task depending on whether the designer is attempting to create a major new product or innovation, or whether the objective is to improve an existing design. In terms of the former, the FRs must be defined in, what Suh phrases, a "solution-neutral environment" which is free of bias and preconceived physical solutions. In the majority of cases, however, the goal for designers is to improve on an existing design by including the "customer attributes" in FRs. One technique for doing this is the "House of Quality".

Suh's criteria for evaluation is based on the premise that the "best solution is the one which satisfies the FRs (functional requirements)" as opposed to "the solution that performs best for the user". In other words, Suh proposes that the form should only provide the functionality that is asked for - nothing more and nothing less. In software engineering/development, however, it is generally believed that it is possible that greater functionality leads to greater simplicity.

Suh concedes that one of the major problems of this approach is that designers and manufacturers do not state explicitly the FRs that their designs must achieve (Suh 1990 : 32). This is similar to Bucciarelli's findings, i.e. he found that not only did the individual members of the design team phrase the performance specification (DPs) in their own individual terms. But, that the design team found it almost impossible to agree on a set of criteria (FRs).

Suh is only concerned on how well a design meets the FRs, **not** on how well the design meets the customers/ users' needs. He considers that performance above that stated by the FRs is "over design" and should be avoided. It is widely acknowledged that products which are designed from a customers/ users' perspective will have more opportunity for success in today's highly competitive market place (Hollins and Pugh 1990, Urban and Hauser 1993).

The FRs and DPs intrinsic to Suh's approach are not well defined. For example, he states that the FRs of a bottle/ can opener are "open bottles" and "open cans" (Suh 1990 : 51). In QFD terms these would be customer attributes. Later, (Suh 1990 : 265), he states that FRs of a machine tool are "stiffness" and "toughness" which, in QFD terms, are engineering characteristics. Suh's definitions of both FRs and DPs lacks a degree of rigour equal to the rigour he subsequently provides in his axiomatic approach. Mistree states in his review of Suh's book in Research in Engineering Design[3] that his book is "short on definitions", and questions "what the actual singular definition of design in the axiomatic approach is?"

One attraction of Suh's axiomatic approach is that it could eliminate the "brute force" approach of evaluating design solutions particularly with respect to manufacturing costs (Suh 1990 : 49-50). The term "brute force" is used here to cover approaches to process design evaluation based on large databases of component and process information, for example see O'Flynn and Ahmad in (Parsaei and Sullivan 1993 : 184-206).

Ullman (1992)

Ullman (1992 : 169) presents four different techniques for evaluation at the conceptual stage of the design process (see Figure 3.1.2d). The evaluation techniques he proposes are:

(i) feasibility judgment - the designer will respond to the concept proposal in one of three possible ways: firstly, not feasible, the concept will never work; secondly, the concept might work; and thirdly, the concept looks worthwhile. These judgments are based largely on a "gut reaction" by the designer based on his/her knowledge, understanding, intuition, etc.

(ii) technology-readiness assessment - used to determine the readiness of the technologies that might be used in the realisation of the concept design. For any technology to be used, it must be mature enough. Ullman reassuringly states, however, that most technologies used in the realisation of product designs are mature.

(iii) go/no-go screening - this technique is based on customer requirements and helps sift through concept proposals. This technique helps point out the weak aspects of the concept so that they can be modified to fix the problem.

[3] Book Review of Principles of Design (1990), Nam P. Suh by Farrokh Mistree in Research in Engineering Design (1992), Vol. 3, pp 243-246

(iv) the decision matrix method, or (Pugh's method), - provides means of comparing and evaluating concepts. The comparison is made between each concept and a predetermined datum relative to agreed criteria.

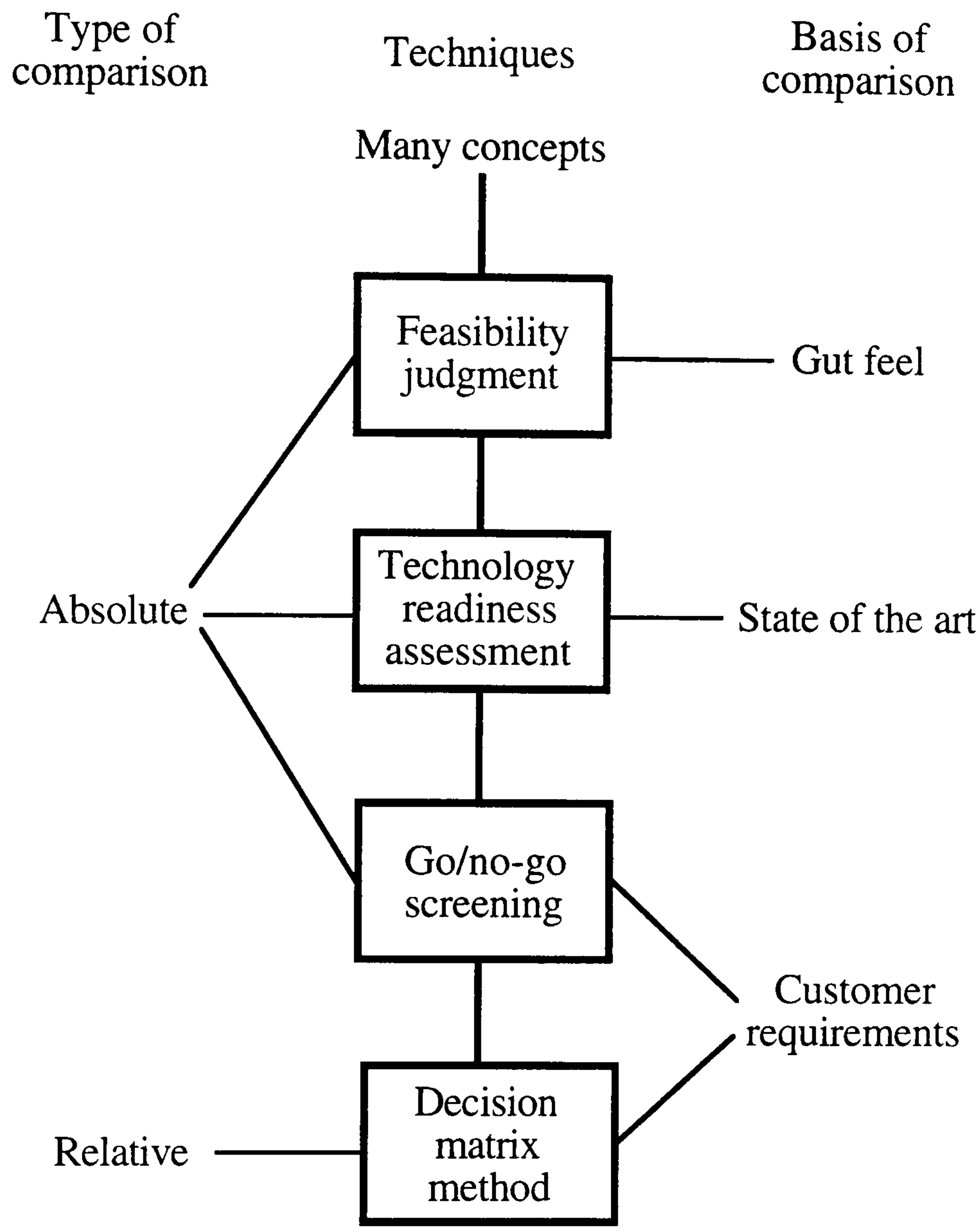


Figure 3.1.2d: Concept Evaluation Techniques (from Ullman 1992 : 169)

Ullman states that there is a continuous need, throughout the design process, for product evaluation. He suggests that at the conceptual stage of the design process the evaluation methods are "coarse" because the concepts are abstract, but as the concept is refined towards a finished product then more sophisticated evaluation techniques become available. Later in his text, Ullman states:

"The sequence of techniques used for concept evaluation (see Figure 3.1.2d) *are useful in product evaluation; however, the list must be expanded to include direct comparison with the engineering requirements."* (Ullman 1992 : 227)

The objectives of performance evaluation, Ullman indicates, is to assess the product design with respect to the target values of the engineering requirements. However, as the target values are expressed as numerical values, the evaluation can only take place after the product is refined to the point that numerical engineering measures can be made.

Ullman describes eight steps that should be observed when carrying out an adequate performance evaluation. The steps are:
(i) identify dependent parameters - the parameters that determine the performance of the product must be identified. These are the parameters that must be measured during product evaluation.
(ii) note the accuracy needed for dependent parameters - as the product develops, the accuracy of the evaluation will increase (e.g. from "back-of-the-envelope" calculations to finite element models).
(iii) identify independent variables and their limits and variations - occasionally it is only after modelling, either analytical or physical, that variables thought to be important are not, and other important variables have been overlooked (see Krottmaier 1993).
(iv) understand analytical modelling capabilities - analytical methods such as basic strength of materials, advanced strength of materials, and finite element analysis will all provide results of varying accuracy. The selection of analytical method usually depends on the level of accuracy required, as well as on further constraints such as time, financial costs, expertise, and equipment.
(v) understand physical modelling capabilities - physical models or three-dimensional prototypes provide, arguably, the designer(s) with greatest amount of information. However, physical models are generally more expensive than analytical models and are subject to the same constraints (i.e. time, money, resources, etc.).
(vi) select best method - the method that furnishes the design team with the accuracy required, and with minimum expense must be selected.
(vii) perform modelling.
(viii) confirm results - evaluating the model, either physical or analytical, should give both an accurate result and an indication of what to change.

There is no guarantee that following these eight steps will result in the development of a high-quality product. Therefore, Ullman proposes robust design, often called Taguchi's method (described later), as a method used to minimise variation of the critical design parameters. The main goal of robust design is to establish values for the design parameters based on "easy-to-manufacture" tolerances and default protection from the effects of aging and the environment so that the "best" performance is achieved (Ullman 1992 : 239).

Ullman's techniques for evaluation at the concept stage has four main shortcomings: (i) his feasibility judgment technique is based on the individual bias, judgment, understanding, intuition, etc. of the designer. This directly contradicts Alexander (1964), Suh (1990), and Cross (1994), who amongst several others, assert that no design decision should ever be made on "gut feeling" alone, (ii) because Ullman adopts Pugh's method, he does not rate or weight individual criteria which means he treats each criteria with the same value or worth, (ii) the PDS is usually stated in terms of the product not the user, (iii) it is enormously time consuming (a whole day for a simple, typical matrix). As the title of Ullman's book suggests, "The Mechanical Design Process", the subject matter is of a predominately objective nature. In other words the subjective aspects of product design, (see Attribute Spectrum - Figure 4.2.1a), such as aesthetics are overlooked by Ullman.

In Ullman's eight-step performance evaluation method, as well as in robust design evaluation methods, the product needs to be refined to some detail so that its performance can be represented numerically against the numerically-based engineering requirements. The main objective of this work, however, is to provide the designer with some measure of how well his or her design proposal scores at the conceptual stage of the design process when the concepts are still relatively abstract. Ullman concedes that his methods for performance evaluation are only good for design problems that can be expressed as an equation. He acknowledges that his system will not work for design problems whose solutions include non-measurable variables, such as colour, shape, etc.

Ertas and Jones (1993)

Ertas and Jones' book is intended to provide a thorough understanding of the various aspects of the modern engineering design process, including elements such as establishing objectives and criteria, synthesis, analysis, environmental considerations, budgeting, scheduling, etc. They suggest that:

"The primary purpose of this textbook is to provide material suitable for instruction in engineering design..." (Ertas and Jones 1993 : 2)

Ertas and Jones reinforce the general consensus that it is now increasingly important for designers to review alternative solutions in the early stages of the design process. They stress that it becomes increasingly costly and difficult to make changes as the design progresses.

Therefore once the recognition of need has been identified, and agreed by all members of the design team, practical solutions need to be specified so that the best proposal can be selected. Assessment of the selected design proposals, state Ertas and Jones, is usually carried out at the conceptual stage of the design process. The reason for assessing the feasibility of concept proposals at this early stage, claim Ertas and Jones, is:

"...to ensure that the project proceeds into the design phase (embodiment and detailing stages) on the basis of a concept that is achievable, both technically and within cost constraints..." (Ertas and Jones 1993 : 10)

Ertas and Jones claim that the need for greater quality in product design is now more important than it ever has been. The current highlight on profitability, early product obsolescence, and strong competition in many areas of product design has forced many industries into adopting new working strategies which are based on the belief that the customer is always right. One such strategy is Total Quality Management (TQM), developed by Dr. W. Edwards Deming. The goals of this approach include improved product quality, reduced costs, new markets, and company longevity. The benefits of adopting this approach are:
(i) satisfied customers;
(ii) shorter product development times;
(iii) minimal product start-up problems; and
(iv) greater customer emphasis within engineering departments (Ertas and Jones 1993).

At the start of a new project, one of the first jobs is to identify and define the objectives. One method for performing this task is the "objectives tree method" (see Figure 3.1.2g). The very

nature of product design practice involves many decisions. For example decisions concerning objectives, criteria, materials, testing, manufacturing, etc. might all have to be made at some stage of a design project. Techniques for helping the designer(s) make these decisions include:
(i) decision matrices; and
(ii) decision trees (Ertas and Jones 1993).

Decision matrices can vary in complexity from a simple chart which consists of rows and columns (see Pugh's method) to a relatively complex array (see "House of Quality"). Another technique for making alternative decisions is the "decision tree method" (Ertas and Jones 1993 : 58-62). The decision tree method is widely used in evaluating business investment decisions, but can also be used in evaluating different design alternatives at the early stages of the design process.

In the decision tree transportation example shown in Figure 3.1.2e the nodes represent decision points and the branches represent courses of action. The first decision is whether to make the trip or not. Next, one would decide what time of day to travel (peak or off peak). The third choice might depend on a number of factors, including availability of vehicles, reliability of public transport, relative costs involved, waiting times, etc. Finally, upon selection of the mode of transport, one may choose one route over another due to a greater saving of time and costs involved (Rowe 1987).

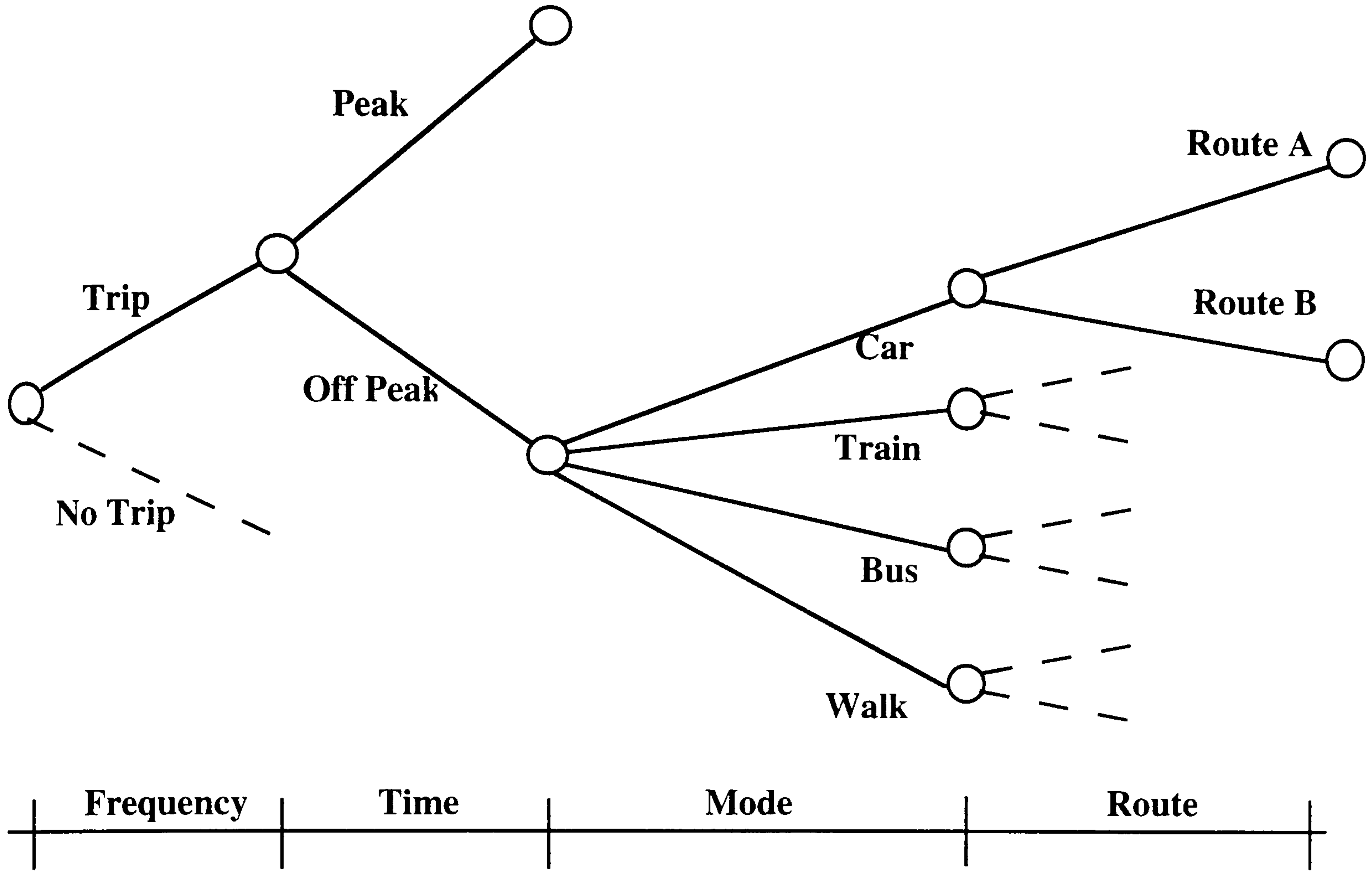


Figure 3.1.2e: A Typical Decision Tree (from Rowe 1987 : 54)

The combination of decisions and the courses of action, for example in terms of time and costs, could be computed relatively easily and the one(s) that meet the criteria, that is minimum time and costs, could be identified (Rowe 1987).

The use of the decision tree technique is based on selection of the best choice at each branch or level of the tree in search for the best solution. There is no guarantee, however, that the best overall solution will be obtained during the first iteration. Therefore, it is usually necessary to repeat this method many times over in an attempt to arrive at the best solution.

Ertas and Jones (1993) state that many methods and techniques can be used during the product design process in an attempt to improve the design, identify potential failures, and generally improve the overall product quality. One such technique is Quality Function Deployment (QFD), a design tool for improving the product, and management of the product's development (see Figure 3.1.2a). In an attempt to better fulfil the needs, wants and/ or desires of the customer, the QFD system is utilised for translating the customer needs into engineering characteristics which can then be implemented in the design and manufacturing stages.

Another technique, presented in Ertas and Jones (1993), is Functional Cost Analysis. This technique involves decomposing the product into its component elements and determining the cost effectiveness of each part in relation to each parts' importance within the overall product. The use of this method, however, can only be applied during the latter stages of the design process (i.e. after the conceptual stage).

The Taguchi method, described in Ertas and Jones (1993 : 65), is a method used to define target values for recognised product characteristics. Deviations in these target values will result in additional costs to both manufacturer and customer. The major objective of this technique is to reduce variability in the performance of the end product. Therefore, the product characteristics which are causing variability in the end product must be well understood so that design sensitivity to these various causes can be minimised. For example Figure 3.1.2f, (Taguchi loss function curve), illustrates the cost versus the force required to close a car boot. Whilst the force required to close the boot is near the target value, there is no cost related with boot closing. However, the further the force gets from the target value, the greater the cost, until the customer's limit is reached. This method quantifies the slight difference in cost related with the forces required to close the boot ***A*** and ***B*** and takes into consideration the customer's increasing dissatisfaction (loss) in going from ***B*** to ***A***.

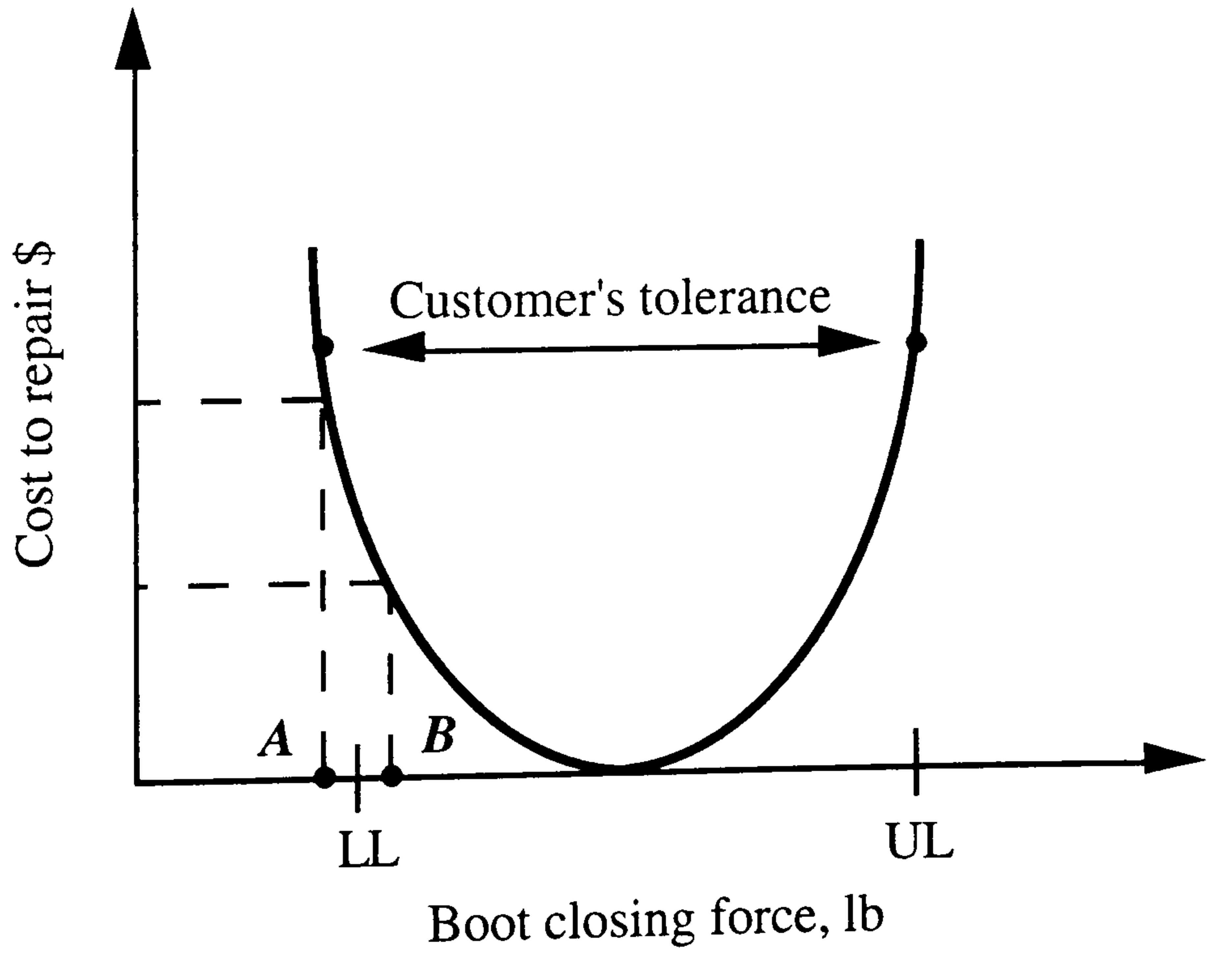


Figure 3.1.2f: Taguchi Loss Function (from Ertas and Jones 1993 : 69)

As Ertas and Jones (1993 : 56) point out, when using decision matrices estimates must be made as to the relative importance of the different criteria. Therefore there is always the possibility that this may result in erroneous conclusions being drawn as to the best solution. The decision tree method can be fairly time consuming, report Ertas and Jones (1993 : 58), as substantial iteration is necessary.

Taguchi's method for product quality is based on the measurement of the deviation from the target for the product characteristics. The PDS (product design specification) constitutes this target and is the actual scale on which Taguchi measures quality. An inherent problem in this technique is in defining the contents of the PDS. Also, it is unclear how Taguchi's technique can be used to evaluate the subjective contents of the PDS such as aesthetics, ergonomics, etc.

Ertas and Jones (1993) dedicate an entire chapter to modelling and simulation in the engineering design process. An essential aspect of product design practice is constructing models. Engineers and designers construct models as a way of representing their ideas and assessing them against criteria. For example a scale model of an automobile can be used to predict accurately certain aspects of the prototypes performance. The advantages of model testing, report Ertas and Jones (1993 : 73-74), are as follows:

"1. When the problem is too complex for an analytical solution, an empirical solution can be developed.
2. Analytical techniques can be substantiated by correlating the predicted model behaviour with the actual behaviour of the model.
3. Prototypes with nonattainable characteristics can be studied, such as those with:
(a) Large structures
(b) Molecular structures
(c) An environment that cannot be simulated
(d) High-speed reactions
(e) Dangerous situations"

There are various types of models employed in the design process and their use is usually dependent upon factors such as time involved to build model, level of accuracy required, resource costs, etc. Models can take various forms, for example heuristic modelling is what might otherwise be called common-sense or rule-of-thumb modelling; heuristic means to discover or to learn. Another common type of modelling used in design is mathematical modelling. Mathematical modelling assumes that the physical system obeys certain laws, for example Newton's laws, conservation of mass, energy momentum, etc.

Dimensional analysis is an integral tool used in model testing. Predicting prototype behaviour from measuring the model requires a degree of similarity between the model and the prototype. The laws that are used to measure the model behaviour are called the laws of similitude (Ertas and Jones 1993). Another aspect of dimensional analysis is identifying the important parameters that affect the model, the omission of an important parameter will burden any subsequent analysis. Techniques for establishing the important parameters that affect the experimental design are presented in detail in Krottmaier (1993).

Again customer/ user requirements are used to formulate objectives and plan projects, but designs are not directly evaluated against them.

Krottmaier (1993)

Krottmaier's text is concerned with evaluation techniques after the concept stage of the design process. Whereas QFD uses empirical models, Krottmaier's models are constructed from experimentation techniques. Krottmaier's method makes use of orthogonal arrays to conduct fractional factorial design experiments. Krottmaier analyses the data acquired from these experiments by means of standardised analysis of variance to evaluate the significance of specific factors.

Krottmaier's product optimisation method is divided into three phases:

(i) System development (primary design)

Specific scientific and engineering knowledge is required at this stage for developing a suitable concept proposal. Market research data and technological knowledge is also necessary for this phase.

(ii) Parameter optimisation (secondary design)

After the primary design is completed, the optimum value for the system parameter has to be determined.

(iii) Determination of tolerances (tertiary design)

In this phase, tolerances are set around the optimum values derived from the secondary design.

Krottmaier asserts that the first step in parameter optimisation is defining the criteria for optimisation in quantifiable terms. He recommends using a weighted scale for evaluation, for example a scale ranging from 0 to 10, if the problem cannot be expressed in quantifiable terms. He suggests that the optimisation criteria can be defined either directly or by using the Quality Function Deployment (QFD) technique for translating the customer requirements into a *"technical language"*.

Krottmaier's method has one main shortcoming: (i) he acknowledges that the disadvantage of this method (weighted selection of parameters) lies in the fact that the parameters are selected on a subjective basis, thus influential parameters could be left unconsidered. Furthermore, the selection of parameters is based on individual bias, judgment, intuition, etc. Also, Krottmaier's technique is better suited to problems that might be accurately termed as "classical engineering" problems. Krottmaier's technique is unsuitable for assessing the feasibility of concept design proposals, (e.g. design sketches), as the design in question has to be at a relatively well refined stage for his technique to be useful. Certain aspects of the design, materials, dimensions, etc., have to be already decided upon in Krottmaier's method of analysis for it to be useful, but however, this is not usually the case at the concept stage.

Parsaei and Sullivan (1993)

Parsaei and Sullivan's book is predominately concerned with introducing manufacturing considerations into product design. The book contains 25 papers which are relevant to many facets of concurrent engineering (CE). Concurrent engineering is now widely recognised as the manufacturing philosophy for the 1990s. The ultimate goal of concurrent engineering is:

(i) to develop high quality products;

(ii) to bring the products to the market in significantly less time; and

(iii) to bring the products to the market at a lower price.

Parsaei and Sullivan suggest a number of design tools and techniques are required at all stages of the design process (i.e. from the concept stage through to the manufacturing stages) to help implement the CE philosophy. The papers within Parsaei and Sullivan (1993) that have most bearing on the early stages of product design are:

(i) Yoshimura in (Parsaei and Sullivan 1993 : 159-183)

Yoshimura presents a methodology for concurrently optimising decision making techniques relating to product design and manufacture. The overall aim of this concurrent optimisation approach is to maximise product performance and minimise product manufacturing cost. The emphasis of Yoshimura's method is based on the objective elements of performance evaluation, that is the design of machine products (e.g. a cylindrical-coordinate robot).

(ii) Thurston and Locascio in (Parsaei and Sullivan 1993 : 207-230)

Thurston and Locascio's paper presents a method for multi attribute evaluation that recognises the importance of the customer. Their approach is based on both QFD and "House of Quality" techniques. They propose two advances to these techniques:

(1) Quantify the relationships between customer attributes and engineering characteristics, in other words, instead of representing the relationship qualitatively, (i.e. √, x, etc.), extend this process by representing the relationship quantitatively; and

(2) Use a multi attribute evaluation function, as opposed to a weighted sum, to represent imputed importance.

Thurston and Locascio prescribe a process of concurrent multi attribute design optimisation which is motivated by the customers' desires, and driven by the "subjective preferences of the designer."

Relying on the subjective preferences, intuition, and personal experiences of the designer is not generally advisable (Cross 1994). Indeed, rationalising the intuitive judgments of the designer(s), and providing a structure that makes the designers' decisions apparent is a key aim of this work (see Chapter 4.0.0). Moreover, although Thurston and Locascio illustrate their methodology through two very different domain examples (a material selection example, and a structural design example), they give no indication of how their method will be of use in domains that are categorised by having engineering characteristics that are not directly measurable (e.g. characteristics such as colour, texture, shape, etc.).

(iii) Nau et al in (Parsaei and Sullivan 1993 : 264-279)

Nau et al present a system for generating and evaluating machining alternatives. The system provides feedback to the designer, in terms of the machinability of the part to be produced, i.e. what problems might arise with the machining processes. The system can estimate four machining processes: turning, boring, drilling, and end milling. If the part to be produced can be manufactured relatively easily, the system will facilitate the manufacturing engineer with several alternative machining processes.

(iv) Zhang and Wang in (Parsaei and Sullivan 1993 : 280-296)

The objective of Zhang and Wang's paper is to develop a solution for formulating a mathematical model for optimising design and manufacturing tolerances that is based on minimum manufacturing costs. They decided to adopt a simulated annealing algorithm for their purposes. Basically the simulated annealing algorithm consists of: configuration, move, neighbouring configuration, objective function, and cooling schedule. Simulated annealing algorithms work well where there is a large number of variables, however the algorithm can get trapped in a local optimum.

With the exception of Thurston and Locascio's paper in (Parsaei and Sullivan 1993 : 207-230), whose approach attempts to take all design attributes into consideration, the emphasis of the computing tool examples presented in this text, (Parsaei and Sullivan 1993), is on evaluating the manufacturability and machinability constraints within the designs proposed.

Parsaei and Sullivan highlight the need for "many design tools and techniques needed at all stages of the design process". Sharon (1992), supports this claim by stating that as yet there are no design tools that will aid in the creative stages of the design process (e.g. the conceptual stage). Consequently, the early stages of design remains a stumbling block in concurrent engineering (CE). CADET is intended for use at the conceptual stage of the design process. Although at the prototype stage, CADET appears to be an effective tool for concept design.

Cross (1994)

Cross presents several techniques which can be applied during the early stages of design. These techniques encompass the following activities:

(i) clarification of the project objectives;

(ii) generation of concept proposals that attempt to meet the objectives (synthesis); and

(iii) evaluation of the concept designs against the objectives (analysis), and selection of a suitable proposal.

Cross describes the "objectives tree method", a method used for specifying or clarifying the design objectives, i.e. what the design must try to satisfy or achieve. He states the list of objectives can be grouped into hierarchical levels of main objectives and sub-objectives, and a diagrammatic tree can be constructed which shows the hierarchical relationships (see Figure 3.1.2g below).

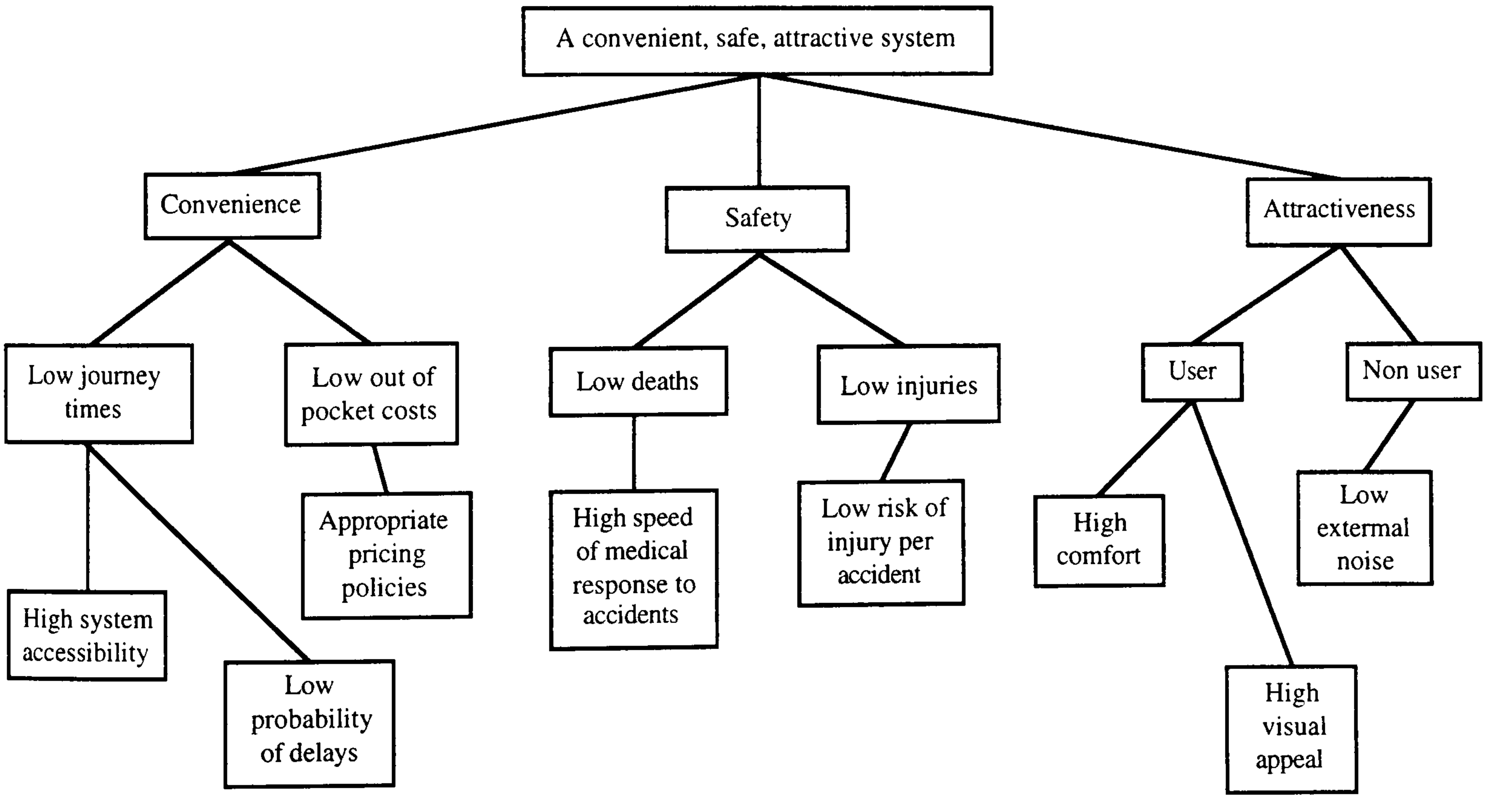


Figure 3.1.2g: Objectives Tree for a Regional Transportation System (adapted from Cross 1989 : 52)

The subsequent step after the "objectives tree method", Cross proposes, is the definition of the performance specification. Cross states that although objectives and sub-objectives are statements of what a design must achieve, they are not usually set in terms of precise limits. This is the purpose of the performance specification. The performance specification limits the range of acceptable solutions and can be used in the evaluation of concept proposals, to check they fall within the acceptable boundaries. Cross recommends that the performance specification should be expressed in quantifiable terms whenever possible. Again, however, the method is for problem formulation and project planning rather than establishing criteria to evaluate design performance against.

Cross (1994 : 91) points out the significance of the relationship between characteristics and attributes, by stating:

"With increased competition in all product markets, it has become necessary to ensure that this relationship between engineering characteristics and product attributes is properly understood."

Cross proposes using the QFD technique as a method for translating what the customer wants into specifications of engineering characteristics (see "House of Quality" - Figure 3.1.2a).

The relative importance of the identified attributes can be defined by using the weighted objectives method. The weighted objectives method is a relatively simple procedure for rank-ordering the list of objectives/attributes. The rank-ordering process is performed by comparing pairs of objectives against one another in turn, thus:

Objectives	**A**	**B**	**C**	**D**	**E**	*Row Totals*
A	-	0	0	0	1	1
B	1	-	1	1	1	4
C	1	0	-	1	1	3
D	1	0	0	-	1	2
E	0	0	0	0	-	0

Each objective is compared against the other objectives, in turn, and a figure 1, 0, or 0.5 entered depending upon whether the first objective is considered more important (1) than the second, less important (0) than the second, or of equal importance (0.5).

Cross cites the performance specification of an electric toothbrush as an example. In it the product attributes are listed as a set of "user needs", including physiological, social, psychological, technical, and time and resource needs. The attribute "massage gums" is listed as a physiological need, however there is no suggestion as to how this might be measured at the concept stage (Cross 1994 : 86).

In Cross' method for problem decomposition, (see Figure 3.1.2g), the decomposition is driven by the solution, whereas the approach taken here is based on Alexander's (1964) method of decomposing the problem into independent sub-problems. The product or form, in Alexander's method, must reflect these sub-problems.

Conclusions

The appraisal of the above texts, specifically those parts of the texts that have some bearing upon product performance assessment in the early stages of design, has led to the following conclusions. These conclusions can be categorised as follows:

(1) Customer/ User requirements versus Functional Requirements (FRs); and

(2) Specification Language.

(1) Customer/ User versus Functional Requirements (FRs)

All the above texts view the user/ customer as the supreme driving force in the product design process. None, however, objectively state measures of user/ customer satisfaction with performance. Rather the emphasis is on establishing, as objective as possible, functional requirements (FRs) rather than customer requirements.

Consequently, there is no formal link to the functional performance of a product and the actual user requirements of it. The closest is QFD which informally, (i.e. not computably), links functional requirements (as engineering characteristics).

Customer requirements are used to drive the generation of designs, but are not used to evaluate those designs.

(2) Specification Language

In all cases of the above texts, specifications are written in Natural Language, although these are relatively formal **if** physical or engineering terms are used (such as in QFD).

The potential for ambiguity and misunderstanding is highlighted by Bucciarelli (1994).

The limitations of the above texts, specifically those parts related to product performance assessment, are as follows:
(i) There is a need for a product performance assessment method which is based on objective statements of user/ customer requirements.

(ii) There is a need for a method that will provide a link between the background research/ information that leads to those statements.

(iii) There is a need for a method that will evaluate design concepts against those statements to determine which is best for the user, rather than which bets satisfies the functional requirements. Furthermore, this method must facilitate evolutionary development, (i.e. the specification of requirements and design evolving together).

In QFD terms, this work wishes to formalise customer attributes into directly measurable/ observable entities and construct formal relationships with the engineering charcaterisitcs that influence them. Therefore, an approach is required that objectively formalises the problem.

A set of objective criteria is required that would be applied to the product in **actual use** to assess its performance. Performance against these objectives would then be simulated at the early stages of design.
The rationale for adopting Alexander's method, as a starting point in this work, was because Alexander bases his requirements against the **actual product** (form) in **actual use** (context).

The next chapter (Chapter 4.0.0) will describe a formal model of the design process for defining and assessing product performance at the concept stage, that will be applicable across the entire spectrum of design. The methodology, inspired by the work of Alexander (1964), is based on abstract descriptions of the operations that are conducted within the design process. It is, consequently, extremely generic and creates a bridge between physical product performance and actual user requirements.

Chapter 4.0.0

A Formal Definition of Product Performance Assessment

4.0.0 A Formal Definition of Product Performance Assessment

This chapter presents a formal model of the design process which makes explicit the element of concept assessment. The model is used to both formally define the process of product performance assessment within the overall design process, and to structure the knowledge it draws on.

Arguably, design is the widest ranging human activity (Dasgupta 1989). Potentially it draws on the entire body of human knowledge and experience plus the personal intuition and experience of the designer. Consequently the terms used to describe this process must be extremely abstract as they reflect common activities based in widely disparate sources of knowledge. It is anticipated that by adopting such an approach that a generic structuring of knowledge can be achieved in a way that will be of genuine use to the designer.

Design has been defined here as the process by which the decisions are taken to move the world from its current situation to a preferred one (Simon 1988). The preferred situation must be perceived to be an improvement on the existing situation by or for those with the power to actually enact the decisions, for example manufacturers have the power to enact the decisions and choose to, based on their perception of the improvement it makes to them, i.e. there is no absolute definition of improvement, it is only relative to the producer.

Product performance assessment is the process of deciding whether or not a proposed preferred situation is an improvement or which proposed situation constitutes the most improvement or otherwise. There are a wide range of elements within the preferred situation that determine if it is an improvement on the current situation. One important element is user satisfaction. It is presumed here that products that satisfy users' needs are a necessary, but not a sufficient, prerequisite for satisfying the producers objectives (Urban and Hauser 1993). Consequently this work only addresses product performance based on users' needs.

In this sense product design is the effort to make products in such a way that they are useful to people (Rams 1984). At the conceptual level it is a predominately intuitive and imaginative activity. In practice there tends to be little formal analysis of proposals and most decisions are value judgments made by experienced practitioners (Cross 1989), (Akita 1991). By intuitive and imaginative it is meant that human beings are capable of some, as yet not completely explained, mental processes which enables them to make the necessary decisions (Alexander 1964). Generally, intuition plays two significant roles at the concept stage of the design process, firstly, in the generation of new ideas and, secondly, in judging the suitability of those ideas. In the latter case judgment becomes successively more rational as greater detail becomes added.

This work is firstly aimed at rationalising the intuitive judgment of suitability at the concept stage of the design process, and secondly in providing a structure that makes the decisions apparent and the designer accountable. Further, it is intended to implement the assessment methodology in some form of computer system. All computer-based systems are based on formal languages and must inherently, although often implicitly, reflect formal models of the situations they apply to. Consequently the starting point in designing computer-based systems is a formal model of the situation that they will be applied to.

4.1.0 Alexander's Design Model

The proposed method of product performance assessment is based on a formal model of the design process developed from that of Alexander (1964). Alexander developed his methodology in an attempt to help designers solve increasingly complex problems. Alexander's main thesis is that large complex problems have to be decomposed into smaller more tangible problems. He argues that the decomposition of design problems is based on subject specialism and theoretical understanding, which he believes is wrong. Instead, he suggests, that this decomposition should be based on (relatively) independent sub-problems. He formalises the problem, or the requirements, so that the mathematical technique of constructive decomposition can be applied to formulate relatively independent sub-problems. The approach taken in this work is not concerned with Alexander's problem decomposition, but his method of requirement formulation using a formal description of the design problem.

The work presented here acknowledges the critiques that have been made of Alexander's work, by, for example (Lawson 1990). Lawson suggests that Alexander's work leads to a *"rather* *mechanistic view"* of design problems and illustrates this by pointing out two notions that are now commonly rejected:

(i) that there exists an exhaustive and complete set of requirements which can be listed at the start of the design process,
(ii) the listed requirements are all of equal value.

This work directly addresses the second criticism of Alexander's method, specifically his listing of requirements being of equal value. It is fairly obvious that certain requirements of products are more important than others. The strategy presented in this thesis incorporates this view by weighting the requirements and combining them, in turn, to give an overall measure of the product's performance.

In particular, this strategy is based on Alexander's analysis of the process which is essentially generic, but it is not utilising his suggested method of solution. The strategy presented here is also extended to deal explicitly with mass produced manufactured items rather than 'one off' constructed items of architecture.

Language for Formal Description of the Design Process
Alexander (1964) uses the abstract mathematical concepts of Sets and Graphs as a language for the formal description of the design process. He states:

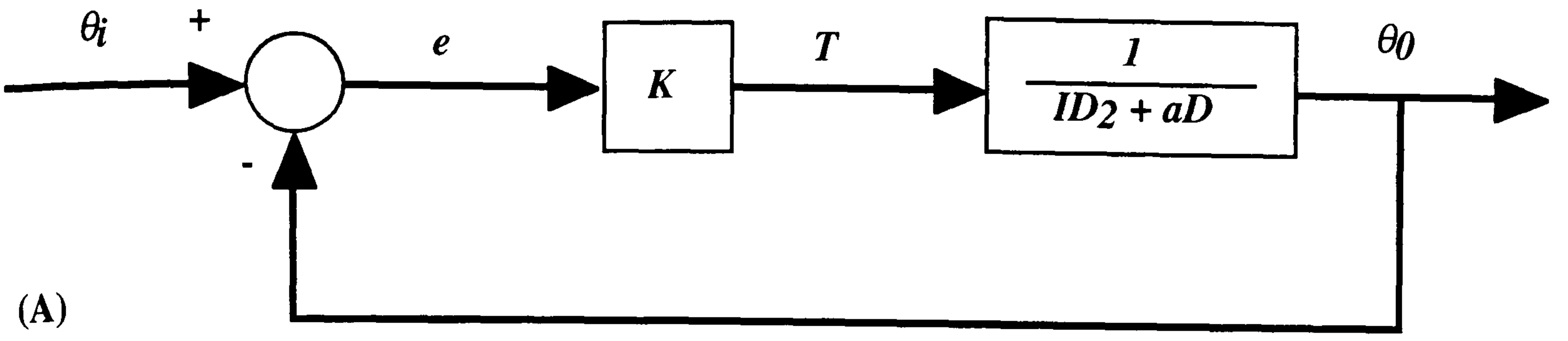
"The great power and beauty of the set, as an analytical tool for design problems, is that its elements can be as various as they need to be, and do not have to be restricted only to requirements which can be expressed in quantifiable form." (1964 : 79)

The model developed here uses the abstract algebraic notation of functions, as well as sets, to describe the basic operations within the design process, described earlier in Section 2.1.0 (The Design Process). The model uses operators and entities to describe what are believed to be the fundamental actions and their objects respectively.

The approach of this work is similar to the approach taken by (Alexander 1964) and (Ganeshan et al 1994), in as much as this work is only interested in the structural relationships between the operations employed in the design process whose actual elements can be *"as various as they need to be"*.

Functional notation is commonly used to describe time dependent behaviour of systems, however, this can sometimes give a strong impression when illustrated diagrammatically, of a sequential or chronological process, such as Figure 4.1.0a below. The model described here is specifically **not** intended to be interpreted sequentially. Although many diagrammatic descriptions of the design process appear to be sequential, they in fact reflect the relationships between activities rather than a fixed procedure to be followed (see for example Chapter 2.0.0 figures). Later in this Chapter, Section 4.1.6, it will be illustrated how sequential descriptions of the design process could be constructed from the relational descriptions of the activities described within the design model presented here.

(A)



(B)

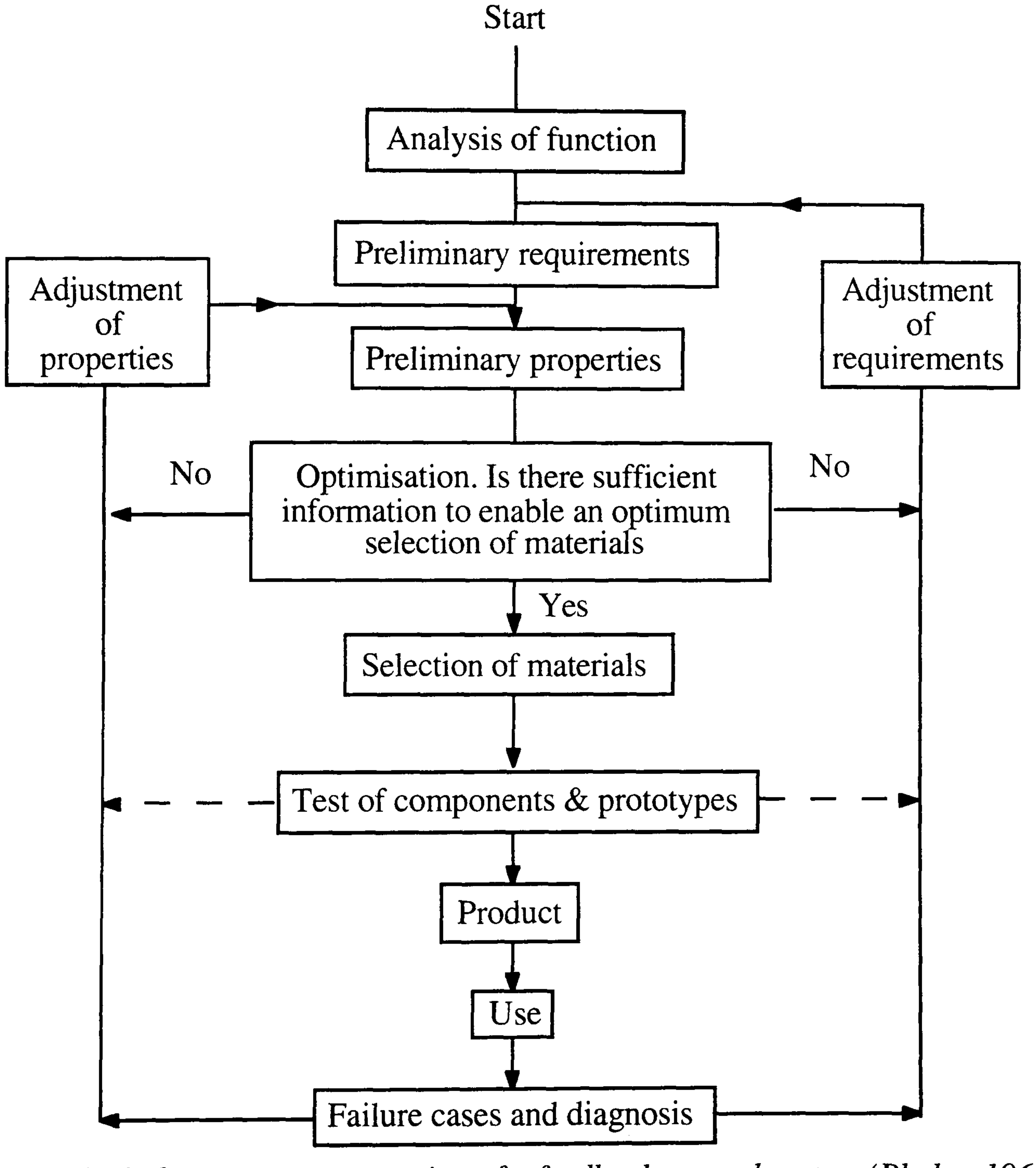


Figure 4.1.0a: (A) Block-diagram representation of a feedback control system (Phelan 1967), (B) Procedural flow-sheet of operations during materials selection (Ostberg 1982)

4.1.1 Definitions

Form

"Form is a part of the world over which we (the designer) have control, and which we decide to shape while leaving the rest of the world as it is." Alexander (1964 : 18, 19)

Context

"The context is that part of the world which puts demands on this form; anything in the world that makes demands of the form is context." Alexander (1964 : 18, 19)

Ensemble

The ensemble is the combination of the form and its context. Alexander (1964 : 18, 19) states:

"...when we speak of design, the real object of discussion is not the form alone, but the ensemble comprising the form and its context."

Alexander suggests that the ultimate objective of design is form. In terms of the design definition used here the ensemble is the situation, and the form is the means of changing the current situation into a preferred one. Alexander's criteria for a preferred situation is "fitness" between form and context. "Good fit" is a desired characteristic of this ensemble.

Alexander (1964 : 18, 19) expresses further that the objective for designers is always to:

"put the context and the form into effortless contact or frictionless coexistence".

Alexander describes two types of the design process on which he bases his own formal methodology; the "Unselfconscious Process", and the "Selfconscious Process".

4.1.2 Unselfconscious Process

In the unselfconscious process, form-making and using are closely integrated and cannot be separated; the problem remains static; novices learn from gradual exposure to the craft in question, by imitating and correcting mistakes. There is a lack of understanding of theoretical background in this process.

Alexander (1964 : 48) describes the unselfconscious process as a type of built-in fixity - types of myth, tradition and taboo which oppose strong modification. Creators of form will only introduce modification under sound compulsion where there are strong and obvious errors (*"misfits"*) within the existing forms which demand correction. Alexander cites the example of an Eskimo responding to temperature change within the igloo by opening holes or closing them with lumps of snow.

In the unselfconscious process the individual (designer) operates by directly observing the ensemble and in the absence of fit s/he determines actions to eliminate the observed misfits. An example of the unselfconscious process is the bespoke tailor fitting a suit to a client. The designer (bespoke tailor) will observe misfits in the ensemble of form (suit) and context (client) and make changes such as letting in or taking out the seams.

Alexander (1964 : 77) emphasises that the unselfconscious designer:

"...reacts to misfits by changing them; but is unlikely to impose any "designed" conception on the form."

Formally the process is illustrated in Figure 4.1.2a.

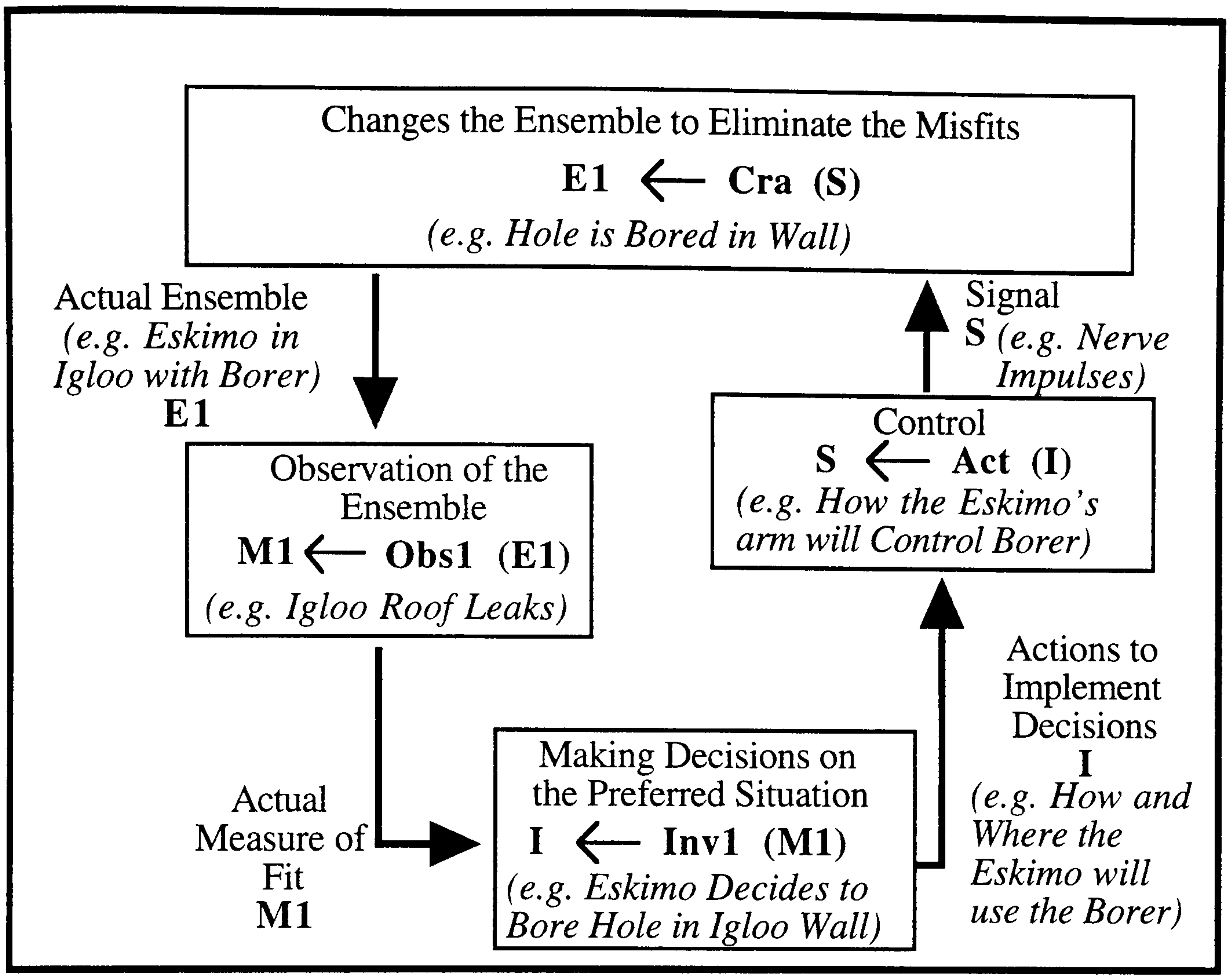


Figure 4.1.2a: The Unselfconscious Process

The nature of this abstract approach, is not, at this stage, defining the content of entities and operators, but only the functional relationships between them. Figure 4.1.2a is explicitly **not** intended as a flowchart representation of the design process. The figures do **not** represent chronological or procedural activities generally represented, for instance, within fields such as control systems (Phelan 1967), and materials selection techniques, described in (Ostberg 1982).

In the unselfconscious process above, (Figure 4.1.2a), the individual (designer) observes misfit entities **M1** in the actual ensemble **E1**. This process is described by the operator **Obs1**. The designer then applies some cognitive process described by the operator **Inv1** to determine the entity **I** of actions to be taken to eliminate the misfits. These actions are realised in the ensemble by actual tools or by hand.

The actions are based on information in the memory of the individual (designer) which have to be converted into real physical events. This is done by a process of actuation described by the operator **Act** which converts information into power denoted by the entity **S**. The entity **S** has both physical and informational significance in that it must be sufficient to cause an effect but controlled to produce the correct effect.

In algebraic terms, the function **Cra** which reflects the unselfconscious designer's scope for manipulating the form is potentially complex. Since it belongs to the ensemble it is within scope for the unselfconscious designer to change, reflecting the unselfconscious designer's capacity for making new tools as part of the form-making process.

4.1.3 Manufactured Products

Alexander's model is motivated by the one-off constructed items of architecture. To apply his model to mass production requires a definition of form for manufactured products. By definition form is anything "over which we have control". For manufactured products the manufacturer has control not only over the products, but also manufacturing methods, distribution, advertising, finance, etc. and the demands that context places on this form will be commercial, environmental, socioeconomic, etc., both on the organisation as well as the product. These considerations, however, lie outside the scope of this work, and consequently this work will only deal with the **manufactured product** and assume all other elements under the manufacturers control are fixed. In the sense of the definition of design used here the manufacturer is the one with the power to enact the decisions resulting from the design process and these decisions impinge only on the product.

The manufacturer imposes a "designed conception" on the product form, and **F1** denotes the actual product form. To be consistent with the definition of form, **F1** is the total production of a type of product, e.g. **F1** represents all the toothbrushes of a given type and not a single exemplar of the type. The demands on **F1** come from both the user and the manufacturer, e.g. the user has certain demands of a toothbrush such as preventing tooth decay, price, etc. whilst the manufacturer has other demands such as cost, producibility, etc.

This work presupposes that products that satisfy users' needs are a necessary, but not a sufficient, requirement for satisfying the producers objectives (Urban and Hauser 1993). The actual context **C1** is defined here as the class of potential users of **F1**, and the aim for designers is to create products in such a fashion that they are beneficial to human beings (Rams 1984). In this case, form fits context if **F1** is beneficial to the users.

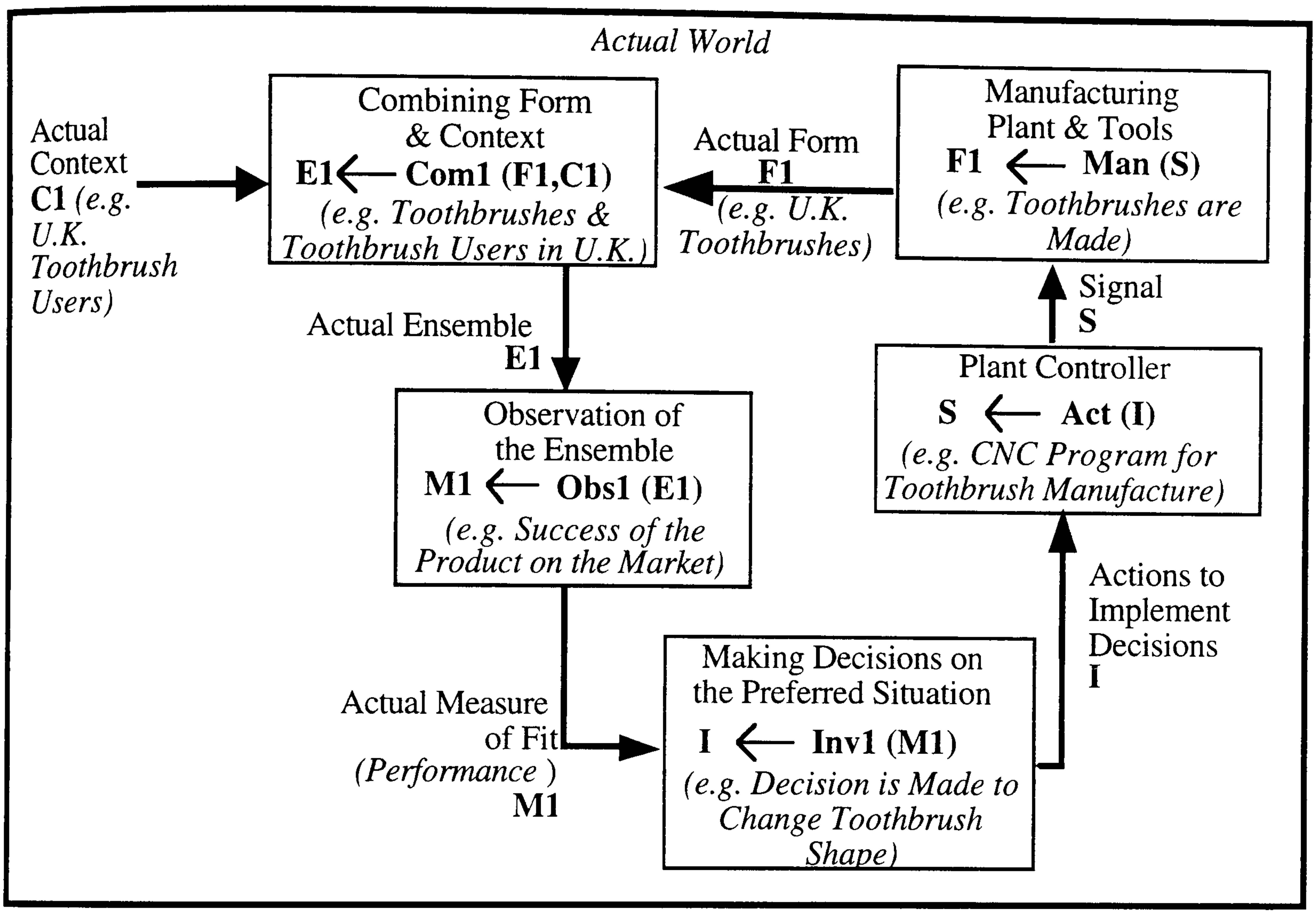


Figure 4.1.3a: Physical Situation for Manufactured Goods (Special Case)

Figure 4.1.3a illustrates a **special case** of a physical situation for manufactured goods to which the selfconscious process, described later, applies. This **special case** assumes that the operator **Man** is fixed.

In the physical situation for manufactured goods (Figure 4.1.3a), the actual form **F1** and actual context **C1** are (real) entities combined by the operator **Com1** to create the ensemble entity **E1**. The designer observes the ensemble by operator **Obs1** to determine the misfit entities **M1**. The designer then applies some cognitive process described by the operator **Inv1** to determine the entity **I** of actions to be taken to eliminate the misfits. These actions are realised in the ensemble by actual tools or plant.

The physical nature of the above process means that there is restricted opportunity for actual iteration, unlike the unselfconscious process. The designer observes the success or otherwise, actual performance, of the ensemble (the form in its context) and makes decisions on improving or eliminating the problems (misfits). In the physical situation, once the decisions have been made (**Inv1**) they are not usually changed.

The actions are based on information in the memory of the designer which have to be converted into real physical events. This is done by a process of actuation described by the operator **Act** which converts information into power denoted by the entity **S**. The entity **S** has both physical and informational significance in that it must be sufficient to cause an effect but controlled to produce the correct effect. For example the operator **Act** may describe an actuator such as a servo motor which (via other hardware) drives a machine tool from instructions **I** in the form of a part program. The output from the servo motor must supply sufficient power to cut material but with sufficient accuracy to cut it in the way required. The effect of **S** in producing a new form **F1** depends on the actual machinery it connects to which is in turn described by the operator **Man**. These operators are intended to be complete and generic describing all processes required to generate the new form **F1**.

A more realistic model may be to describe **Man** as a differential operator, i.e. causing a change to an existing actual form rather than generating a completely new form. The given definition is used in the interests of simplicity later.

In the unselfconscious process, (Figure 4.1.2a), actuation **Act** is predominately performed by the human mind in determining how tools should be operated or utilised. The unselfconscious designer need not be able to invent forms at all, but just respond to misfits (Alexander 1964 : 58). Most importantly the iterative modification of form to fit context occurs physically and is defined by the actual experience and satisfaction of the designer. Although an apparently obscure name the "Unselfconscious Process" is particularly apt. The designer is unconscious of form in context and responds directly to direct experience of the ensemble without consciously considering the change in form required to eliminate the misfit.

The observations made by the unselfconscious designer are determined by the physical configuration of the ensemble, which may be inorganic or organic, and the physical, social, cultural, and/or economic laws that apply to the configuration. Whilst the unselfconscious designer need have only intuitive knowledge of them, since he deals directly with the consequences, it will be seen later that they must be codified to produce rationalised predictions.

The unselfconscious approach is clearly unsuitable for industrially mass-produced goods for the reasons cited by Jones (1980):

(1) Specifying dimensions (form) in advance of manufacture makes it possible to split up the production work into separate pieces which can be made by different people. This is the 'division of labour' which is both the strength and the weakness of industrial society.

(2) Initially this advantage of defining before making made possible the planning of things that were too big for a single craftsman to make on his own, for example, large ships and buildings. Only when critical dimensions have been fixed in advance can the works of many craftsmen be made to fit together.

(3) The division of labour made possible by scale drawings can be used not only to increase the size of products but also to increase their rate of production. A product which a single craftsmen would take several days to make is split up into smaller standardised components that can be made simultaneously in hours or minutes by repetitive hand labour or by machine.

4.1.4 Selfconscious Process

In the selfconscious process the method of form creation is very different from that in the unselfconscious process, in that the designer is **remote** from the user of the product and the physical product itself. In this process the arrangement of the form is decided before it is physically realised. Modifications are no longer made upon actual observation of error or misfit. Alterations are no longer in the hands of the dwellers, as they are in the unselfconscious process, failures have to be reported and described several times over, and permanent adjustments are only made after a process of explanation and definition by the **specialist** involved (Alexander 1964 : 55). The challenge for designers is to ensure that there will be no misfits when the actual form **F1** is placed in its actual context **C1**.

The Mental Picture in the Selfconscious Process

In the selfconscious process (Figure 4.1.4a) the designer is remote from the user of the product and the actual product itself. In this process, form-making and using have become distinct; the problem may suddenly change; the novice learns on the basis of general principles. In the unselfconscious culture, form is shaped by the interaction between the actual context's demands and the actual inadequacies of the form, while in the selfconscious culture, form is shaped by a conceptual interaction between contextual pictures and representations of form, by using fairly concrete pictures, diagrams and drawings.

Instead of being able to directly observe the ensemble, the designer investigates, explores and researches the actual context **C1** and constructs a mental picture of it **C2**. This process is described by the operator **Exp**.

Instead of working on the actual form the designer must work with a description or representation of it, **F2**, and through the operator **Com2** combine the form and context to make a mental picture of the ensemble **E2**. From this mental picture of the ensemble the designer attempts to identify potential misfits **M2**. This process is described by the operator **Obs2**. In the same way as in the unselfconscious process the designer makes intuitive judgments, but this time on modifications to the form rather than actual actions to be taken. This process is described by the operator **Inv2**.

The process of inventing a form and physically realising it are separate. As Dormer (1993) indicates designers do not manufacture things. They think, they analyse, they may model or draw, and they specify. The most important distinction between the unselfconscious designer and the selfconscious designer is that the latter must define in detail complete and unambiguous descriptions of the shape, size, materials, and material finishes of the form prior to manufacture.

Although designers may take manufacturing considerations into account there are further operations of manufacturing planning **Pla**, which determines the instructions **I** that will physically realise the form represented by **F 2**, for example a BS 308 drawing (Parker 1984).

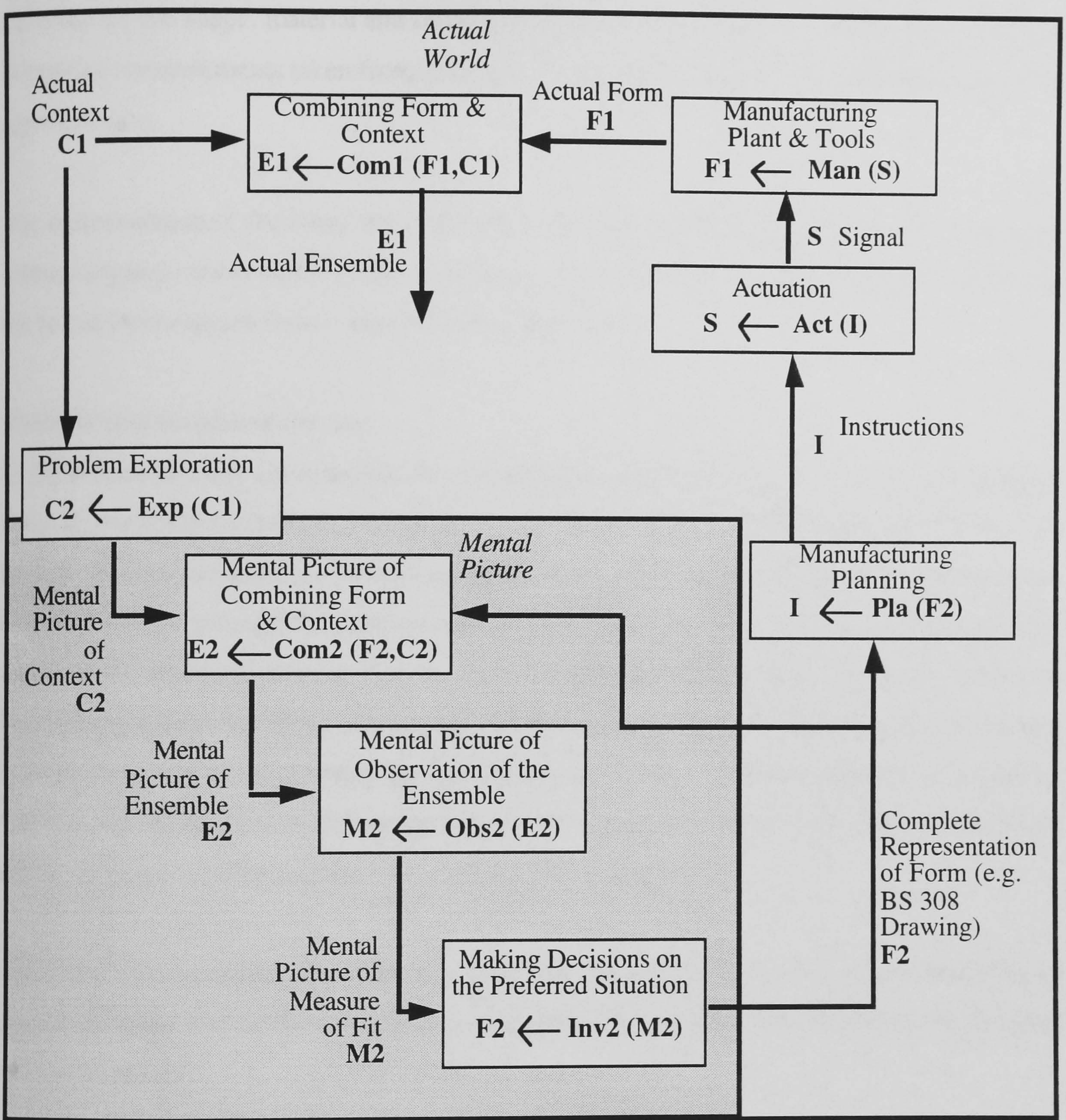


Figure 4.1.4a: The Selfconscious Process

The process of determining fit is a mental simulation of the observations the unselfconscious designer uses to determine his actions. Whilst the unselfconscious designer is dealing with reality the selfconscious designer is attempting to mentally predict a future reality.

Representation Of Form

In the unselfconscious process the designer works directly with the physical form. In the selfconscious process he works on some representation of it. The representation is a complete definition of the shape, material and finish that the form will consist of[4] When the actual form is realised measurements taken from it should correspond exactly to the measurements in the representation.

The representation of the form does not define a unique physical form. Because of inevitable tolerancing and measurement errors it defines a class of admissible actual physical forms and the actual form realised from it must be within that class.

Misfits Within the Mental Picture

In the selfconscious process misfits are determined in part intuitively or by intuitively designed tests. In practice the selfconscious designer may well go through a process similar to that of the unselfconscious designer. For instance, taking as an example an "off-the-peg" suit designer, s/he may well go through the same process of a series of successive changes or "fittings" with respect to the standard mannequin as the bespoke tailor does with a client. However, unlike the bespoke tailor the result of identifying and eliminating misfits is not within the actual suit, but it is the cutting patterns representing the typical form of the suit. Although apparently identical the "off-the-peg" designer is undergoing a process of testing to predict the fit of the actual suits, whilst the bespoke tailor is going through a process of production.

The mannequin represents the sizes of a large class of people that the suit is intended to fit, in exactly the same way as the cutting patterns represent not a single individual suit, but the class of suits produced.

Difficulties with the Selfconscious Process

In the unselfconscious process, the human being (designer) is only present as an *"agent"*. The designer reacts to misfits by changing them, but is unlikely to impose any *"designed"* creation on the form. The operations defined within the selfconscious process, however, are **remote** from the actual ensemble itself, form is shaped not by interaction between the context's

[4] To the most part the representation may contain symbolic descriptions of standard components, e.g. (electrical or electronic) but these will always be supported by shape and material representations elsewhere. However, some functionality cannot be achieved purely from geometrical/material definitions and have to be explicitly specified.

demands and the actual inadequacies of the form, but by a *"conceptual interaction"* between the mental picture of the context which the designer has learned and created, on the one hand, and diagrams and drawings which represent forms, on the other.

Generally, in design practice, the preparation and translation of the problem into a design usually depends on some sort of intuition. As stated initially, although the creation of form may well be intuitive, imaginative and not completely understood there is no reason why the fit of form with context should not be rationalised in an attempt to maintain the designer's intent. Alexander (1964 : 77, 78) addresses this problem by creating a formal picture of the mental picture by abstracting and defining its necessary features in formal terms. The fit of form with context can be formally defined in terms of the formal picture.

4.1.5 Formal Process

Alexander argues, the selfconscious process can be improved by taking the use of pictures a step further from concrete drawings towards abstract diagrams, which retain only the abstract structural features of the form. Alexander asserts that within the selfconscious process the designer works entirely from the mental picture in his mind, and this mental picture is almost always wrong. He suggests eradicating this problem by constructing a formal picture of the design problem. This formal picture can then be scrutinised in a way not subject to the bias of language and experience (Alexander 1964 : 78). The formal picture is not intended to eliminate the intuitive and imaginative components of the design process, but to make it visible and the designer accountable (Lawson 1990).

Alexander defines the formal picture in terms of the observations of the form in context which could cause a misfit (Figure 4.1.5a). The observations are called misfit variables which are either true or false. Alexander requires the selfconscious designer to state the criteria of the intuitive judgment of fit from the mental picture. Overall fit is the conjunction of the misfit variables. In the formal process the designer constructs a formal picture of the context **C3** from the mental picture of the context **C2**. This process is described here by the operator **For**. The designer combines the formal picture of form **F3** and context **C3** to produce the formal picture of the ensemble **E3**. This process is described here by the operator **Com3**. The measure or quality of fit **M3** is then determined through **predicted** observations of the ensemble **E3**. This process is described here by the operator **Obs3**. Synthesis of a new form **F3** is created in response to the predicted measure of fit or misfit **M3**. This process is described here by the operator **Inv3**. The concept representation of the form **F3** (e.g. drawing, annotated sketch, etc.) is then subject to a process of embodying the concept and adding greater detail which results in a complete and unambiguous description of the form **F2** (e.g. BS 308 Drawings).

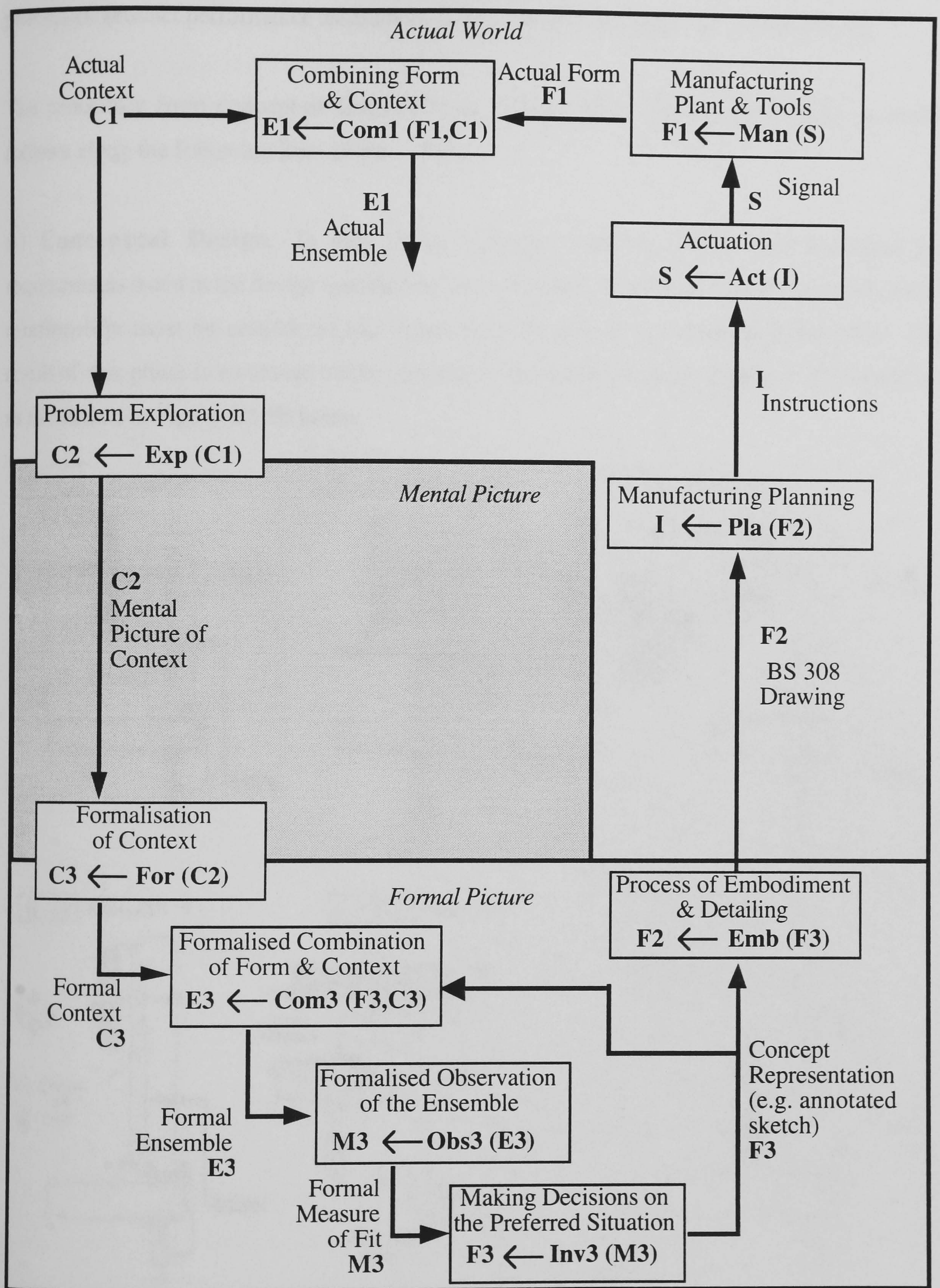


Figure 4.1.5a: Formal Picture

Determining the formal measure of fit **M3** within the formal picture (Figure 4.1.5a) is the process of product performance assessment at the conceptual stage of the design process.

The procedure from concept of form (**F3**) to detailed description of form (**F2**) generally follows along the following lines (French 1985):

(i) **Conceptual Design**. In this phase, concepts with the potential of fulfilling the requirements listed in the design specification are generated. The overall functional and physical relationships must be considered and combined with preliminary embodiment features. The result of this phase is a concept model (drawings, annotated sketches, diagrams, 3-D models), as illustrated in Figure 4.1.5b below.

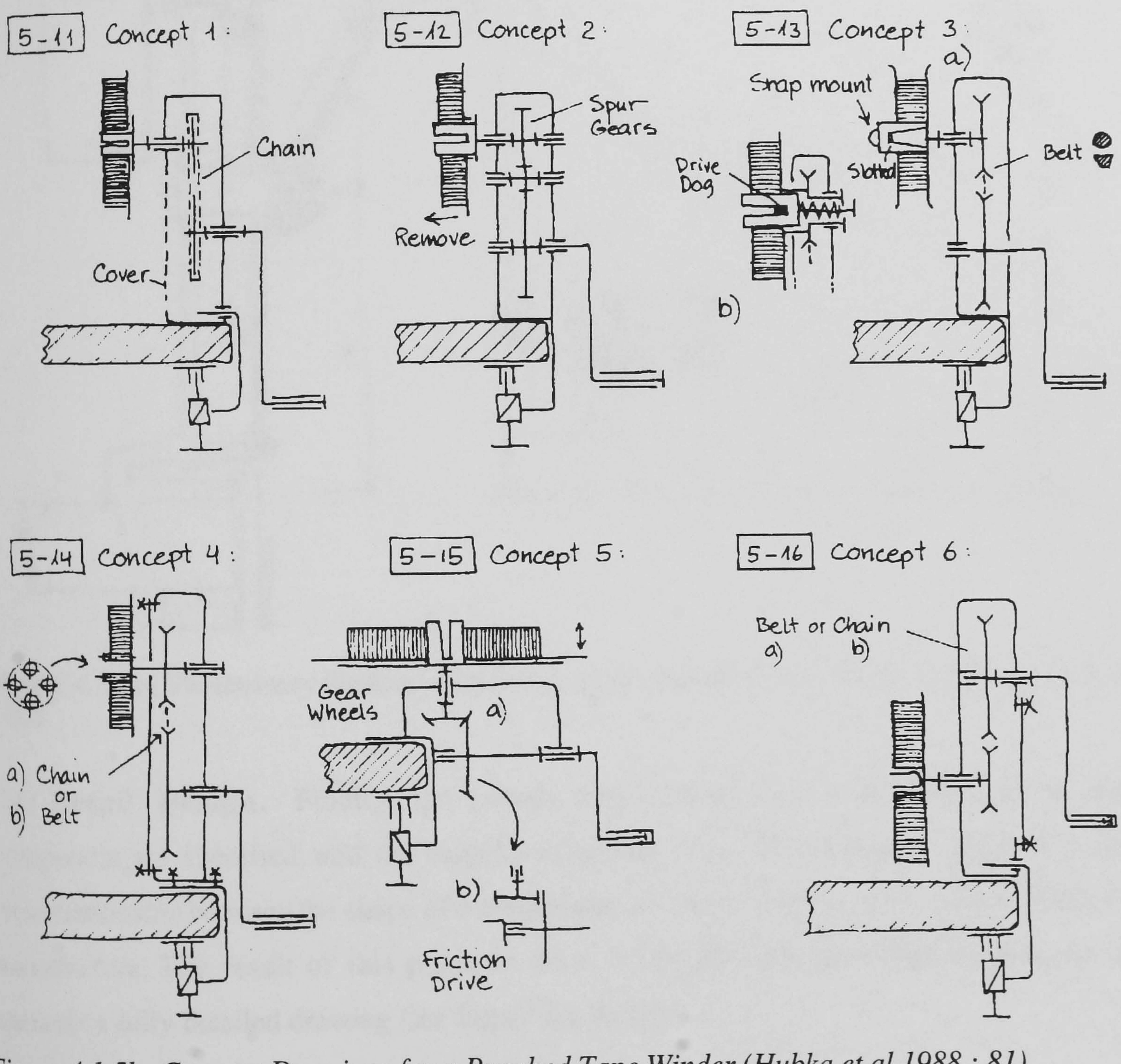


Figure 4.1.5b: Concept Drawings for a Punched Tape Winder (Hubka et al 1988 : 81)

(ii) **Embodiment Design.** In this phase, the foundations are laid for detail design through a structured development of the concept. In the case of a mechanical product, the result of this phase is a detailed embodiment model (drawing) showing the preliminary shapes of all the components, their arrangement and, where appropriate, their relative motions (see Figure 4.1.5c below).

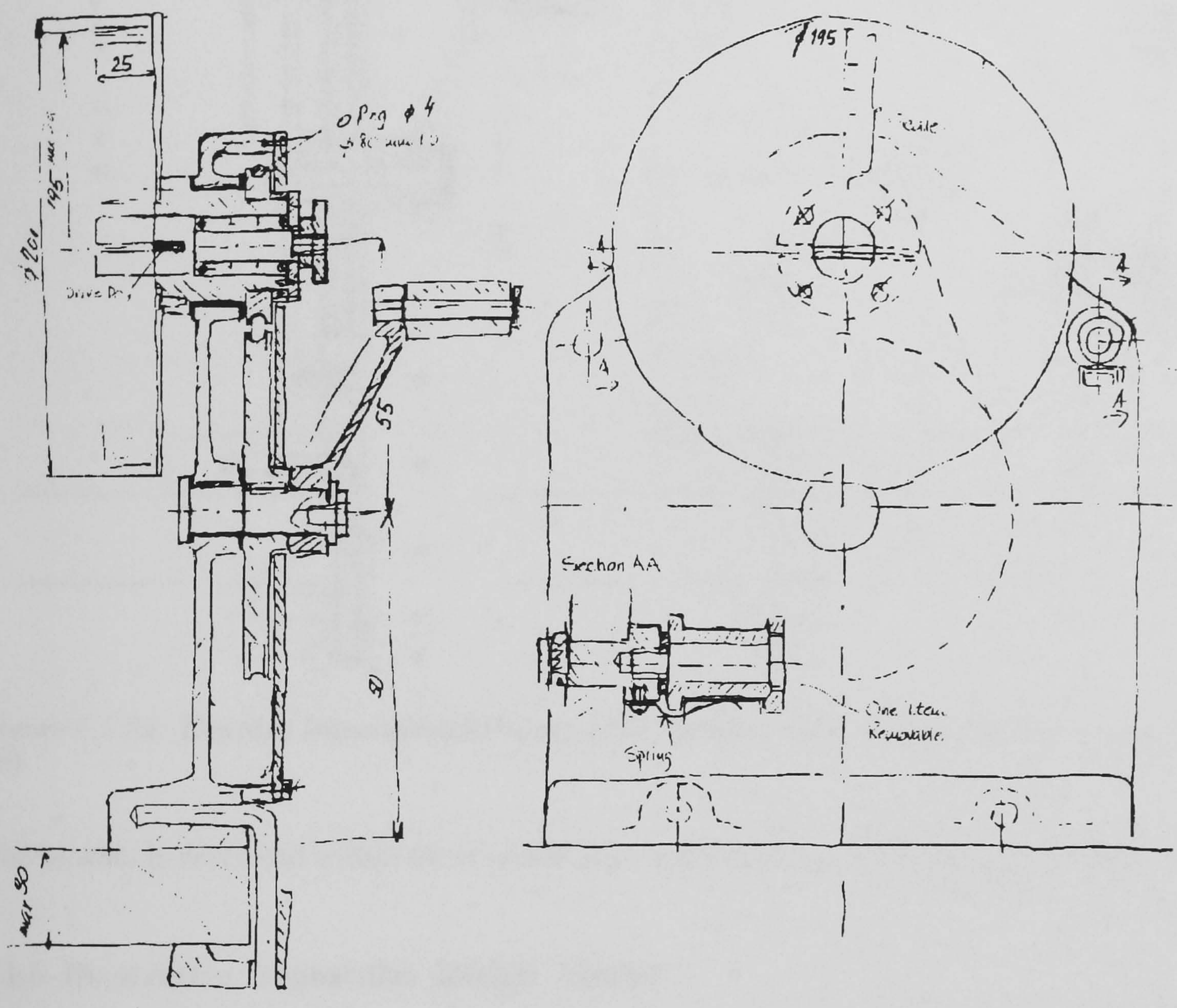


Figure 4.1.5c: Preliminary Embodiment Drawing for Punched Tape Winder (Hubka et al 1988 : 83)

(iii) **Detail Design.** Finally, the precise shape, dimensions and tolerances of every component are specified, and the material selections made, or confirmed. There is a close interrelationship between the shape of a component, its material and the proposed method of its manufacture. The result of this phase is a set of detailed manufacturing instructions, for example a fully detailed drawing (see Figure 4.1.5d below).

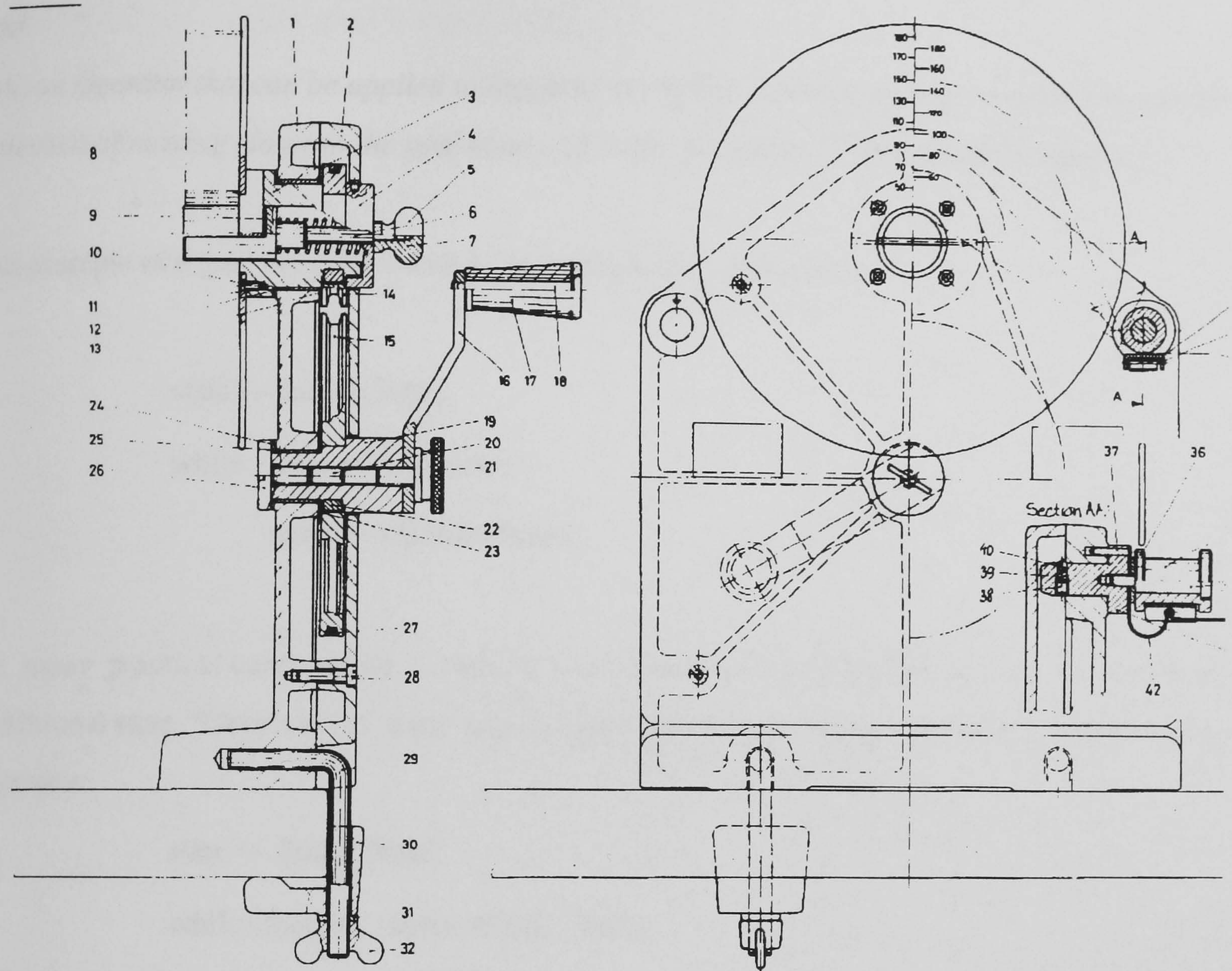


Figure 4.1.5d: Detailed Dimensional Drawing for Punched Tape Winder (Hubka et al, 1988 : 86)

This process is described within the research work presented here by the operator **Emb**.

4.1.6 Illustrative Sequential Design Model

The operations described so far represent the activities and their relationships within the design process. Whilst it is not a specific concern of this work these operations can be used as the basis of a sequential model. One simple way is illustrated here. As described earlier in the thesis, (in Chapter 2.0.0), design is a problem solving activity. The simplest cognitive model of problem solving is the goal directed search. Generally goal directed searches consist of:

"(i) an Initial state;

(ii) a Goal state;

and

(iii) an Operator that can be applied to any state to change it into another state, with the specific intention of moving closer to the goal state with each operation." (Newell and Simon 1972)

An example of a goal directed search is algorithmically expressed as:

state ← Initial_State;

while state ≠ Goal_State

state ← Operator (state)

In many practical cases when a state is too complex to directly observe in its whole an additional state "Observer" is used and the goal rather than being a state is a value of this operator:

state ← Initial_State;

while Observer (state) ≠ Goal_Value

state ← Operator (state)

If this algorithm was applied using the operators of the previous section,

Initial_State = ∅

State = **F3**

Observer = **Com3(C3,)•Obs3**

(The observed value is the Boolean variable **M3**)

Operator = **Inv3**

Goal_Value = **True**

For example

(i) while kitchen area is not less than 100.0 - Observer (state) ≠ Goal_Value,

(ii) then change kitchen area - state ← Operator (state),

(iii) redo test to check if the goal has been met by introducing the change,

(iv) if not repeat until the goal is met (i.e. stages ii and iii).

The following pseudo code illustrates how the relational descriptions of the design activities described previously, in (Figures 4.1.2a, 4.1.4a, and 4.1.5a), could be constructed into a sequential description:

```
while;
        Com3(C3,)•Obs3 (F3) > 100.0;
        F3 ← Inv3 (F3);
```

The above code represents the method of prediction of product performance assessment at the conceptual stage of the design process. The code denotes that whilst the prediction (**Com3(C3,)•Obs3**) of the form (**F3**) is greater than 100.0; then decisions (**Inv3**) must be made as to what part(s) of the form (**F3**) must be changed to achieve the goal (i.e. kitchen_area less than 100.0), or at least reach an optimum solution.

4.2.0 Actual Product Performance

4.2.1 Attributes and Ensemble

Misfit Variable

Alexander's formalisation of context is based on a set of Boolean variables. However this implies that each requirement is of equal importance, a notion now widely rejected by many authors including Lawson (1990).

It is important to note that a misfit variable is **defined** as an observation that **could** be made of an actual ensemble. This presents two problems of firstly defining the observation and secondly predicting it from the representation of form before the actual ensemble exists. Before this is done misfit variables have to be extended to enable requirements of differing importance to be incorporated. To do this the misfit variable is extended to an attribute variable which can take on a wider range of values appropriate to the observation.

Attributes

An attribute a is defined by the set of values it may take which is defined as its type A.

$A = \{a : S(a)\}$

where S is an open sentence defining inclusion within A (Blyth 1975).

$a \in A$,

with the constraint that A must be scalar and totally ordered. S is a rule regarding whether a is an element of A ($a \in A$), for example:

$A = \{a \mid$ "a is a fruit"$\}$ is the set of fruits, S (a) = "a is a fruit", and S (Chicken) = "chicken is a fruit". Obviously chicken is not a fruit so S (Chicken) is **false** and chicken is not a member of the set of fruits.

Misfit variables (Alexander 1964), are special cases of attribute variables equivalent to an enumerated type {false, true}.

Attributes have names which reflect perceived user requirements, and a method of observation which determines their value. An attribute observation is a function Oba from an actual ensemble **E1** to an attribute value A.

$$Oba \mid \mathbf{E1} \rightarrow A$$

For example 'consumes_fuel_efficiently' is the name of an attribute, and its method of **observation** could be miles per gallon in actual use.

An attribute is the observation of an element of performance of an actual form **F1** within an actual ensemble **E1**, i.e. of the product in use. For example, a performance element of a car could be that it should consume fuel efficiently. The attribute 'consumes_fuel_efficiently', for example miles per gallon, could be directly measured under stated conditions. Another attribute such as 'looks_fast' would have to take values from an enumerated set such as {slow, average, good, quick, fast} but ultimately could only be measured from the stated responses of individuals.

It is important that attributes are based on direct observation and do not implicitly contain theories about their causes. For example a suitcase may have an attribute 'comfortable_to_carry' which could be reasonably objectively defined and evaluated in terms of muscular discomfort. It should not however be defined in terms such as weight which implicitly reflect ergonomic theories of human capacity. Such considerations are clearly essential to the assessment but are not contained within definitions of attributes.

In general attributes range from the objective to the subjective (Figure 4.2.1a).

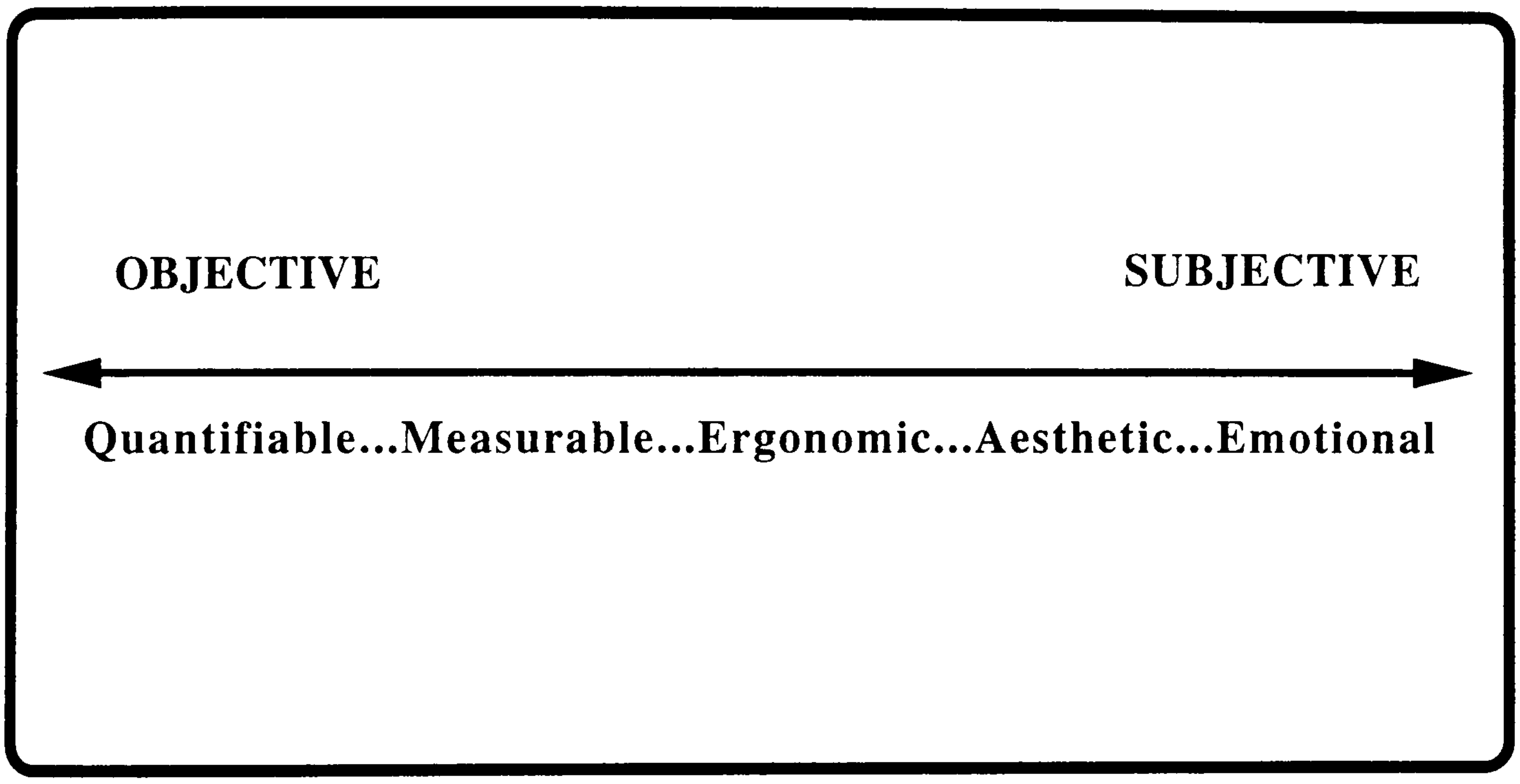


Figure 4.2.1a: Attribute Spectrum

At the objective end of the attribute spectrum are quantities that can be objectively defined and subsequently observed. At the subjective end are the physiological or even emotional responses to the form which in part depend on user perception and do not easily lend themselves to quantitative evaluation and in many cases have to be elicited directly from the users' responses.

Definition of the attributes formalises the designer's view of the significant requirements of the form in use. All the attributes **A** for a form is the product set of the n individual attribute types defined,

$$\mathbf{A} = A_1 \times A_2 \times \ldots . A_n.$$

The elements of **A** are the n-tuples reflecting the evaluations of each attribute,

$$\mathbf{a} \in \mathbf{A}, \quad \mathbf{a} = <a_1, a_2, \ldots a_n>.$$

The corresponding n attribute observation functions are,

$$Oba_1, Oba_2, \ldots Oba_n,$$

and the single function which produces the attribute n-tuple is,

$$\mathbf{Oba} \mid \mathbf{E1} \rightarrow \mathbf{A}$$

$$\mathbf{a} = <Oba_1(\mathbf{E1}), Oba_2(\mathbf{E1}), \ldots Oba_n(\mathbf{E1})>$$

The attribute variables define the relevant aspects of the product in use.

4.2.2 Combining Attributes

To get a single performance evaluation of the form in context the individual attributes must be combined in a way that reflects their relative importance. The combination of attributes is described by a combination function **Cob** which reflects their relative importance and the result of this function is denoted **M1′**.

$$\mathbf{Cob} \mid \mathbf{A} \rightarrow \mathbf{M1'}.$$

This addresses Lawson's (1990) major criticism of Alexander (1964) of not accounting for the relative importance of the misfit variables.

4.2.3 Product Performance

Rather than simply determining fit or misfit, **M1**, **M2** and **M3** are now measures of performance. The **formal definition** of actual product performance **M1′** is a rationalisation of the intuitive measure of performance **M1** defined by the attributes and combination function.

$$\mathbf{M1'} \leftarrow \mathbf{Oba{\bullet}Cob(E1)}.$$

M1 comes from the (intuitive) observation of the actual ensemble **Obs1(E1)**,

$$\mathbf{M1} \leftarrow \mathbf{Obs1(E1)},$$

illustrated in Figure 4.1.2a. (Chapter 4.0.0). Thus the relationship between **M1′** and **M1** in algebraic terms is,

$$\mathbf{M1'} \leftarrow \mathbf{Obs1^{-1}{\bullet}Oba{\bullet}Cob(M1)},$$

and is represented diagrammatically below (Figure 4.2.3a),

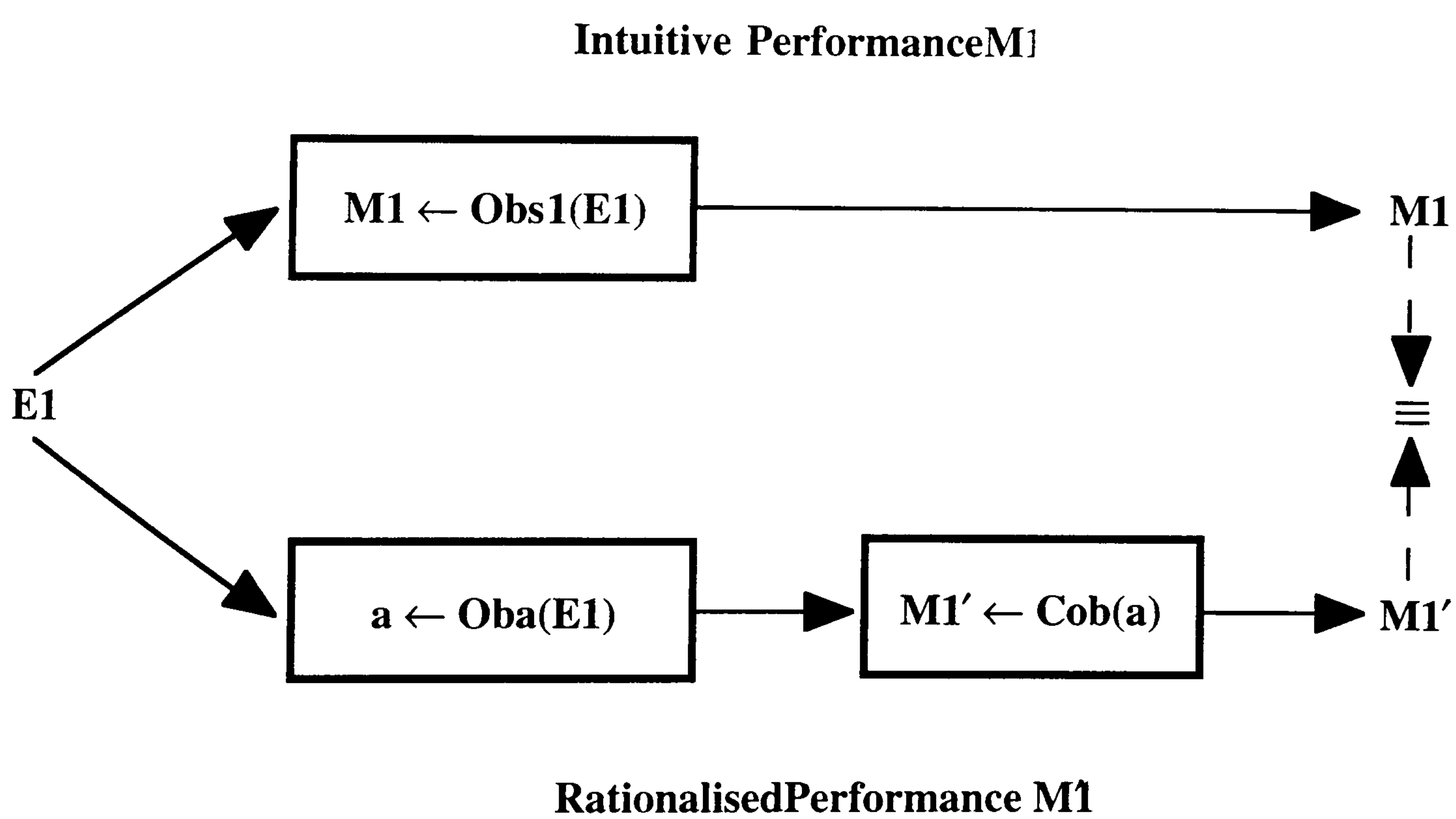


Figure 4.2.3a: Relationship Between Intuitive Performance M1 and Rationalised Performance M1′

In practice however the results of the preceding two equations would have to be compared.

This type of problem is dealt with in value theory (Lera 1981).

4.3.0 Product Performance Prediction

At the concept stage of the design process the designer has only a representation of the actual form **F3** and must predict its measure of performance **M1′**. The formalisation of performance **M3** is the designer's prediction of **M1′**. To make this prediction meaningful the representations within the formal picture of design must be put into relationship with the actual elements they represent.

4.3.1 Form

The detailed representation of form **F2** should be a complete and unambiguous representation of an actual form **F1**. However due to the inevitable measurement and manufacturing errors, **F2** in practice defines a class of actual forms. **F2** is an inclusion condition for a class of admissible actual forms. The usual practice is to treat measurement as perfect and incorporate measurement error within the range of permissible actual forms. For example a component is measured and that measurement compared to a toleranced drawing. If the measurement is within tolerance then the component is, in that respect, within the class of admissible forms, otherwise it is not. It is not generally assumed that if a component is out of tolerance that it may still be within the class of admissible forms due to the measurement error.

This leads to algebraic complications since the manufacturing operator **Man** would have to be defined as producing classes of admissible actual forms rather than a single actual form. Consequently tolerancing and measurement error will be ignored and it will be assumed that there is a unique actual form **F1** associated with its representation **F2**. The relationship between **F1** and **F2** is defined by a measurement operator **Mes**,

$$\mathbf{Mes} \mid \mathbf{F1} \rightarrow \mathbf{F2}.$$

Similarly it will be assumed that a concept representation **F3** is associated with a unique actual form **F1** also related by the operator **Mes**,

$$\mathbf{Mes} \mid \mathbf{F1} \rightarrow \mathbf{F3}.$$

This of course implies that the process of embodiment, detailing **Emb**, and manufacture **Man** are completely deterministic for a given concept. This is clearly not the case in practice but makes little difference to the problem of product performance assessment at the concept stage of the design process.

4.3.2 Context

It is very difficult to bring actual context **C1** into a formal relationship with its formalisation **C3** in the same way as form can be. Alexander (1964) avoids the problem by defining actual context as *"...that which puts demands on form"* but by defining formal context as the set of misfit variables which are in fact the demands on form. This work takes a similar approach to Alexander in defining formal context as the set of attributes and their combination.

The formalisation of context is the combination function **Cob**. Notice that defining the combination function implicitly defines the attributes as well as explicitly defining their relative importance. This definition is equivalent to Alexander's formalisation of context when all attributes are Boolean and their combination is conjunction. Notice again that the formalisation of context is defined in terms of observations that **could** be made of an actual ensemble.

Because **C3** does not represent context as initially defined the combination of form and context will have to be treated slightly differently. Instead of being a function of two variables it will be treated as a function of one variable (which will be form) for a fixed context (see Appendix XI). Secondly the composition of combination and observation operations will have to treated as a single operation.

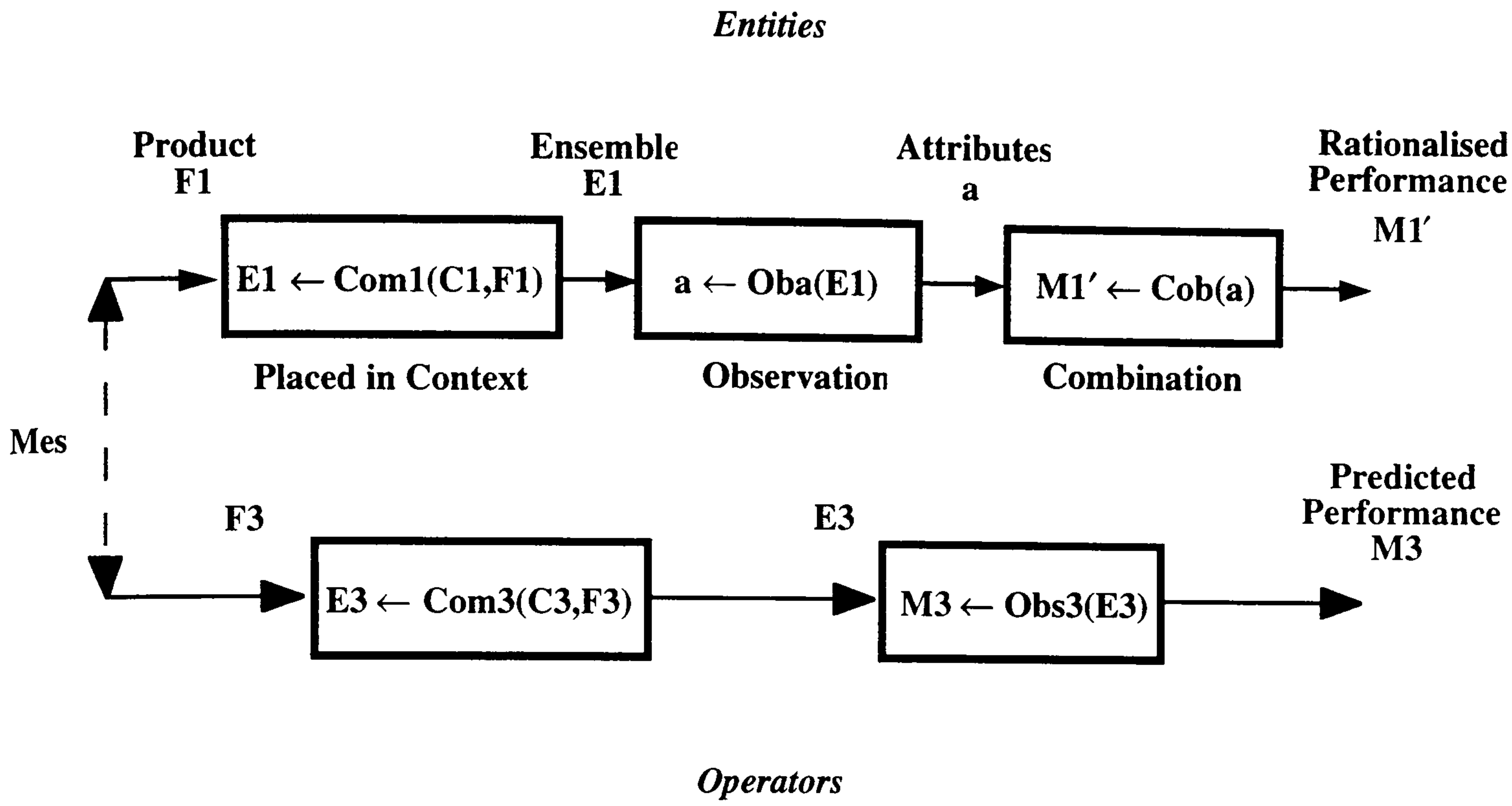


Figure 4.3.2a: Rationalisation of Actual Product Performance Assessment

The assessment of an **actual** product in context is by implementation of the operators **Oba**, which evaluates the attributes and **Cob**, which combines them into a single performance assessment (Figure 4.3.2a). However, at the conceptual stage of the design process there is no actual product. From Figure 4.1.5a, **M3** is predicted by the operator **Com3(C3,)•Obs3**. The requirement of product performance assessment at the conceptual stage is that,

$$\mathbf{Mes \cdot Com3(C3,) \cdot Obs3 \equiv Com1(C1,) \cdot Oba \cdot Cob}.$$

The product performance assessment methodology described will enable the designer to quantify and compare his/her design at the conceptual stage of the design process. The methodology is based on the abstract descriptions of the operations conducted within the design process. It is, therefore, extremely generic and produces a bridge between physical product performance and actual user requirements. The methodology is based on defining product attributes in terms of observable parameters of the product in use. Defining an attribute in this way inherently reflects its required interaction with the user and consequently can truly be said to be in "user terms". The next chapter (5.0.0), discusses the implementation of this methodology by comparing three different examples of product assessment.

Chapter 5.0.0

Methodology for Product Performance Assessment at the Conceptual Stage of the Design Process

5.0.0 Methodology for Product Performance Assessment at the Conceptual Stage of the Design Process

5.1.0 Existing Methodologies

Of the many different models of the design process that exist, they all have one thing in common - the need to improve on traditional methods of working in design. There are many reasons for this interest in using new design methodologies, tools, strategies and procedures. Generally, however the main reason is the potentially enormous costs and investments involved in design projects. Figure 5.1.0a illustrates the costs involved in the design of a new product.

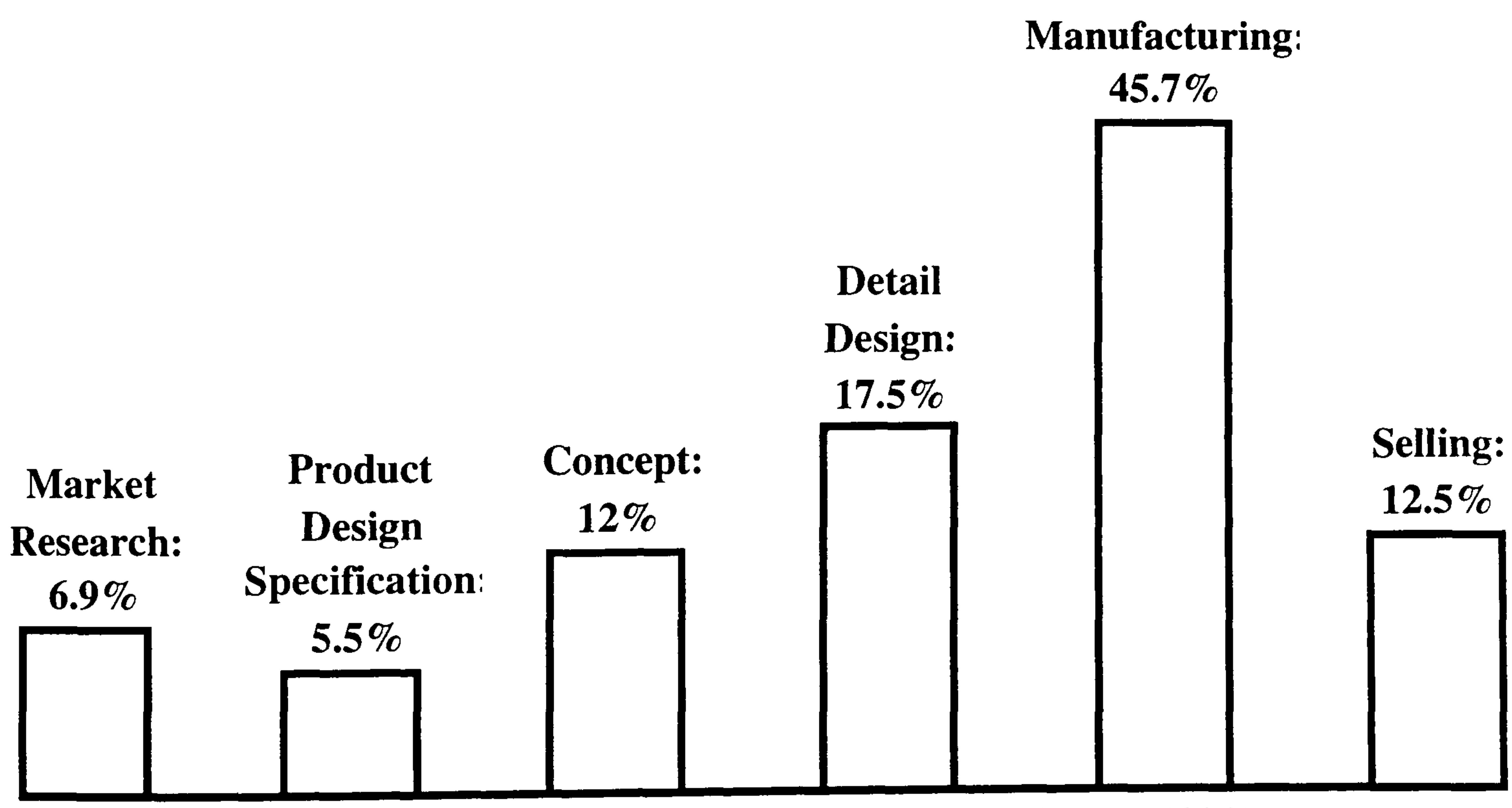


Figure 5.1.0a: Costs Involved in New Product Design (Hollins and Pugh 1990)

The figure shows that the costs involved at the early stages of the process of product design (e.g. concept stage), where the major decisions are made, is at the low-cost end, and costs in the final stages (e.g. manufacturing) are much greater. Hollins and Pugh argue that if the problems and possible sources of error can be detected at the early stages of design, then costly modifications or product abandonments will be eliminated.

One such method intended to improve design practice is Quality Function Deployment (QFD). Quality Function Deployment (QFD) is a set of planning and communication routines which focuses and coordinates skills within an organisation, first to design, then to manufacture and market goods that customers want to purchase and will continue to purchase (Hauser & Clausing 1988), (King 1989), (Fox 1993), and (Cross 1994).

The system originated from the Mitsubishi Kobe shipyard (Japan) in 1972. Often referred to as the "House of Quality", it has been used successfully by Japanese and American manufacturers of consumer electronics, domestic appliances and engineering equipment etc. The foundation of the house of quality is the belief that products should be designed to reflect customers' desires and tastes - which is a principal that has been incorporated in this project. QFD maintains contact with the 'voice of the customer' through the product development process, identifying engineering requirements, parameters to be maintained for functional response and drawing specifications to support the manufacturing processes. Also, it can help identify the major competitors' strengths and weaknesses.

QUALITY CHARACTERISTICS (how)

CUSTOMER DEMANDS (what)

	length	sharpening	lead dust	hexagonality	A importance	N company-now	competitor-X	competitor-Y	P plan	B improvement	C sales point	D absolute wt.	demanded wt.
Easy to hold	● 42			● 42	3	4	3	3	4	1	1	3	14
Does not smear		● 69	▲ 207		4	5	4	5	5	1	1.2	4.8	23
Point lasts	■ 44	▲ 396	● 132		5	4	5	3	5	1.25	1.5	9.4	44
Does not roll	■ 19			▲ 171	3	3	3	3	4	1.33	1	4	19
Total												21.2	100

	length	sharpening	lead dust	hexagonality	
Total	105	465	339	213	1122
%	9	41	30	19	99
company-now	5"	3	3g	70%	
competitor-X	5"	5	4g	80%	
competitor-Y	4"	2.5	3g	60%	
plan	5.5"	6	2g	80%	

▲ -strong correlation

● -some correlation

■ -possible correlation

D = A * B * C

B = P / N

Figure 5.1.0b: Quality Function Deployment Chart 1

The plan (Figure 5.1.0b) like most of the QFD charts, is a matrix. The left section of Chart 1 compares customer demands with quality characteristics and identifies strong, moderate and possible correlations (the example illustrated is a pencil). The right section of Chart 1 lists on a scale of 1-5 customer demands, company's current performance, competitors' performance, company plan and potential strong and moderate sales points. It combines these weights into an absolute quality weight and a relative quality weight (percentage). The purpose of this first chart is threefold:

(i) It lists customer demands and develops the initial plan of how they will be met based on the current performance levels in comparison to the other competitors' performance levels.

(ii) It prioritises the importance of each customer demand and takes into account potential sales points.

(iii) It identifies the three or four key quality characteristics to work on.

Chart 1 is used at the product planning phase of the design process. It is used as a basis for defining individual products or for executing a major upgrade of an existing product.

Figure 5.1.0c illustrates the next stages of the QFD method, namely Chart 2 - the comparison of product functions with quality characteristics, and Chart 3 - the examination of correlation between the quality characteristics and the detail or parts of the product.

▲ -strong correlation
● -some correlation
■ -possible correlation

Chart 2

FUNCTIONS \ QUALITY CHARACTERISTICS	length	time between sharpening	lead dust generated	hexagonality
write	●	▲	●	■
erase		●	▲	■
chewing				
pointing	●			■

Chart 3

PARTS \ QUALITY CHARACTERISTICS		time between sharpening	lead dust generated	
lead		▲	▲	
wood		●		
eraser				
eraser holder				

Figure 5.1.0c: 2: Characteristics/Functions Comparisons (Left) - 3: Characteristics/Parts Correlations (Right)

Chart 2 identifies functions of the product that may be unknown to the customer. The chart makes it possible to represent the functions in a logical format to ensure that none are missed. Chart 2 focuses attention on the voice of the engineer. King (1989), asserts that it is better to put the voice of the customer in Chart 1 and the voice of the engineer in Chart 2 to avoid any confusion. Chart 2 shows that there are strong correlations for the functions of writing and erasing. Chart 3 is used to identify which parts of the product are most related to the three or four key quality characteristics which are being highlighted to work on. The chart highlights that lead is the part to be worked on because it has a strong correlation with time between sharpening and lead dust generated. The wood part is of some significance because it can affect lead breakage.

The next chart of the QFD procedure shown (Figure 5.1.0d) is a matrix bounded on the top by the product functions and on the left by the customer demands. The columns are added vertically and converted to percentages to identify the relative value of each function. This percentage is multiplied by the target cost to give the targeted cost for each function. This targeted cost is compared to the actual cost to identify functions for cost reduction by value engineering.

▲ - strong correlation

● - some correlation

■ - possible correlation

FUNCTIONS

CUSTOMER DEMANDS	demanded weight	write	erase	chewing	pointing	
easy to hold	14	● 42	● 42		■ 14	
does not smear	23		▲ 207	■ 23		
point lasts	44	▲ 396	■ 44		■ 44	
does not roll	19	■ 19			■ 19	
column weight		457	293	23	77	850
function weight		54%	34%	3%	9%	
function target cost		6.5p	4p	0.4p	1p	12p
function actual cost		4p	4p	3p	2p	13p

Figure 5.1.0d: Chart 4 - Product Functions/Customer Demands

The purpose of Chart 4, (Figure 5.1.0d), is to identify functions of the product that will be targeted for cost reduction by identifying which functions have an actual cost which is greater than the expected cost.

The following chart, (Figure 5.1.0e), illustrates the combined totals of the previous three figures. The purpose of this final chart is to identify new concepts that will positively relate to all the criteria of the last three figures without causing other problems. The output from this chart will provide a grand total for new concept selection.

SUMMARY	NEW CONCEPTS: spring loaded lead	retractable lead	Datum - best in class	friction fit eraser	pocket clip	china pencil
customer demands	1+	2+			1+	3-
product functions	1+	1+		1+	1+	2-
quality characteristics	2+	3+				3-
Total +'s	4+	6+		1+	2+	
Total -'s						8-

Figure 5.1.0e: Concept Selection Totals (Pugh System)

From the above chart, (Figure 5.1.0e), one can detect that the retractable lead (6+, 0-) and the spring loaded lead (4+, 0-) both look very promising. Moreover, it is obvious that the china pencil does not look like a viable replacement concept (8-).

For a more detailed explanation of Pugh's concept selection technique, see Pugh (1990). The Pugh concept selection system requires input from the designer or design team in the form of rating each concept in turn against a preselected "datum".

The eleven basic rules, for the Pugh concept selection method are as follows:

(1) All ideas and concept solutions must conform to the Product Design Specification, i.e. all solutions must satisfy the same requirements and constraints.

(2) Having developed a number of possible solutions to the problem, they are produced in sketch form to the same level of detail in each case.

(3) A concept evaluation matrix is established. This compares the generated design concepts against the criteria for evaluation. In making the comparisons between concepts it is important to ensure that they are all at the same generic level.

(4) The criteria against which the design concepts will be evaluated are chosen from the detailed requirements of the Product Design Specification. It is essential that the criteria are unambiguous and understood by all participants in the evaluation. Also, the PDS must be established before the concept selection begins.

(5) A reference or datum is chosen with which all other concepts will be compared. An existing design in the product area is selected as the first datum choice.

(6) Each concept/ criteria combination is evaluated against the chosen datum. In order to facilitate communication and comparison Dieter (1991) recommends that the following symbols are used:

+ : indicates better than, less than, less prone to, etc. relative to the datum.

- : indicates worse than, more expensive than, more difficult to develop than, more complex than, etc. the datum.

S : indicates equivalence. It is used when there is doubt as to whether a concept is better or worse than the datum.

(7) An initial comparison of concepts is made using the above scheme. This establishes a score in terms of the number +'s, -'s and S's relative to the datum. These scores are for guidance only and must not be summed at this time.

(8) Examine the scores for the individual concepts. If certain concepts show unusually high scores try to determine why they score so high. Redo the matrix to see whether on reexamination the same concepts score highly. If so, these are likely to be the best concepts with which to proceed.

(9) If a pattern of one or more strong concepts does not emerge, change the datum and reevaluate. If a strong concept still does not emerge it means either that the criteria are ambiguous or that one or more concepts are subsets of the others.

(10) If one concept continues to remain the strongest, change the datum and repeat. If the same concept continues to predominate, let this strong concept be the datum and redo the matrix.

(11) As strong and weak features of each concept emerge it is important to attempt to make

changes that will improve the situation. Often a new concept will emerge. If the effort to eliminate defects in a concept fails then it reinforces the view that it is a weak concept.

The approach of this research work has some similarities with the concept selection method developed by Pugh (1990). Pugh's method however, is generally insufficient as it does not provide the designer with the facility of a combination function, since it does not weight or set maximum or minimum (GO - NO-GO) levels for product characteristics. For example, material of a product that may be inappropriate (e.g. for toxicity reasons). Therefore, there is always the possibility of Pugh's system selecting the 'best concept' from a 'bad bunch of concepts'. Furthermore, Pugh's system does not compensate for certain product attributes being more important than others.

The approach taken within this research programme is analogous to the approach described earlier in Hauser and Clausing (1988), King (1989), and Fox (1993), in so much as the product is designed in an attempt to meet the requirements of users'. Although they take a similar approach to this work, they rely on the Pugh concept selection method and therefore fail to address the problems within Pugh's system aforementioned.

5.2.0 Definition of Assessment

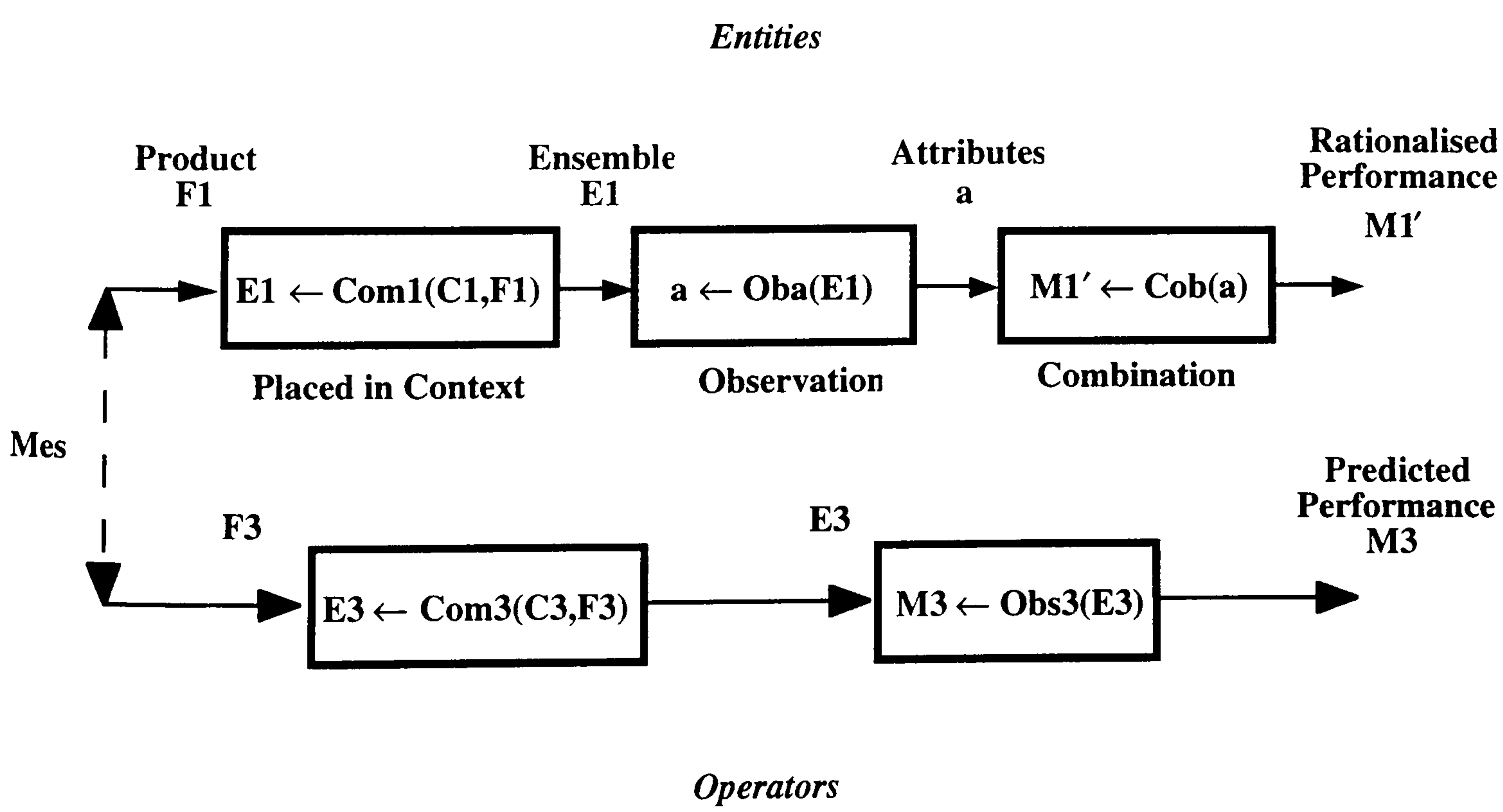


Figure 5.2.0a: Rationalisation of Actual Product Performance Assessment

Product performance assessment at the conceptual stage was defined in the previous chapter by implementation of the composite operator,

Com3(C3,)•Obs3,

on the concept representation of form **F3** (see Figure 5.2.0a).

To assess the performance of a product at the concept stage requires two basic operations of:

Problem Definition

The assessment problem is defined by determining entity **C3**. In Alexander's design model (Figure 4.1.5a) this is by execution of operator **Exp•For**. Since by definition of **C3**, this is equivalent to rationalising the intuitive measure of performance **M1′**.

Evaluation

Having defined the problem a product is assessed by execution of the operators **Com3** and **Obs3** on **F3** to generate **M3**, which is the predicted measure of rationalised actual performance **M1′**.

This work will start with the evaluation problem since the requirements of evaluation will influence problem definition.

At the concept stage, where there is no **actual** product, the operator **Oba** must be simulated to predict the performance **M3**. This requires prediction of each individual attribute to be combined by the operator **Cob**. The operator **Oba** is simulated using two further operators **Ext** and **Mod** to be described later.

5.3.0 Attribute Prediction

The prediction of objective attributes such as: 'consumes_fuel_efficiently' is well defined.

although in many cases may be mathematically difficult. The engineering sciences are, for example thermodynamics, predominately concerned with making these types of predictions, the results of which are embodied in available computer software, e.g. RASNA MECHANICA®. This work is not concerned with these techniques but with the formal structure that would enable a common interface to all of it as required. Similarly, there is a wealth of knowledge, for example human factors and ergonomics, that can be incorporated at this stage.

For predicting the subjective attributes critical design theory exists, for example Athavankar (1989), and although less reliable than the theories of engineering science seek to analyse forms in a relatively objective and consistent way. Authors such as Sudjic (1985) and Kobayashi (1990), suggest that certain colour finishes have specific meanings such as black metal almost universally used to signify "serious" and "professional", yellow for underwater equipment, and primary colour finishes generally used for sports products to project the meaning of "health" and "fitness". Moreover, Russell (1991) points out several important factors for designers when making decisions concerning colour selection, such as:

* Colour should be considered in relation to form and function, and should be seen in context with texture and surface effect.
* Colour is an important safety factor; a colour 'code' such as yellow and black warns that a toxic substance is present.
* The fact that colour has psychological and physiological effects on human response should be considered.
* Proportional use of colour controls the perceived colour; for example, placing red and yellow together affects the appearance of both colours.

Theoretical models for predicting behaviour are based not of the complete form itself but on specific properties extracted from it. In many cases the same property will appear in more than one attribute. It is therefore convenient and expedient to implement the operator **Com(C3,)•Obs3** into a composition of further operators of extraction **Ext**, and model **Mod**, and a new entity of the extracted properties called characteristics **Ch**.

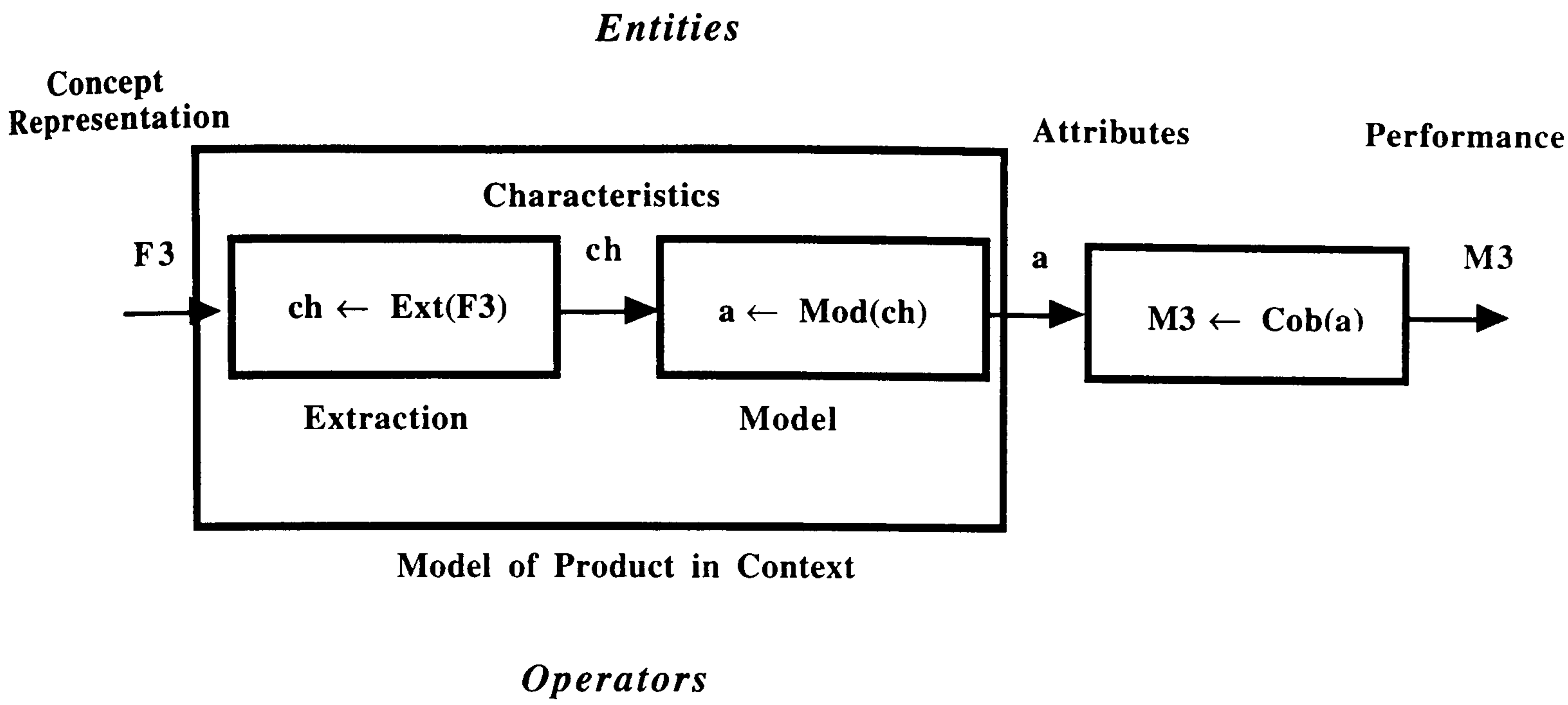


Figure 5.3.0a: Performance Assessment at Concept Representation Stage

Characteristics are inherent properties of any product, independent of the products use, and can be determined purely from the representation. Product characteristic examples include mass, colour, material specifications, dimensional information (length, width, height, etc.).

Characteristics have the same mathematical structure as attributes. A characteristic ch is defined by the set of values it may take which is defined as its type Ch.

$Ch = \{ch : S\,(ch)\}$

where S is an open sentence defining inclusion within Ch (Blyth 1975).

$ch \in Ch$,

The characteristics of a form **Ch** are the product set of the n individual characteristic types defined for the form,

$\mathbf{Ch} = Ch_1 \; X \; Ch_2 \; X....Ch_n.$

Consequently the elements of **Ch** are the n-tuples reflecting the determination of each characteristic,

$\mathbf{ch} \in \mathbf{Ch}, \quad \mathbf{Ch} = \langle ch_1, ch_2, ...ch_n \rangle.$

The operator **Ext** is a function from form **F3** to characteristics **Ch**.

$$\mathbf{Ext} \mid \mathbf{F3} \rightarrow \mathbf{Ch}$$

and the model **Mod** a function from characteristics **Ch** to attributes **A**.

$$\mathbf{Mod} \mid \mathbf{Ch} \rightarrow \mathbf{A}.$$

5.4.0 Attribute Evaluation Examples

The operation of product performance evaluation is illustrated by the following three examples. The examples will describe the assessment of a single attribute within three disparate areas of design. It will illustrate that the assessment methodology developed is applicable to any design problem within the entire Design Spectrum shown in Figure 2.0.0a (e.g. from aesthetics to ergonomics to materials to engineering science).

The first example (cantilever desk design) is taken from a traditionally engineering design problem. The second example (toothbrush design) concentrates more on the ergonomic or human factor area of the design spectrum. The third example (cup or bowl visual categorisation) deals with a design problem that is linked to cognitive psychology (Eysenck 1993) where the problem is associated with visual perception.

5.4.1 Example 1: Cantilever Desk

In this example, the concept representation of form **F3** is an annotated sketch of a cantilever desk (Figure 5.4.1a). In practice most individuals would have an intuitive feel for the structural requirements of office furniture and could certainly decide if a cantilever desk was sufficiently rigid for its application. Rationalising rigidity requires some defined relationship between applied loading and deflection. In this case the attribute is objective, and is defined in terms of an end load F and corresponding deflection v.

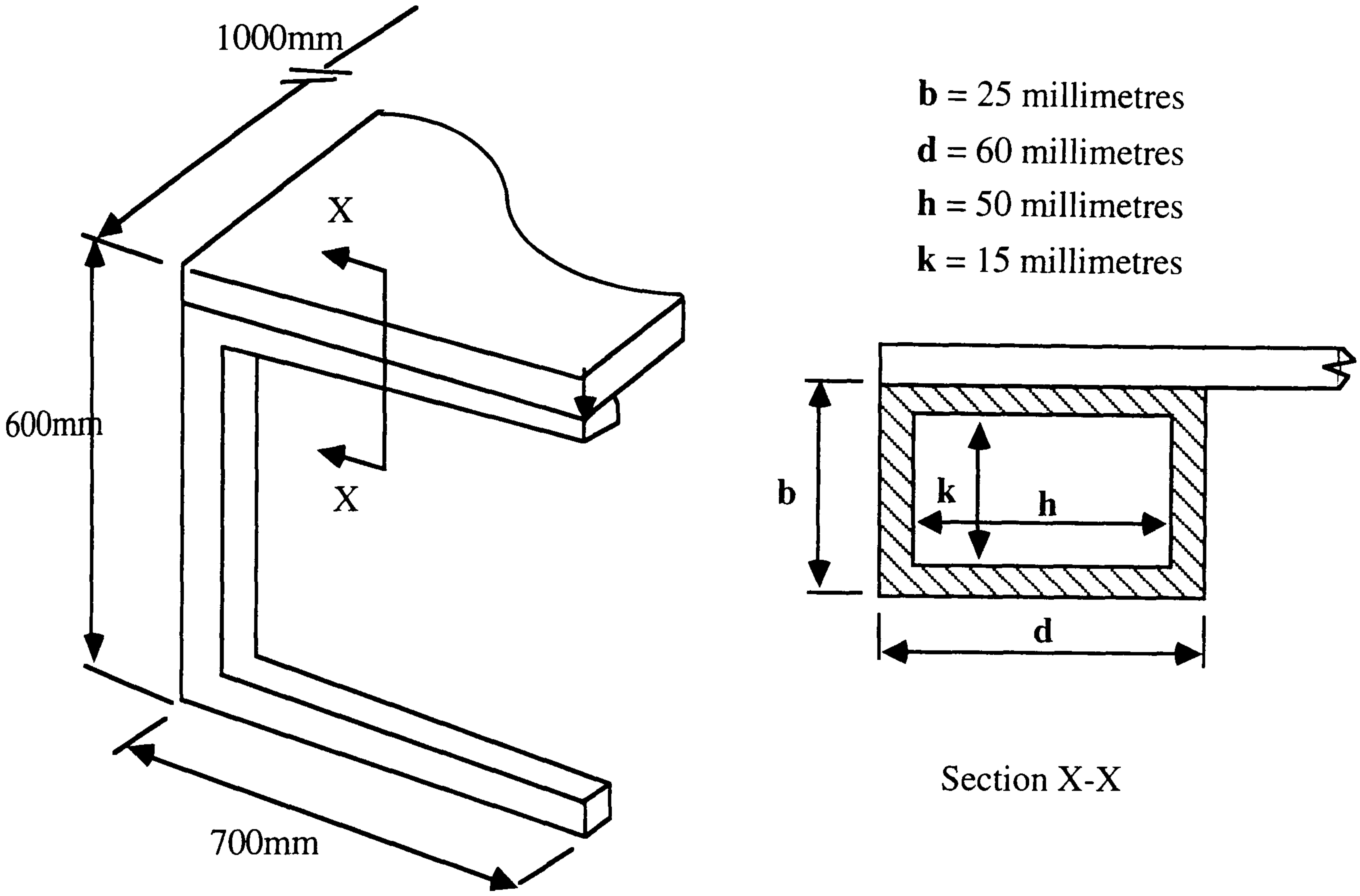


Figure 5.4.1a: Cantilever Desk Sketch

Attribute

sufficiently_rigid ∈ {true, false}

Method of Observation

sufficiently_rigid = ($v \leq 0.005$) **and** ($F = 700$)

Based on Figure 4.1.5a (Formal Picture), Figure 5.4.1b below illustrates the actual procedure one would have to follow to actually measure whether or not the cantilever desk would be sufficiently rigid. From the designer's sketch, detailed drawings would be produced that would be complete and unambiguous descriptions of the desk. This in turn would lead to the desk's manufacture, perhaps in another part of the country or even in another country altogether. At this stage, after manufacture, the attribute could be directly measured or observed. If it was found that the desk was not sufficiently rigid then the model used to predict it would have been in error.

Next, the desk would then be marketed, sold, and placed in its desired environment, for example a drawing office. The only "real method" to test if the desk was sufficiently rigid would be by judgments of user satisfaction. If the user was dissatisfied then the problem would have been incorrectly rationalised and the attribute wrongly defined.

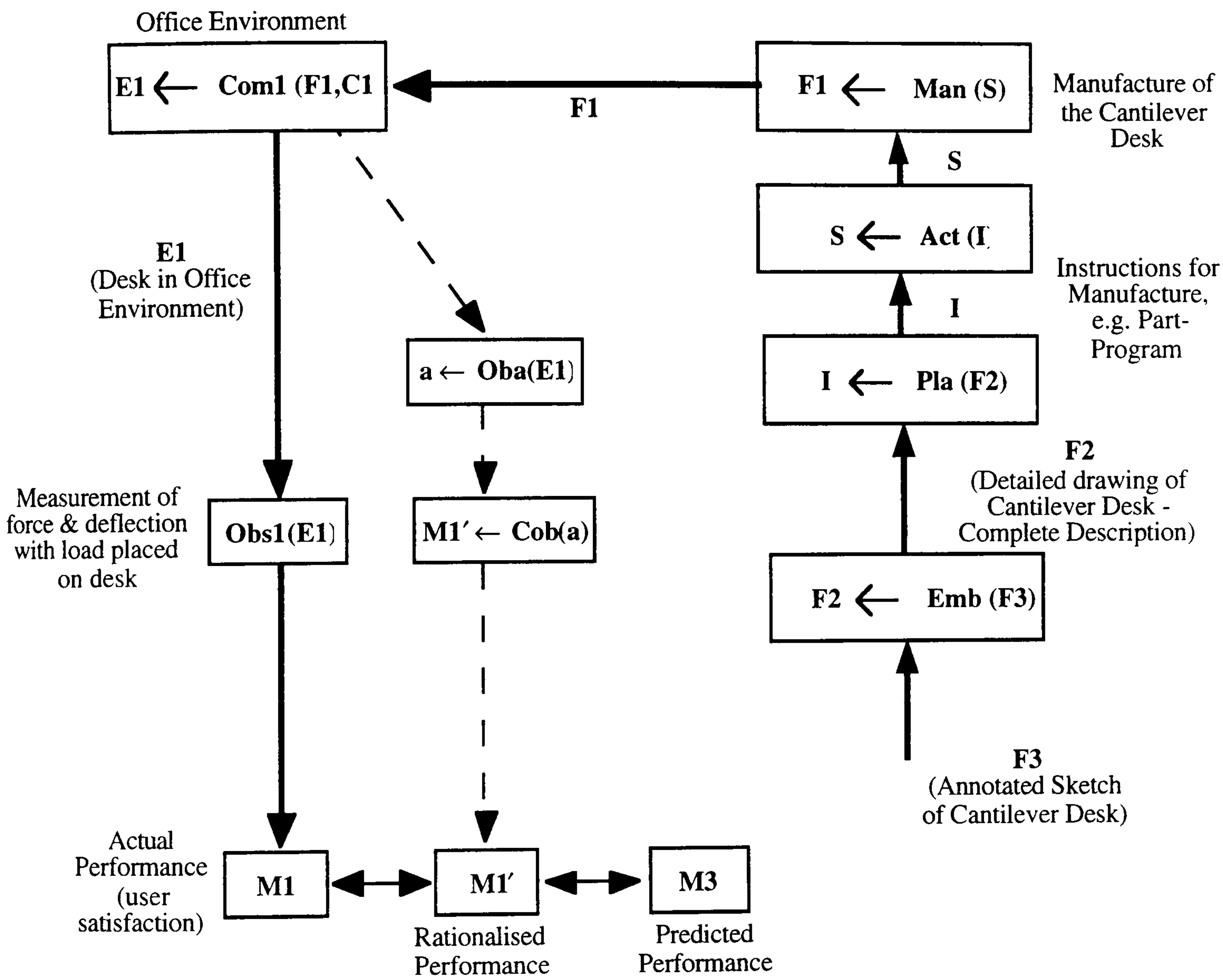


Figure 5.4.1b: Actual Product Test

Model

In this case the model is constructed from the physical principles employed in simple beam theory, for example Ryffel (Ed. 1988), by assuming the desk to be an end loaded cantilever.

$$v = \frac{Fl^3}{3EI}$$

Characteristics

The characteristics required for this model are (with reference to cantilever desk figure):

L = 0.6 (Cantilever length),

E = 208 x 10^9 (Youngs modulus of the material - mild steel),

I = (2nd moment of area of the beam section),

Extraction

L (cantilever length) is extracted by manual inspection of the Form **F 3**, E (Youngs modulus of the material) is extracted by reference to a materials data reference for the stated material in turn determined by inspection of the form **F 3**, and I (second moment of area) using the standard formula:

$$I = \frac{bd^3 - hk^3}{12},$$

where values of b,d,h and k are determined by inspection of **F 3**.

Notice that the extraction operator **Ext** is more than simple inspection. It may involve reference to external data, such as Young's modulus, or further calculations as in the second moment of area. Notice however that the extracted characteristics are intrinsic to the form and independent of context, i.e. the characteristic second moment of area exists even when there are no structural considerations in the attribute.

Attribute Evaluation

$$\mathbf{A} = \{<\text{sufficiently\_rigid}> \mid \text{sufficiently\_rigid} \in \{\text{true,false}\}\},$$

$$\mathbf{Oba} = (v \leq 0.005) \textbf{ and } (F = 700)$$

$$\mathbf{Ch} = \{<L,E,I> \mid L,E,I \in \Re\},$$

$$\mathbf{ch} = \mathbf{Ext(F\,3)} = <L = 0.6, E = 208 \times 10^9, I = 0.25 \times 0.0603 - 0.023 \times 0.0583/12>,$$

$$\mathbf{Mod(ch)} = \left(\frac{Fl^3}{3EI} \leq 0.005\right).$$

$$\mathbf{a} = (700 \times 0.6^3/(3 \times 208 \times 10^9 \times 0.34 \times 10^{-6})$$

a = True

5.4.2 Example 2: Toothbrush Performance Assessment (Based on Rodgers, Patterson and Wilson, 1993)

In this example the concept representation **F3** is again an annotated sketch (Figure 5.4.2a).

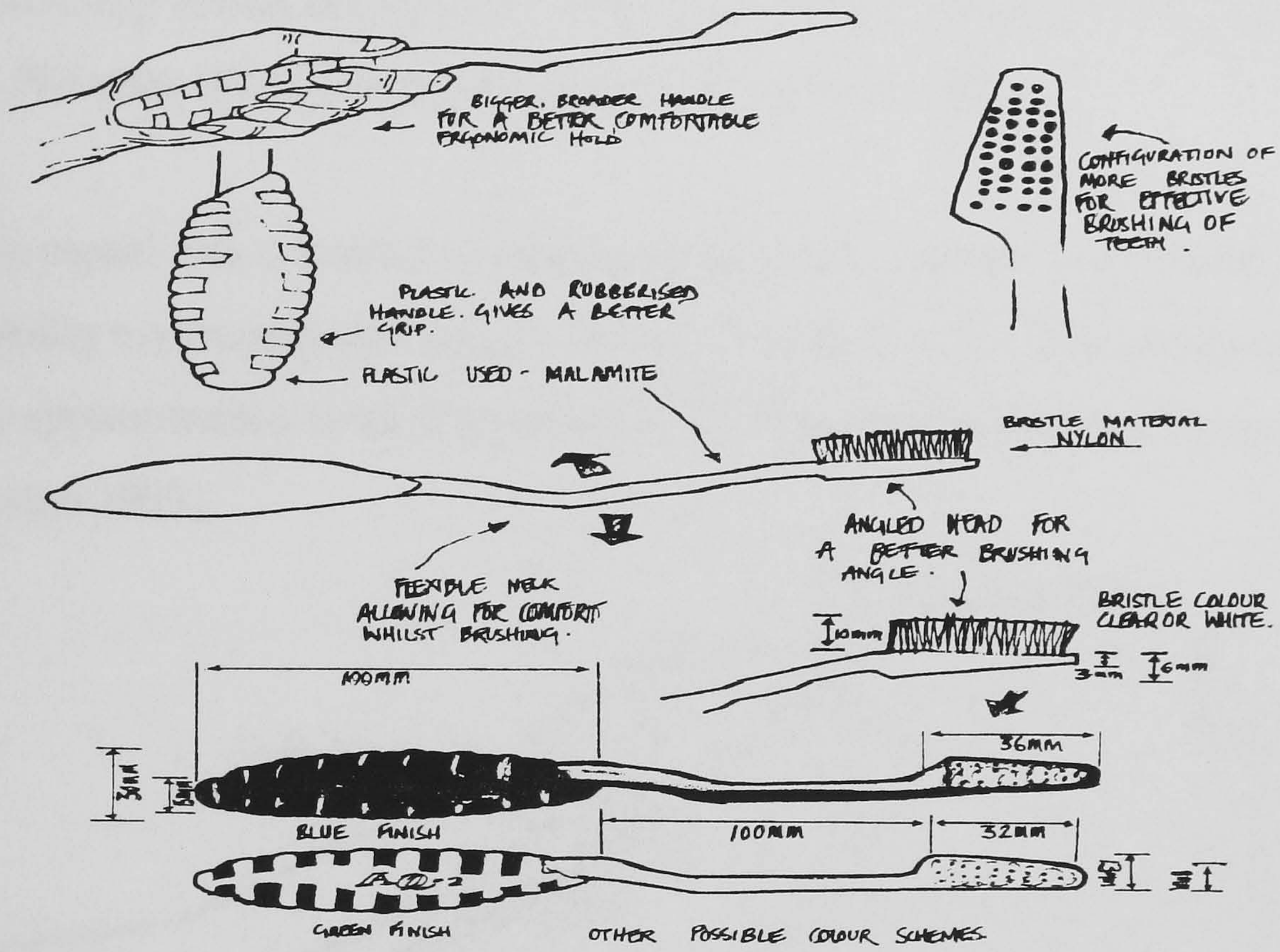


Figure 5.4.2a: Design Sketch of Toothbrush

In this case the attribute is objective but less easy to define since one has had to use natural language to describe the observation rather than mathematical language representing specific observations.

Attribute

reaches_all_teeth ∈ {True, False}

Method of Observation

reaches_all_teeth = "filament ends contact with every tooth surface in the mouth".

In the previous example the attribute could be mathematically defined in terms of direct measurements, however in this example natural language formulation has been used and is denoted within double quotation marks.

Model

The model is constructed from considerations of spatial occupancy of the toothbrush drawn from computer-generated three-dimensional models representing the access region in the mouth for a given brushing action drawn from expert knowledge (Appendix III), and from dental anatomy data (Woelfel 1990), (Berkovitz et al 1992) and (Ash 1993).

In this case the model was constructed empirically by using a plaster cast of teeth and estimates of cheek flexibility to determine the region **Access** (Figure 5.4.2b). The sweep trajectory **M** is a conservative approximation to ideal brushing action determined from interviews from dentists (Walsh and Lamb 1993).

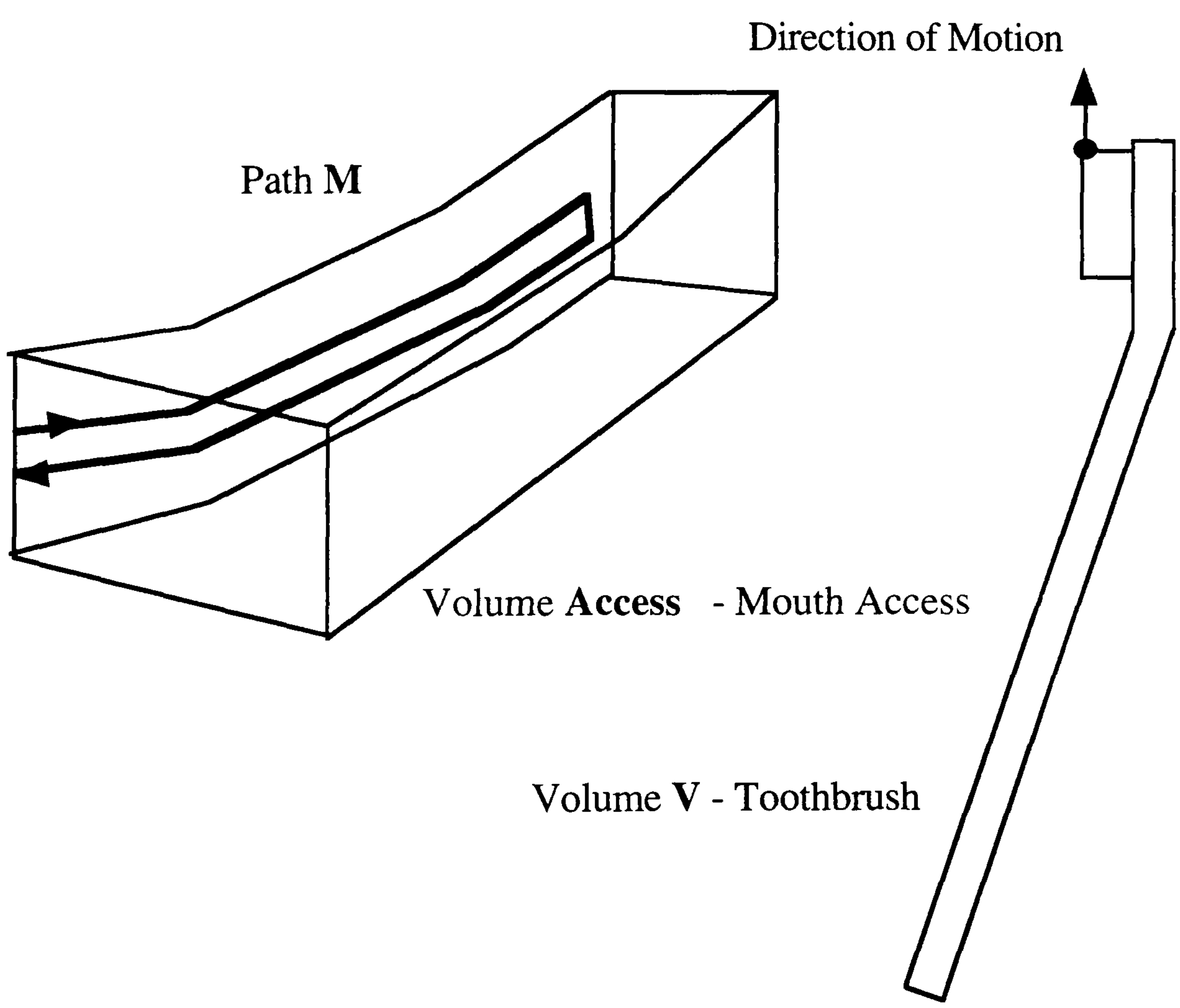


Figure 5.4.2b: Diagram of Access Volume Within Mouth (Empirically Based Model)

The model is expressed as :

reaches_all_teeth = (**SWEEP**(V,M) $\cap^*$ Access* = Ø)

where : V is the volume describing toothbrush spatial occupancy,

M is the path it is to be moved along,

SWEEP(V,M) denotes the SWIVEL 3D™ PROFESSIONAL operator for moving a volume V along a path M,

Access* is the regularised complement of the mouth access volume,

$\cap^*$ denotes regularised set intersection

and Ø the empty set.

(i.e. The work requires the toothbrush to be fully contained within the Access volume for the tooth brushing action)

Characteristics

V is the volume representing the spatial occupancy of the toothbrush.

Attribute Evaluation

A = {<reaches_all_teeth> | reaches_all_teeth ∈ {true,false} },

Oba = "filament ends contact with every tooth surface in the mouth".

Ch = {<V> | V ∈ bounded regular subsets of **E3** },

ch = **Ext(F3)** = "Construction of V in SWIVEL 3D™ PROFESSIONAL",

Mod(ch) = "Definition of M and Access within SWIVEL 3D™ PROFESSIONAL",

a = "Execution of the **Sweep** operator in SWIVEL 3D™ PROFESSIONAL and visual inspection of the generated image (Figure 5.4.2c)"

a = True

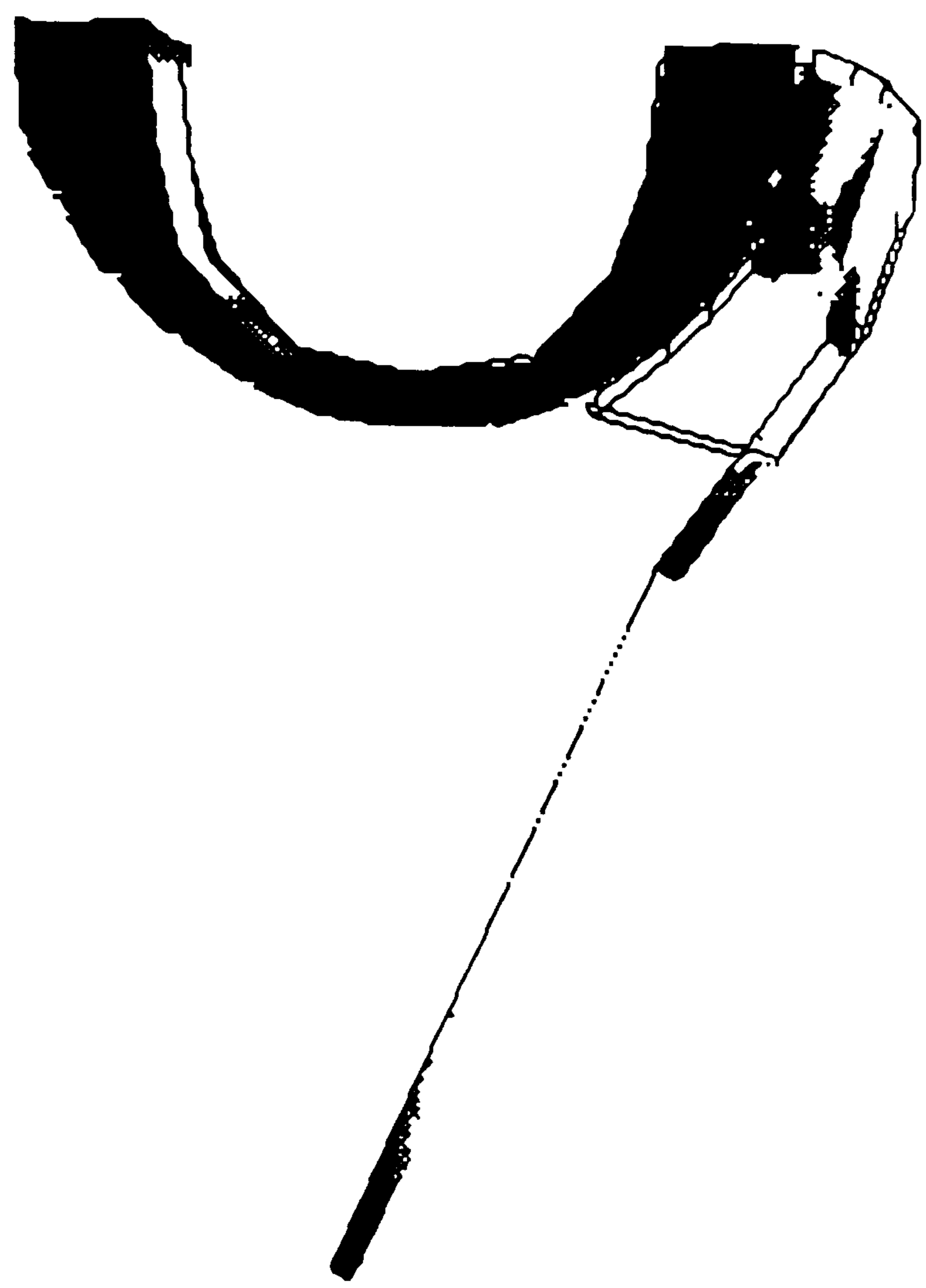
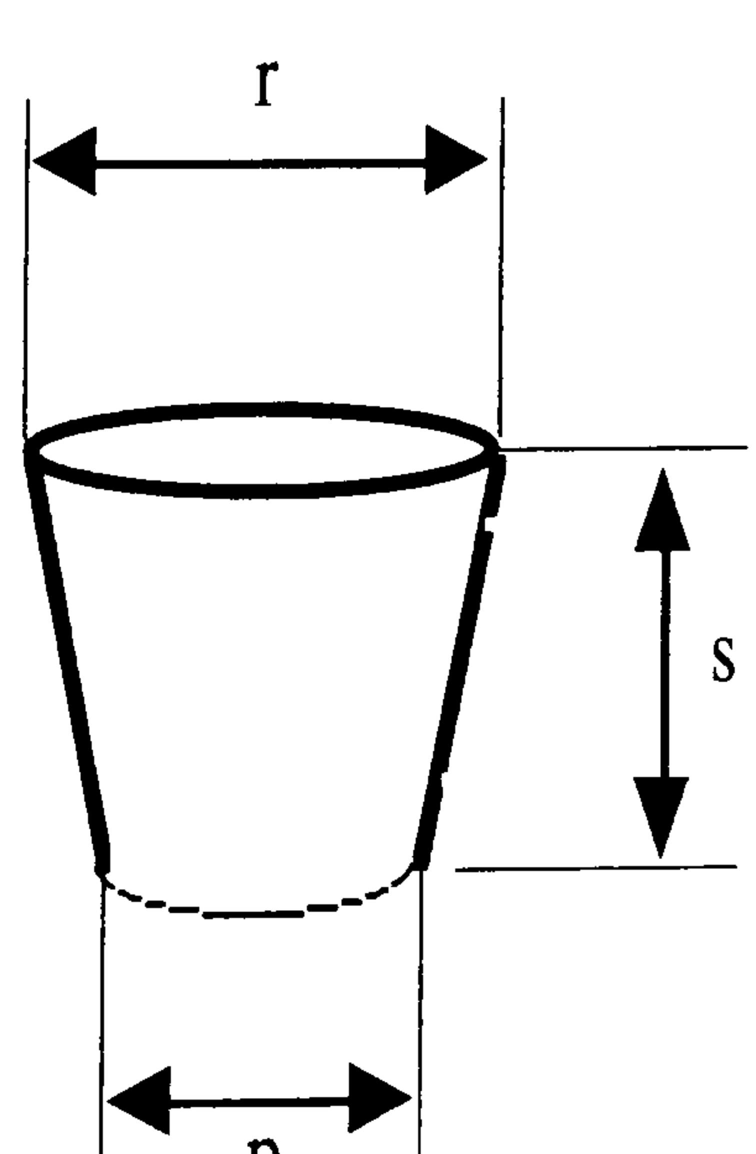


Figure 5.4.2c: SWIVEL 3D™ PROFESSIONAL Generated Model of Toothbrush in Mouth

5.4.3 Example 3: Visual Categorisation (Based on Athavankar 1989)

The previous two examples draw on physical rules underpinning the problem. This example draws on theories of cognitive psychology (Rosch 1976) and (Eysenck 1993). In this case the attribute is simply determining whether the form, represented in a sketch (Figure 5.4.3a), would be perceived as a cup or as a bowl within a particular cultural environment.



base diameter (p) = 100
lip diameter (r) = 140
height (s) = 110
all dimensions in millimetres

Figure 5.4.3a: Cup or Bowl ?

Attribute

shape $\in$ {cup,bowl,cup_or_bowl,neither}

Method of Observation

shape = "shape perceived by user"

Model

Based on (Athavankar 1989) and (Labov 1973).

if (base_diameter $\geq$ 40) **and** (base_diameter $\leq$ 90)
and (lip_diameter $\geq$ 50) **and** (lip_diameter $\leq$ 90)
and (height $\geq$ 60) **and** (height $\leq$ 110)
then shape = cup

else if (base_diameter $\geq$ 80) **and** (base_diameter $\leq$ 120)
and (lip_diameter $\geq$ 100) **and** (lip_diameter $\leq$ 200)
and (height $\geq$ 90) **and** (height $\leq$ 170)
then shape = bowl

else if (base_diameter $\geq$ 80) **and** (base_diameter $\leq$ 90)
and (lip_diameter > 90) **and** (lip_diameter < 100)
and (height $\geq$ 90) **and** (height $\leq$ 110)
then shape = cup_or_bowl
else shape = neither.

Characteristics

The product characteristics are the visual elements:

base_diameter,
lip_diameter,
height.

Note that whilst these appear to be geometric elements they are in fact perceived visual elements (Athavankar 1989). The process of extraction requires more than just examining the drawing. It requires an intuitive understanding of 'base_diameter', 'lip_diameter', and 'height'.

Attribute Evaluation

A = {<shape> | shape ∈ {cup,bowl,cup_or_bowl,neither} },

Oba = "shape perceived by user"

Ch = { **Ch** | **Ch** = <base_diameter, lip_diameter, height>, **Ch** ∈ $\Re 3$ },

ch = **Ext(F3)** = < base_diameter = 100, lip_diameter = 140, height = 110 >,

Mod(ch) =

if (base_diameter ≥ 100) **and** (base_diameter ≤ 100)

and (lip_diameter ≥ 140) **and** (lip_diameter ≤ 140)

and (height ≥ 110) **and** (height ≤ 110)

then shape = cup

else if (base_diameter ≥ 100) **and** (base_diameter ≤ 100)

and (lip_diameter ≥ 140) **and** (lip_diameter ≤ 140)

and (height ≥ 110) **and** (height ≤ 110)

then shape = bowl

else if (base_diameter ≥ 100) **and** (base_diameter ≤ 100)

and (lip_diameter > 140) **and** (lip_diameter < 140)

and (height ≥ 110) **and** (height ≤ 110)

then shape = cup_or_bowl

else shape = neither.

if (100 ≥ 40) **and** (100 ≤ 90)

and (140 ≥ 50) **and** (140 ≤ 90)

and (110 ≥ 60) **and** (110 ≤ 110)

then a = cup

else if $(100 \geq 80)$ **and** $(100 \leq 120)$

and $(140 \geq 100)$ **and** $(140 \leq 200)$

and $(110 \geq 90)$ **and** $(110 \leq 170)$

then **a** = bowl

else if $(100 \geq 80)$ **and** $(100 \leq 90)$

and $(140 > 90)$ **and** $(140 < 100)$

and $(110 \geq 90)$ **and** $(110 \leq 110)$

then a = cup_or_bowl.

else **a** = neither.

a = bowl.

5.4.4 Critique of Worked Examples

The three previous examples illustrate the method of assessment. They show the organisation of information embedded within the assessment procedure. The procedure contains the following elements:

Association between user and designer views

An attribute is a formalisation or rationalisation of the intuitive judgment that would be made by the designer, or in other words the designer's "feel" for the problem, based on the requirements of the user. However, disagreement and misunderstanding can, and does, arise between the designer and the user (of the product, system, etc.). Cross (1994), states that this is because the designer and the user focus on different aspects of the products requirements. The user generally focuses attention on the attributes of the product and states his or her requirements in natural terms, for example "easy to clean". The designer, however, concentrates more on the products characteristics, which seek to establish the product attributes, which in turn attempt to satisfy the users' requirements. This approach addresses the problem by formally linking the physical characteristics of the product to a clear statement of the user requirements. For example in the case of the toothbrush the attribute and its observation,

reaches_all_teeth = "filament ends contact with every tooth surface in the mouth",

clearly reflect the user requirement whilst the model links the relevant characteristics of spatial occupancy, which are under the control of the designer, to it.

Attribute Selection

It is questionable whether a complete list of requirements (attributes) can be defined for a product at the start of the design process. Many requirements of products become apparent only through the actual process of assessing design proposals.

Model

Whilst the problem of attribute selection is in determining an adequate, even if incomplete, set of attributes, the potential difficulty in the model is in accurately simulating those attributes that are defined.

Information Structuring

Construction of the model draws on information which could be categorised as accepted[5] theories[6] and associated data which is not available from the representation of form. For example the cantilever desk draws on laws of solid mechanics and data on the material it is constructed from, the toothbrush draws on laws of spatial occupancy and physiological data of the mouth, and the cup or bowl example on theories of cognitive psychology. In each case the model is the central element that draws together all the information required and makes apparent the basis of the design decision and the data used. However, whilst the computation is apparent, the rationale for the models formulation is not and a further explain facility would be required. Information is automatically structured according to how it is used.

Integration with other CAD systems

Firstly, the extraction of many product characteristics is an automated feature in most CAD systems, for example extraction of the second moment of area I in the desk example is available within the most elementary drafting system, e.g. AUTOCAD™, RASNA MECHANICA®.
In an integrated computer based system implementation of many extraction operations would simply be a matter of data exchange protocols.
Secondly, the use of the SWIVEL 3D™ PROFESSIONAL package in the toothbrush example

[5] By accepted it is meant accepted by the designer, i.e. the designer believes them to be true.

[6] By theory it is meant any law, rule, hypothesis, or general statement about physical, biological, psychological, or social experiences.

indicates how existing computer based analysis and simulation software could be integrated by its use in evaluating the model operator **Mod**.

Automated and Guided Evaluation

In the first two examples the attribute evaluation could be automated once defined, however in the cup or bowl example it is more likely that the designer would have to be interactively guided through the evaluation since he or she needs to make decisions based on their cognitive recognition. It seems likely that evaluation of subjective attributes rather than being a computable function would be an interactive guided evaluation.

Attribute Type

The assessment of two of the three attributes in the previous examples was to predict whether the forms proposed would be suitable, for example in the first case the prediction was would the cantilever desk be 'sufficiently_rigid' and in the second case, would the toothbrush 'reach_all_teeth'. The assessment of these two examples was either true or false, in other words Boolean. However, it would be more useful to facilitate the designer with a numerical result that rates or scores the attributes. This would then assist the designer to address the specific characteristics that failed.

Chapter 6.0.0
Computer Aided Evaluation of Product Performance Assessment

6.0.0 Computer Aided Evaluation of Product Performance Assessment

Design as a creative activity has been practised since the beginning of our civilisation. The belief that necessity drives on inventive effort is one that has been constantly invoked to account for the greatest part of technological activity. Humans have a need for water, so they dig wells, dam rivers and streams, and develop hydraulic technology. They need shelter and defence, so they build houses, forts, cities, and military machines. They need food, so they domesticate plants and animals. They need to move through the environment with ease, so they invent ships, chariots, carts, carriages, bicycles, automobiles, aeroplanes, and spacecraft. In each of these examples humans use technology to satisfy a pressing and immediate need (Basalla, 1988).

Generally, it has been expected, that some particularly talented group of people were able to make substantial achievements, and these achievements were then recognised as adding to the overall well being or welfare of man. Design as a process thus requires two fundamental elements, firstly a creative act followed by an acceptance that the results of the design process are in some way useful.

Design is an ill-structured activity; that is, it lacks a well defined objective. Although certain aspects of the objective may be known (through a design specification or through market research) there is no unique solution. Different designers will create different solutions, each with certain strong points and certain weaknesses, but all meeting the design specifications. The process of design involves iterative decision-making. The solution to a design problem involves making and implementing several decisions, both large and small decisions; important and trivial decisions, throughout the process of design. Dixon and Simmons (1983), class these decisions into the following categories:

(1) Technical decisions. These decisions are made in order to select materials, determine dimensions, specify components, manufacturing methods and so on.

(2) Planning or Process decisions. These decisions do not affect the technical design directly, but they do have an indirect bearing on the control of the quality and order of the technical design questions.

Dixon and Simmons (1983), go on to indicate that it is not uncommon for designers to make design decisions based on their own experiences, preferences, intuition, knowledge and common sense, and that these decisions must also be accounted for during the design process.

As has been stated earlier in Chapter 3.0.0, during the last 30 to 40 years there have been trends towards developing more logical and systematic methods of design, no doubt with the specific intention to either be more successful in accomplishing design tasks or in tackling design problems which have yet to have well defined solutions.

Nowadays design problems are reaching increasing levels of complexity (Alexander 1964 : 3). Alexander indicates that there is a growing body of information and specialist experience to match the ever increasing complexity of design problems. The designer initially requires information to understand the problem and propose feasible solutions to the problem. Later in the design process this information is used for testing candidate solutions. It is likely in the future that all information will be based on some form of digital media and use of it will be by making connections to it rather than by retrieval and duplication. The continuing growth of knowledge, expansion of technologies and ever increasing complexity of design problems has led to increasing specialisation. Alexander states:

"This information is hard to handle; it is widespread, diffuse, unorganised. Moreover, not only is the quantity of information itself by now beyond the reach of single designers, but the various specialists who retail it are narrow and unfamiliar with the form-makers' peculiar problems, so that it is never clear quite how the designer should best consult them." Alexander (1964 : 3-4)

In effect Alexander was asking for some sort of computer aided support. The advent of computers has accelerated this interest immensely. The 1950's brought a flurry of activity in the field of design methods. Jones (1984), suggests that these methods are basically intended to have two effects:

(1) To reduce the amount of design error, redesign and delay.

(2) To make possible more imaginative and advanced designs.

Digitally stored information was categorised in the previous chapter as data or accepted theories, (e.g. laws, rules, hypotheses, etc.) usually embodied in formulae or analysis packages such as RASNA MECHANICA®, SWIVEL 3D™ PROFESSIONAL, etc. Within the assessment methodology described here the relevant information is embedded within the model (**Mod**). The model defines what and how information is used. Computerisation of the assessment methodology provides both the computational facility and the opportunity to link to digitally based information of all types.

6.0.1 Application of Computers in Design

A wide range of computing techniques and packages have been applied in design. Generally speaking, one is now aware of terms such as AI (Artificial Intelligence), expert systems and knowledge-based systems. Essentially these developments have come from the recognition that certain aspects of design practice may be more difficult to understand than was previously thought. Furthermore, it is also now commonly accepted that some synergy between designers and computers may be able to encourage and provide an effective compliment to the skills of both man and machine. In this way it may be possible to make steps forward in improving the nature of certain design tasks.

Innumerable examples of expert systems have been created to assist in several areas of product design that exist today. The approach taken is generally that of retaining and exploiting the strengths of the human design expert whilst providing computer-based tools and techniques to overcome their weaknesses. However, several authors including (Ulrich and Seering 1988), (Miles and Moore 1989), and (Hollins and Pugh 1990), have focused on the fact that there is a clear shortage of research activity into the early stages of product design, for example the concept stage. Part of the reason for this may be because much of conceptual design is generally subjective in nature, which relies to a great deal on the knowledge, intuition and experience of the individual and therefore does not readily lend itself to formal expression. A very brief selection of some examples of expert system tools and computer systems developed to provide support to designers throughout various stages of the design process is given below:

Specific Domains

Several applications of AI techniques and knowledge based expert systems in design are to be found in narrow domains, such as:

(i) Hugh and Kim (1991), developed an interactive knowledge based system (RIBBER) for generating features of injection-moulded plastic parts. RIBBER contains heuristic knowledge of ribs, bosses, part mouldability and causal effects on the material properties of the part. This knowledge is encoded as production rules in the knowledge base.

(ii) Arafat et al (1991), present RAMZES, a computer system that can be used as a decision support tool for concept evaluation of steel roof truss designs for industrial buildings. The knowledge base for the roof trusses consists of two parts:

(a) A complete system of evaluation criteria and properties describing the roof trusses.

(b) The possible ranges of the evaluation properties.

(iii) Olivero et al (1993), describe the development of DXPERT, an expert system to assist analytical chemists in the selection of experimental chemical system designs involved in research projects. DXPERT utilises mathematical properties, including fuzzy logic and information theory, into empirical formulas in an attempt to emulate human intuition.

Concept Design

The design of any product, system or structure usually commences with the concept design stage. Many of the major decisions within the design process are made at this stage, for example the overall form of the product.

(i) In Miles and Moore (1989), the implementation of a PROLOG based system to assist in the conceptual design of bridges is outlined. The work focused on the conceptual nature of bridge design dealing with subjective properties, such as aesthetics, as opposed to detailed structural analysis and calculations. The system, written using LPA PROLOG, LPA FLEX, and DBASE III CLIPPER, features nearly 400 rules which refer directly to bridge design. The authors claim that the system has given 'the correct answer' 86% of the time on 50 real-life bridge design situations.

(ii) Bjerklie (1992), describes a computer based system developed by David Wallace and Mark Jakiela of the Mechanical Engineering Department, Massachusetts Institute of Technology. To use the system, designers specify the product components, for example in the case of portable audio radio-cassette players: the speakers, controls, and cassette-tape drive. The computer program organises the components into various arrangements, guided by principles of organisation, such as stability and aesthetic composition. Designers can then select the configuration they prefer and encase it in a box with a surface finish selected from the program's library. The system also adds further details such as buttons, graphics, and colour finishes that are in harmony with the overall style.

Embodiment Design

The embodiment stage plays a significant role in product design. All the components of the artifact are defined, with regard to both geometry and materials, during this stage.

(i) By applying artificial intelligence techniques to this stage of the design process, Bertini (1993) developed an expert system (EMBMEC). EMBMEC possesses a 'hybrid' structure, utilising both symbolic inference and numerical calculation techniques. The system contains a supervisor module, named General Design Manger (GDM), and three area modules for the solution of problems, namely the material selection module (MSM), the rod geometry design module (RGDM) and the hinged joint design module (HJDM). The system includes both 'heuristic' and 'analytical' knowledge and utilises simple shape libraries in order to define the geometry of the links.

Evaluation

(i) West and Randhawa (1988), present a framework for evaluating advanced manufacturing technologies. The authors suggest the problem of evaluating manufacturing systems is a multi-attribute decision problem. They indicate that the attributes may be classified into three categories:

(a) Production attributes, for example equipment accuracy, tooling compatibility, etc.

(b) Economic attributes, for example material savings, set-up time reductions, manufacturing efficiency, etc.

(c) Intangible attributes, for example the vendor's service reputation and service response, etc.

(ii) Rosenman (1990), based his work on the idea that certain areas of the building design process are knowledge-based rather than computation-based and as such the building design process lends itself to be encapsulated in an expert system. BUILD, an expert system shell written in QUINTUS PROLOG, has been developed to evaluate concept building design proposals against acceptable values represented in the form of rules.

Rosenman goes on to describe three examples of rule-based expert systems, all utilising BUILD, for design analysis and evaluation;

(i) PREDIKT- a system for the preliminary design of kitchens.

(ii) CODE- a system for compliance checking of building design codes.

(iii) SOLAREXPERT- a system for evaluating passive solar energy designs.

(iii) Dewhurst and Boothroyd (1986), report on a system which has been developed as a tool to assist product designers in the design of products which are to be assembled efficiently by robots. The system provides rapid evaluation of the manufacturing and assembly costs involved for any particular product, and identifies potential difficulties in the robot assembly. The procedure in the product or assembly analysis system is to estimate the assembly costs using the most appropriate robot assembly technique. Costing information stored in the software database permits these estimates to be made.

Features-Based Design Aids

In general CAD-CAM systems have been developed around various types of geometric modellers and their associated databases. The intention is that the models created by this approach will provide an automatic link between CAD and CAM (Lawlor-Wright and Hannam, 1989), such as:

(i) Luby et al (1986), outline the development of CASPER, a features-based design tool, that assists the process of evaluating the manufacturability of aluminium casting designs. CASPER develops castings with two types of features; macro-features and co-features. Macro-features are classes of geometric forms such as boxes, U-channels, L-brackets and so on. Co-features are attachments or details which can be added to macro-features, such as holes, bosses, and ribs. The authors claim that using CASPER will aid manufacturability evaluation, functional analysis, process selection, and possibly other computer-integrated-manufacturing (CIM) tasks.

(ii) Lawlor-Wright and Hannam (1989), describe the methodology developed and implemented through CADETS: a design for manufacture package which utilises features' terminology, such as 'blind clearance holes', 'open pockets', and 'T-slots'. The authors claim that CADETS will increase manufacturing integration through CIM, and consequently reduce manufacturing lead-times and costs.

The above selection reinforces the point made earlier that the majority of computer systems developed have been created to operate in very narrow domains, and tend to be aimed at the more objective or analytical side of product design.

The lack of a well-defined goal or exhaustive list of objectives is what distinguishes current product design practice fundamentally from the other problem domains to which AI techniques and expert systems have been most generally applied.

AI techniques and expert system tools are potentially a powerful, and perhaps even a revolutionary, instrument for improving the practice of product design. However, not all design problems are candidates for the development of expert systems. Developers and designers alike must, therefore, be able to use their discriminatory skills in deciding when to apply expert system technology instead of traditional methods. Perhaps one of the major benefits of marrying expert systems technology and product design practice will be a better understanding of the design process and the knowledge that is required within it.

6.1.0 *FLEX* - An Expert System Toolkit

It is clear from the previous examples in Section 5.4.1, (cantilever desk, toothbrush, cup or bowl), that the comparison of a series of products with a range of attributes requires substantial computation which would not be feasible manually. A computerised system is clearly necessary. From the conclusions drawn from these examples the system must give the opportunity for embodying a wide range of knowledge and information, both procedural and rule-based, which is both available and clear to the designer. The system selected which best satisfied these needs was *LPA FLEX*[7].

A computer implementation of the assessment method has been written in *FLEX* - an expert system toolkit that offers frame based, data driven and rule based functionality fully integrated into a PROLOG environment. *FLEX* has an English-like Knowledge Specification Language (KSL) that is both easy to program and easy to read. KSL is used for defining rules, frames, relations, instances, groups and procedures. The higher level KSL sentences are then compiled into PROLOG, by the incremental *FLEX* compiler. *FLEX* offers the possibility to write simple and concise statements about the experts' world, and can be understood and maintained by non-programmers. Because knowledge is expressed in a natural way, KSL knowledge bases are virtually self documenting. *FLEX* has been used in numerous exercises to help solve very diverse problems, such as: a Practitioner's Awards System to help calculate retirement pension for some 18,000 medical and 16,000 dental practitioners, a VAT adviser system for accountants, and a bridge design system (Murphy 1993).

6.1.1 *FLEX* Implementation of the Evaluation Procedure

The computerisation of the assessment methodology (Figure 6.1.1a) requires implementation of the same operators used in the manual examples previously (Section 5.3.0).

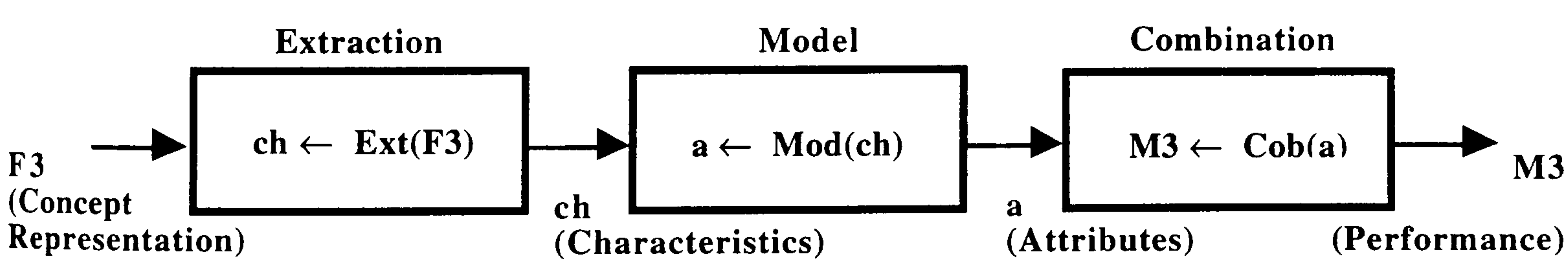


Figure 6.1.1a: CADET System Implementation Requirements of ***Com(C3,)•Obs3***

FLEX implementation of the previous defined operators, **Ext, Mod,** and **Cob** is required. The implementations are illustrated using the performance of an actual product, i.e. a toothbrush, as an example.

In this example the attributes of the toothbrush and their methods of observation are:

[7] *FLEX*™ Expert System Toolkit Version 1.05 Logic Programming Associates Ltd., 1994

A1 : long_lasting $\in$ {0..100}

Oba1 : long_lasting = "percentage of wear after three months use"

A2 : comfortable_to_hold $\in$ {0..100}

Oba2 : comfortable_to_hold = "degree of comfortable to hold whilst brushing teeth"

A3 : removes_plaque_efficiently $\in$ {0..100}

Oba3 : removes_plaque_efficiently = "percentage of plaque removed each brushing"

A4 : does_not_irritate_gums $\in$ {0..100}

Oba4 : does_not_irritate_gums = "degree of gum bleeding and oral irritation"

A5 : reaches_all_teeth $\in$ {0..100}

Oba5 : reaches_all_teeth = "percentage of surface area of teeth reached by filament ends of toothbrush"

A6 : looks_attractive $\in$ {0..100}

Oba6 : looks_attractive = "degree of attractiveness within a bathroom environment"

The attribute set for this problem is:

A = A1 X A2 X A3 X A4 X A5 X A6,

a $\in$ **A** = < long_lasting, comfortable_to_hold, removes_plaque_efficiently, does_not_irritate_gums, reaches_all_teeth, looks_attractive >.

and the corresponding observation set,

{"percentage of wear after three months use", "degree of comfortable to hold whilst brushing teeth", "percentage of plaque removed each brushing", "degree of gum bleeding and oral irritation", "percentage of surface area of teeth reached by filament ends of toothbrush", "degree of attractiveness within a bathroom environment"}.

The combination function in this case is a linear weighting of the attributes,

$$\textbf{Cob}\ (\mathbf{a}) = \sum_{1 \le i \le 6} w_i\, a_i$$

where w_i is the relative weighting of attributes a_i.

6.1.2 *FLEX* Implementation of Operator Cob

Operator **Cob** is implemented by the *FLEX* structure action. Within this structure each attribute is identified by a *FLEX* relation identifier of the same name (Figure 6.1.2a).

```
combination function

action combination_function(Name,Score);

do restart
and looks_attractive(Name,Score)
and reaches_all_teeth(Name,Score)
and comfortable_to_hold(Name,Score)
and does_not_irritate_gums(Name,Score)
and lasts_long(Name,Score)
and removes_plaque_efficiently(Name,Score)

and total_performance(Name,Score) =
looks_attractive(S1 * Weight) + reaches_all_teeth(S2 * Weight) +
comfortable_to_hold(S3 * Weight) + does_not_irritate_gums(S4 * Weight) +
lasts_long(S5 * Weight) + removes_plaque_efficiently(S6 * Weight) / 6 * (100).
```

Figure 6.1.2a: Combination Function

6.1.3 *FLEX* Implementation of Operator Mod

The model for each of the attributes in the combination function is coded as a relation in *FLEX* based on knowledge extracted from experts (Appendix III), and from relevant literature (Tsujita et al 1988), (Silverstone and Featherstone 1988), (Walsh and Lamb 1992/93), (Rawls et al 1989), (Davies et al 1988), (Rawls et al 1990), (Silverstone and Featherstone 1988), (Golding 1982), (Chong and Beech 1983), (Delaunay 1982).

For example the model for the attribute 'does_not_irritate_gums' is a model of the observation "doesn't make gums bleed or cause sore gums" and is shown below (Figure 6.1.3a).

```
does not irritate gums

/* DOES NOT IRRITATE GUMS CODE */

relation does_not_irritate_gums(Name,Score)

 if Name is an instance of toothbrush

if the head_length of Name is greater than 18 and the
head_length of Name is less than 31

if the head_width of Name is greater than 6 and the
head_width of Name is less than 13

if the filament_diameter of Name is greater than 0.15 and the
filament_diameter of Name is less than 0.31

if the filament_material of Name is some instance of
non_irritate_oral_material

if the toothbrush_material of Name is some instance of
non_irritate_oral_material

if the head_shape of Name is some instance of
non_irritate_head_shape

if the head_cross_section of Name is some instance of
non_irritate_section
```

Figure 6.1.3a: 'does_not_irritate_gums' Model

The model consists of a collection of clauses based on either the product characteristics or sub-relations. For example, the first clause, 'if Name is an instance of toothbrush', ties the attribute to the class of product defined as toothbrushes. The second clause, 'if the head_length of Name is greater than 18 and the head_length of Name is less than 31', is directly based on the product characteristic 'head_length' and reflects expert opinion (Chong and Beech 1983). The fifth clause, 'if the filament_material of Name is some instance of {non_irritate_oral_material}', is based on the sub-relation '{non_irritate_oral_material}'. This sub-relation is intended to be applicable to any item which is placed in the mouth and forms part of a library of similar sub-relations. This is implemented in *FLEX* by the following code shown below (Figure 6.1.3b).

Sub-Relations

```
/* SUB-RELATION LIBRARY */

relation non_irritate_oral_material (Material)

if Material is an instance of plastic
and
the density of Material is greater than 1.0 and the density of
Material is less than 5.0
and
the water_absorption of Material is less than 4.0
and
the tensile_strength of Material is greater than 65 and the
tensile_strength of Material is less than 80
and
the impact_strength of Material is greater than 100 or some
instance of no_break
and
the melting_temperature of Material is greater than 200
and
the Material is some instance of non_toxic.
```

Figure 6.1.3b: CADET System Library of Sub-Relations

Each attribute has a similar model and their combination is the *FLEX* implementation of the operator **Mod**.

6.1.4 *FLEX* Implementation of Operator Ext

Each of the attribute models defines the characteristics necessary for its computation. The list of characteristics required are shown below (Figure 6.1.4a).

Product Characteristics \ Attributes, in users' terms	LONG LASTING	COMFORTABLE TO HOLD	REMOVES PLAQUE EFFICIENTLY	DOES NOT IRRITATE GUMS	REACHES ALL TEETH	LOOKS ATTRACTIVE
Handle Length		X				
Toothbrush Length		X			X	
Head Length				X	X	
Filament Length	X		X		X	
Filament Diameter	X		X	X		
Handle Width		X				
Head Width				X		
Handle Thickness		X				
Head Thickness						
Number of Filaments in One Tuft (Packing Density)	X					
Number of Tufts in Head						
Filament Material	X		X	X		
Toothbrush Material	X			X		X
Head Shape				X	X	X
Handle Shape		X	X			X
Filament-End Shape	X					
Handle Cross-Section		X				X
Head Cross-Section				X		X
Tuft Arrangement			X			
Toothbrush Colour(s)						X
Filament Colour(s)						X
Toothbrush Finish		X				
Angle between Toothbrush Head & Handle			X		X	

Figure 6.1.4a: Selection of Attributes with Product Characteristics Required to Construct each Model

The above figure has clear similarities with a QFD matrix. In principle the relative importance of each characteristic to an attribute could be derived from its model using its partial derivatives with respect to each characteristic (Patterson 1993). Notice that certain product characteristics such as 'filament_diameter', 'handle_cross_section' and 'head_shape' occur in more than one attribute model. The system automatically indicates the most significant characteristics to the designer.

In the current implementation of the CADET system the process of extraction is manual. The designer must inspect what ever concept representation s/he is assessing in response to system prompts. In principle however if the system was linked to a CAD system then the type of feature extraction facilities available on some systems could be exploited either to automatically extract the characteristics or at least provide user friendly interactive methods, analogous to the systems described by (Tovey 1994) and (Buck 1992/93).

6.2.0 Example of the CADET System in Use

The CADET system may be used for either a total evaluation or for individual attribute evaluations.
Each attribute can now be computed by selecting it from the pull down menu (Figure 6.2.0a).

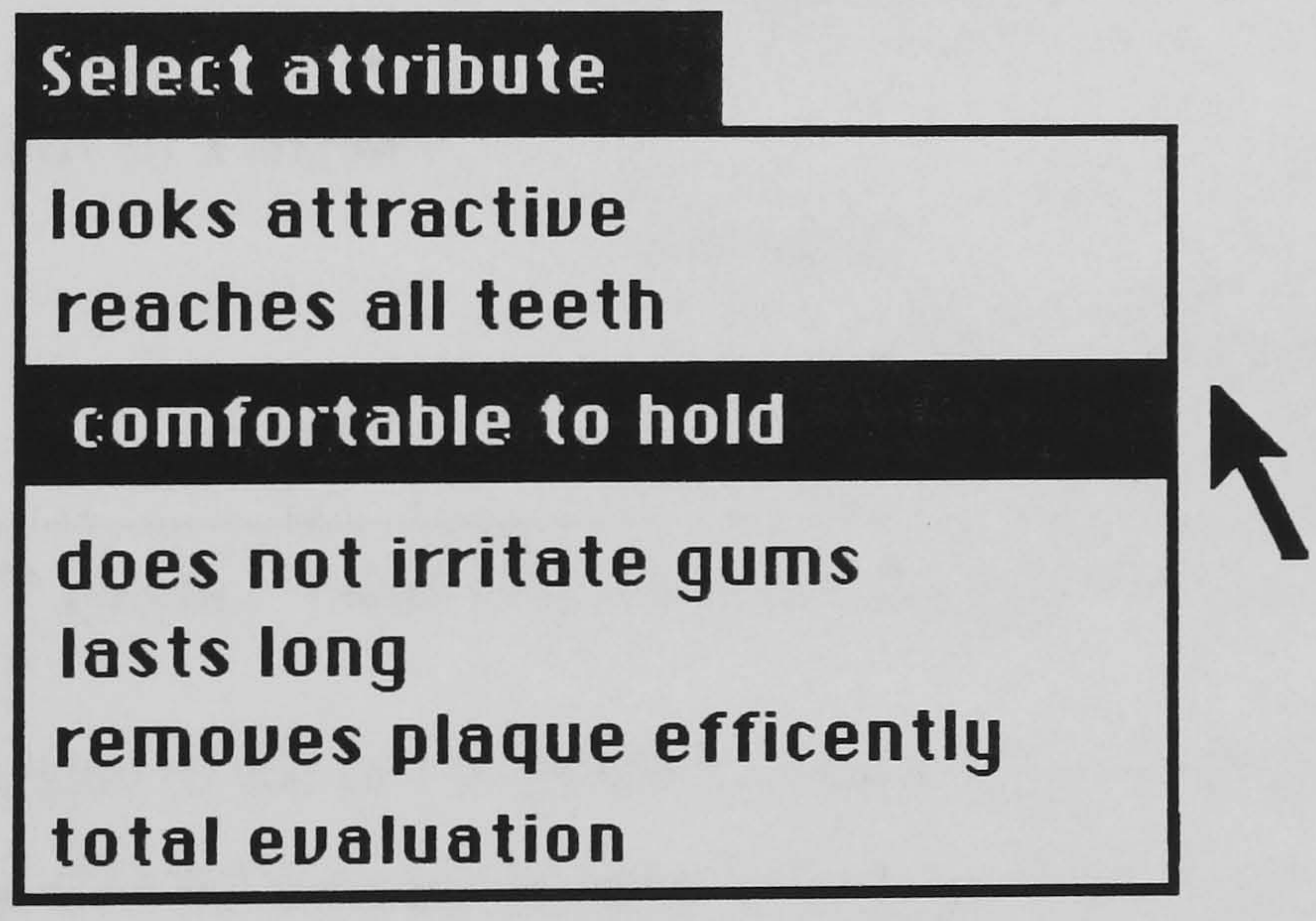


Figure 6.2.0a: Attribute Selection Menu

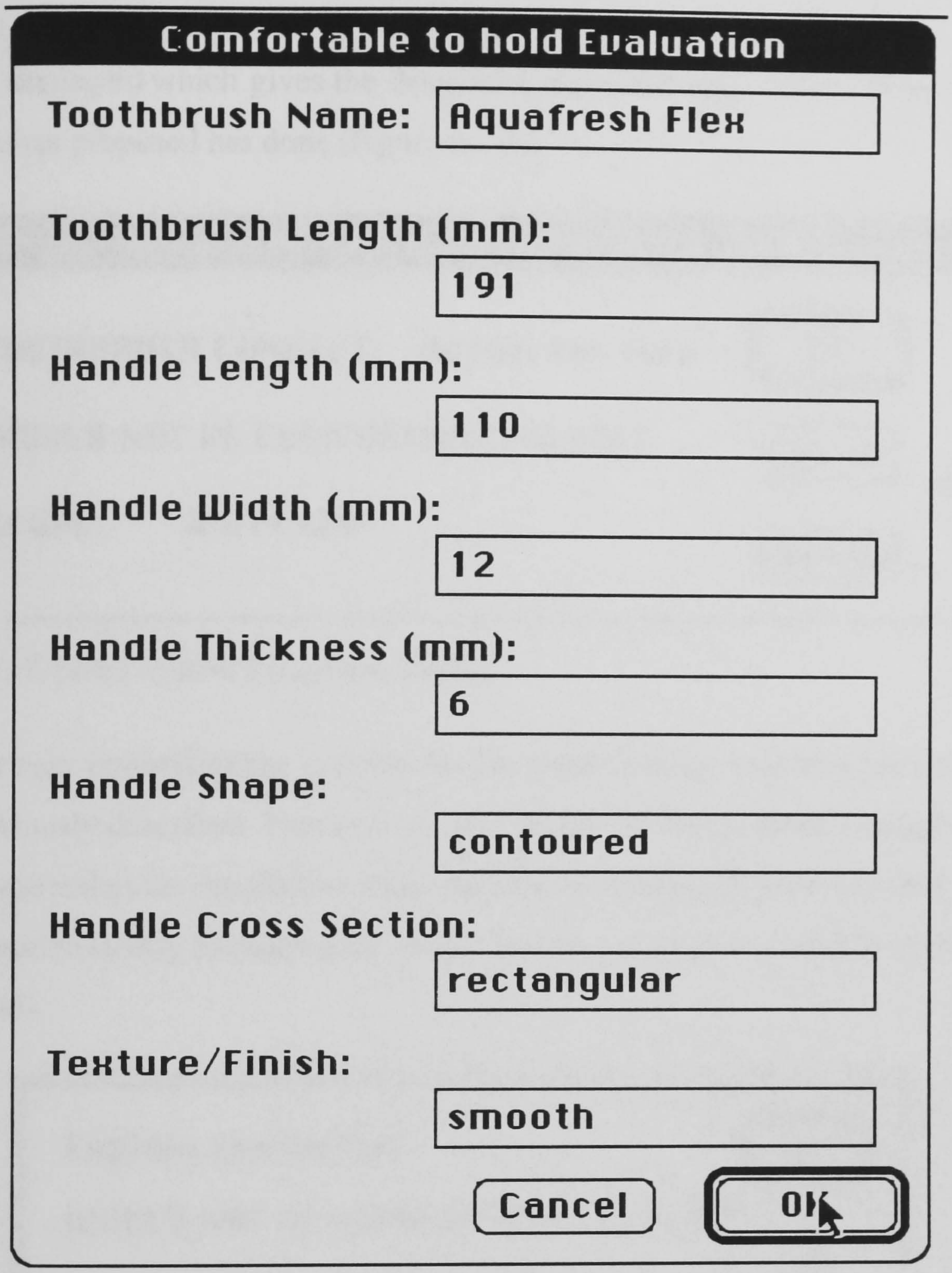


Figure 6.2.0b: CADET System Product Characteristics Extraction Dialog

The designer is requested to fill in the product characteristics describing his or her concept design proposal at the CADET System dialog box prompt (Figure 6.2.0b), in this case actual characteristics of the toothbrush concept design proposed, for example 'toothbrush_length', 'handle_thickness', 'handle_cross_section', etc.

Notice that the CADET system obliges the designer to have defined sufficient detail for the concept to be evaluated. Having entered the product characteristic data into the system the designer can then quickly evaluate the potential for success of his or her concept design proposal.

The result is displayed which gives the designer a numerical indication of how well or how badly the concept proposed has done (Figure 6.2.0c).

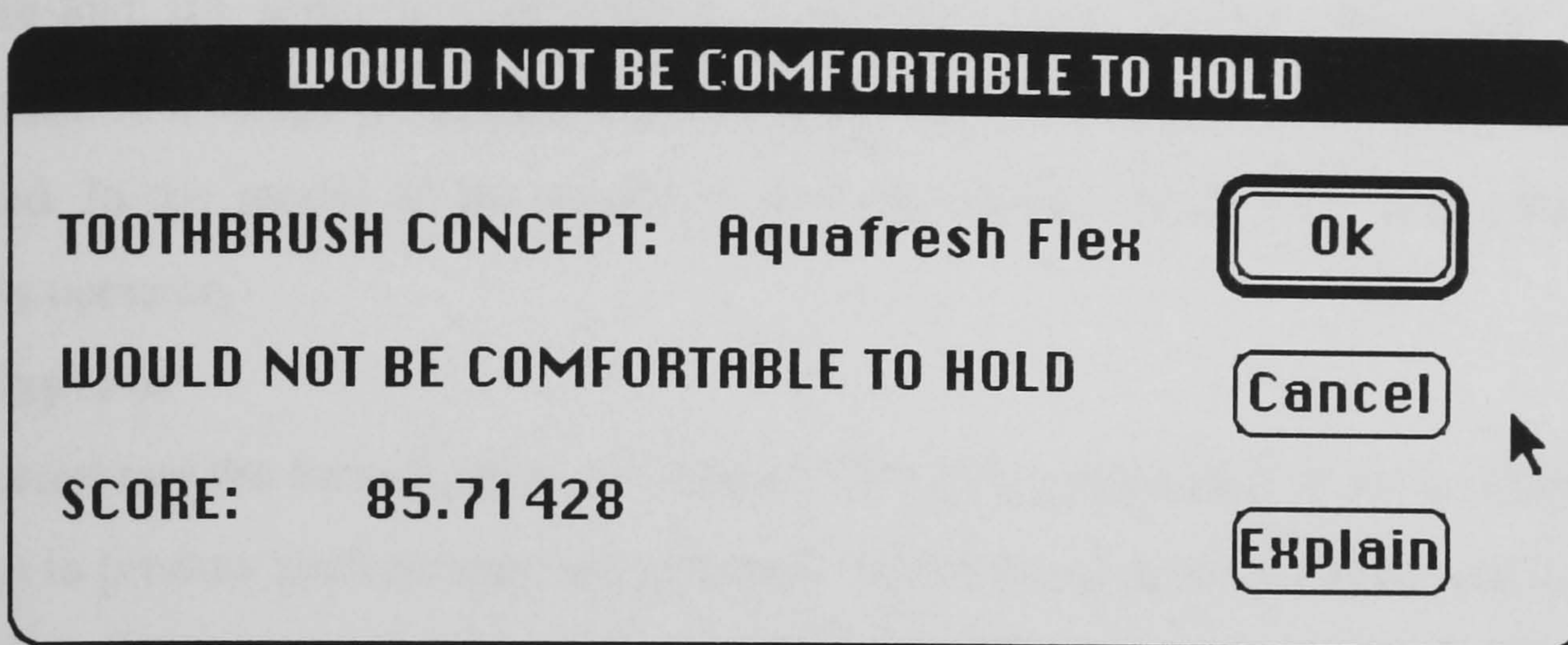


Figure 6.2.0c: CADET System Evaluation Dialog

The designer may investigate the reasons for the evaluation by referring back to the *FLEX* relations previously described. However as was found in the previous examples whilst the *FLEX* language makes the calculations clear the underlying rational is not apparent. To achieve this an explanation facility containing the expert knowledge used is available for each attribute (Figure 6.2.0d).

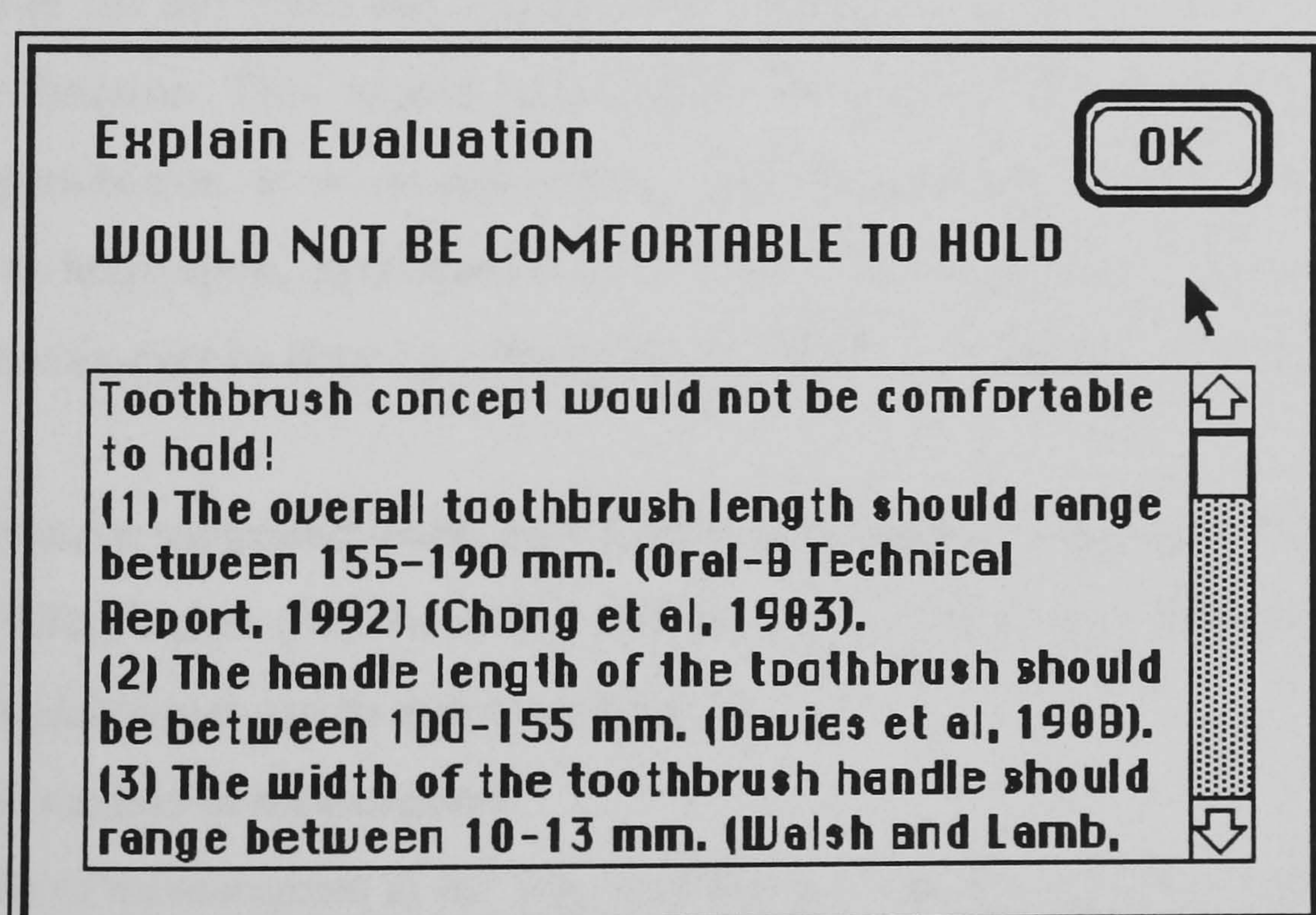


Figure 6.2.0d: CADET System Explanation Facility

6.3.0 Problem Definition in Product Performance Assessment

The previous chapter and the previous section described the product performance assessment procedure and its implementation in a computer based system. However, before the performance of a range of products or concepts can be evaluated, the problem has to be formalised. In the model of the design process described earlier, this was defined by the composite operator,

Exp•For

which determined the formalisation of context **C3** is the combination function **Cob**. Thus the first stage in product performance assessment is the rationalisation of performance. However, before this can be done the scales of measurement for individual attributes has to be determined.

6.3.1 Measurement Scales

The CADET system as currently implemented confuses the absolute observation of an attribute with its relative value to the user, for example the attribute 'reaches_all_teeth' could be measured in the percentage of tooth surface reached. It may be better to use absolute observations of the attributes and confine considerations of relative value to the user to the combination function. This would help clarify the choices usually left to the designer's intuition, experience or, at worst guesswork. The choices can now be based on some more rational, or at least open, procedure (Cross 1994). However, the measurement of design proposals can only ever be done by considering the list of criteria the proposal must fulfil.

Many authors have suggested techniques for the measurement of design solutions, including DeMarle (1972), Archer (1974), Jones (1980), Lera (1981), Lawson (1990), and Cross (1994). These techniques can be summarised as:

(1) Ratio scale method of measurement

The ratio scale of measurement is the way numbers are usually organised along a scale where four represents twice two, nine represents five added to four, and so on.

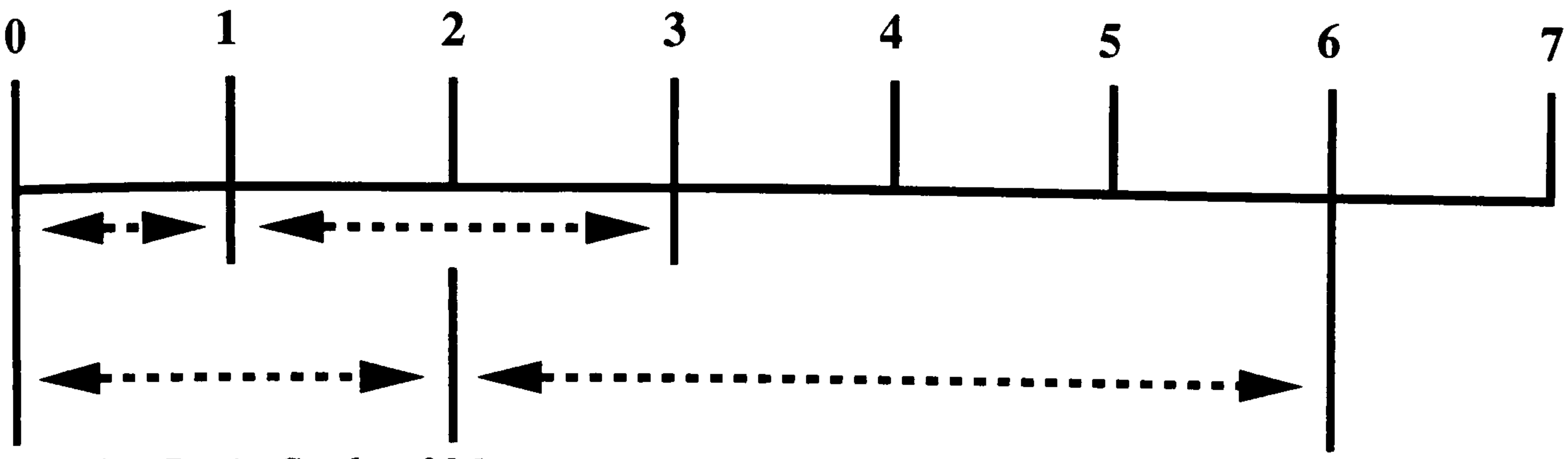


Figure 6.3.1a: Ratio Scale of Measurement (Ratios are equal e.g. 3:1 = 6:2, for instance inches or millimetres)

Measurement on a ratio scale demands five tests: membership of the set; individuality of the individual elements in the set; order between elements; equality of intervals and equality of the ratio of intervals. Almost all mathematical and statistical operations can be carried out on the data expressed by ratio scales (Archer 1974).

(2) Interval scale method of measurement

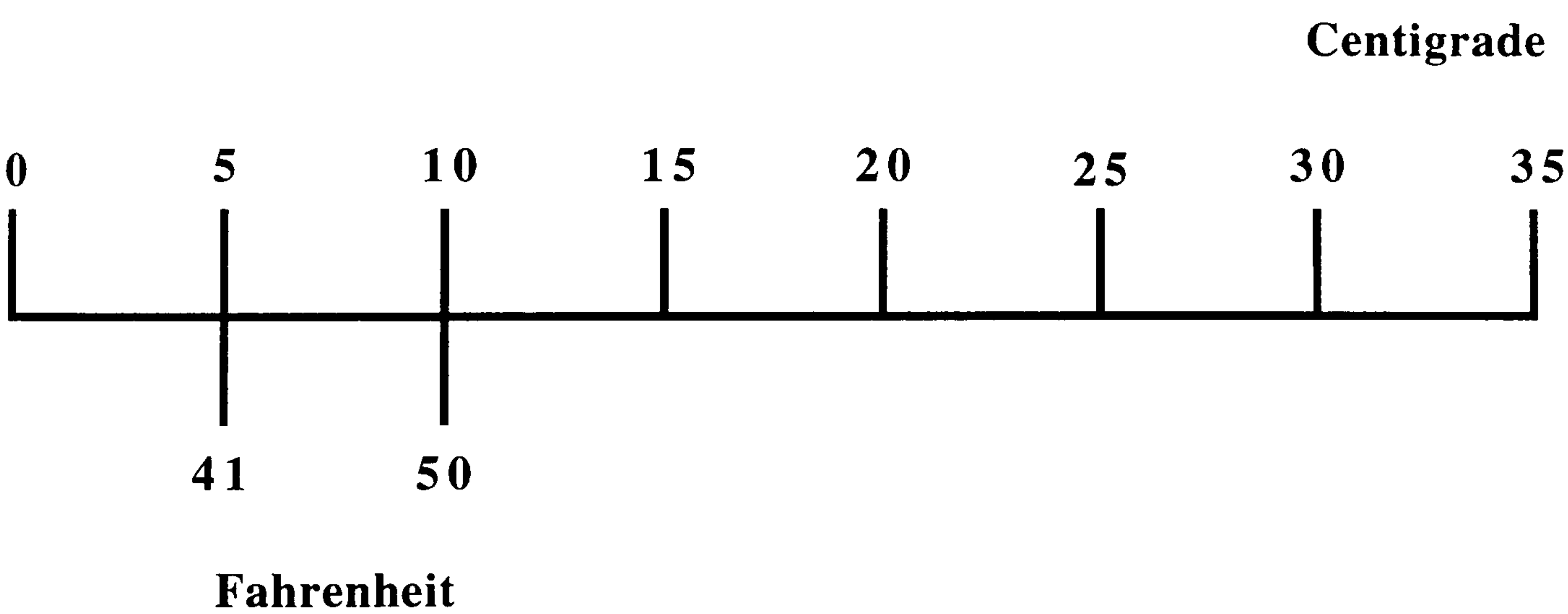


Figure 6.3.1b: The Interval Scale of Measurement. Temperature is not measured on a ratio scale since the ratios of two temperatures are different in Centigrade and Fahrenheit (e.g. 50:41 = 1.2)

Interval scales are quantitative scales. A good example of the interval scale is the centigrade scale where there exists one hundred equal intervals between the freezing point and boiling point temperatures of water. Although 10°C cannot be described as twice as hot as 5°C the difference, or interval between 0°C and 5°C is exactly equal to the interval between 5°C and 10°C. Interval scales are frequently used for subjective assessment.

(3) Ordinal scale method of measurement

Figure 6.3.1c: The Ordinal Scale of Measurement. (e.g. military ranking system)

A more cautious scale of measurement where the interval is not considered to be reliably consistent is called the ordinal scale. An example of an ordinal scale is the order of finishers in a race, i.e. first, second and third, however there is no indication of how large the gaps were in between.

(4) Nominal scale method of measurement

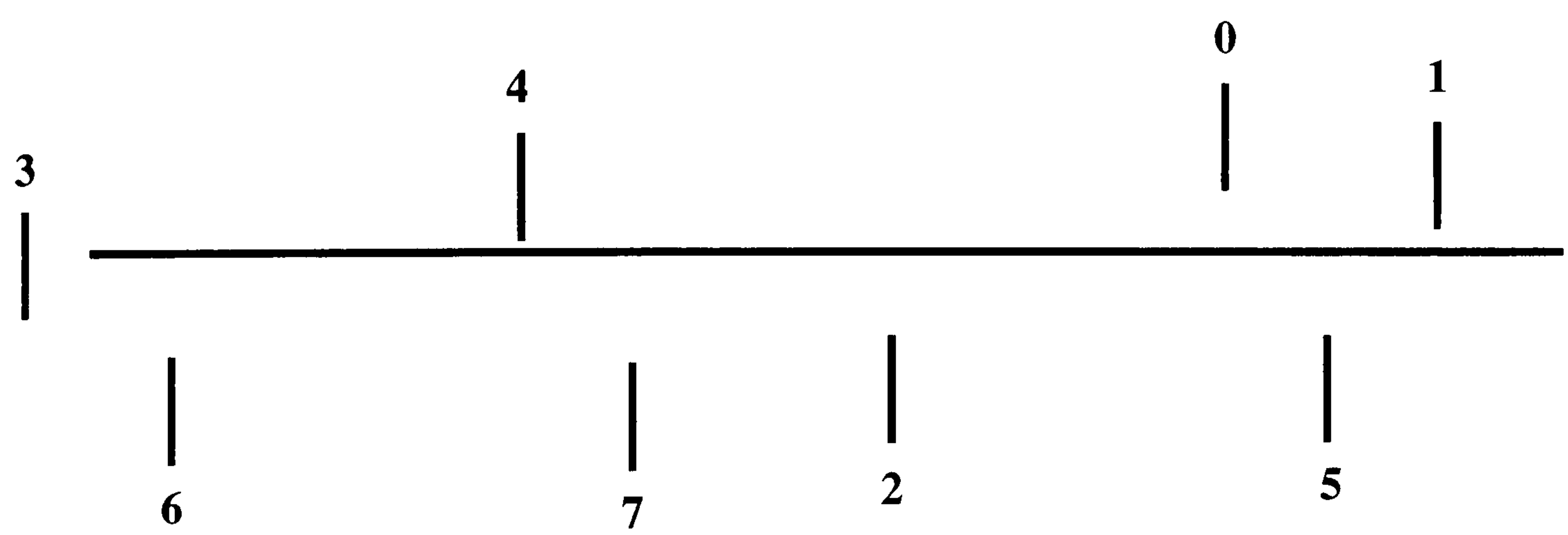


Figure 6.3.1d: The Nominal Scale of Measurement.

The least precise of these measurement systems is the nominal scale, so called because the numbers really represent names or sets, an example being the set of numbers on football players' shirts. One cannot add, subtract, multiply or divide the numbers on the football players' shirts. For example a forward player with a number nine shirt is not three times as good as a defender wearing a number three shirt. However, one can use the operations of set theory or Boolean algebra with perfect validity (Archer 1974).

Care must be taken when assigning numerical scales in design. The inappropriate use of a particular scale may lead to misleading results and, in turn, wrong decisions may be made based on false arithmetic conclusions. For this reason in particular the CADET system utilises an ordinal scale of measurement.

6.3.2 Rationalising Product Performance

The following methods of market testing are aimed at rationalising product performance, and at a better understanding of customer behaviour. Test marketing is perhaps the best-known step in new product development (Urban, Hauser and Dholakia, 1987). Test marketing is learning from the evaluation of *real* market response **C1** to *real* new products **F1** and their marketing programmes. At one extreme, the new product may be tested in a *real* market environment with a *real* marketing programme. At the other extreme, it may be tested in a simulated market environment with a hypothetical marketing programme. Test marketing can take a variety of forms, three popular types used in practice are *simulated*, *controlled*, and *conventional* test marketing (Thomas, 1993b).

Simulated Test Marketing

Simulated test marketing (STM) is a method that enables the measurement of market response to a product and its marketing plan among potential customers in a pseudo market environment. The method can be executed in a laboratory environment, in homes, offices, shopping centres, or in other places that lend themselves to simulating the purchasing process as accurately as possible (Sawyer et al, 1979), (Nevin, 1974).

Controlled Test Marketing

The real value of controlled test marketing is the ability to evaluate different marketing strategies in a market environment that is much closer to *real* market conditions than simulated test marketing.

Conventional Test Marketing

Conventional test marketing is useful for assessing response to the product from a broader set of participants, including competitors, the media, regulators, and others. The real benefits of conventional test marketing are the learning and subsequent modifications that aim to ensure a successful launch of the product - especially in new product situations where there is high investments involved, and high environmental and market uncertainties.

The very nature of test marketing is extremely expensive and time consuming and this has led to the introduction and implementation of 'pretesting' techniques and strategies (Urban, Hauser and Dholakia, 1987).

Pretest market techniques are not intended to replace a test market, but serve as a harbinger to a test market. The need for pretest-market research is especially evident in industries where test marketing is not possible, for example in automobile or industrial equipment design. Premarket information mat be the only information available to enhance product success and eliminate the risk of product failure.

There are many market research techniques that can be used to improve the collection of information about product user requirements and preferences. These procedures include 'product clinics' where users are asked what they prefer about particular products, and 'hall tests' where various competing products (e.g. washing machines, cars, etc.) are laid out on display in an appropriate environment or 'hall' and users are asked to examine the products and give their comments and reactions, for example what products they like, what products they dislike, and why (Cross, 1994). Generally, users talk about products in terms such as "I like the colour and shape of this product" and "I don't think this product is comfortable to hold", therefore the main aim for designers involved in 'hall tests' is to identify and capture accurately the users' preferences.

The procedure used here for assigning relative weightings for each product attribute within the combination function **Cob** were by using the results of a questionnaire survey carried out by the author, and by adopting the weighted objectives method described in Cross (1994). For example Figure 6.3.2a illustrates the use of the weighted objectives method for defining the relative weights of the toothbrush product attributes within the combination function (**Cob**).

	Looks Attractive	Reaches all Teeth	Doesn't Irritate Gums	Removes Plaque Efficiently	Comfortable to Hold	Long Lasting	Row Totals
Looks Attractive	X	0	0	0	0	0	0
Reaches all Teeth	1	X	0.5	0	1	1	3.5
Doesn't Irritate Gums	1	0.5	X	0	1	1	3.5
Removes Plaque Efficiently	1	1	1	X	1	1	5
Comfortable to Hold	1	0	0	0	X	0.5	1.5
Long Lasting	1	0	0	0	0.5	X	1.5

Figure 6.3.2a: Weighted Objectives Method: Combination Function (Cob) Construction

The relative weighted objectives method is carried out by comparing pairs of product attributes in turn one against the other. A figure 1 or 0 is entered into each matrix cell in the above figure, depending on whether the first characteristic is deemed more important (enter 1) or less important (enter 0) than the second attribute, then the next attribute, and so on. For example, in the above figure (6.3.2a) one starts by considering if "Looks Attractive" is more or less important than "Reaches All Teeth" (1 or 0), or if they are considered of equal importance (0.5). From the above figure one can observe that "Removes Plaque Efficiently" is deemed most important, followed by "Reaches All Teeth" and "Doesn't Irritate Gums" who are deemed to be of equal relative importance. When all the comparisons have been completed, the row totals give an indication of the rank ordering of the product characteristics. Thus one can see that the rank order for the above exercise would be:

(1) "Removes Plaque Efficiently"

(2) "Reaches All Teeth", "Doesn't Irritate Gums"

(3) "Comfortable To Hold", "Long Lasting"

(4) "looks Attractive"

The questionnaire survey breakdown of 70 subjects, carried out by the author, consisted of 39 female and 31 male participants, and the age breakdown scanned a wide cross-section, as indicated below:

Age 18 to 25 - 20 subjects

Age 25 to 35 - 10 subjects

Age 35 to 45 - 10 subjects

Age 45 to 55 - 11 subjects

Age 55 to 65 - 9 subjects

Age 65 and over - 10 subjects

Those questioned were asked to rate the importance of each attribute on a scale of 1 to 5 (5 - extremely important, 4 - above average importance, 3 - important, 2 - below average importance, and 1 - desirable). The results drawn from this exercise indicated 23% of those questioned thought "Removes Plaque Efficiently" most important, followed by "Doesn't Irritate Gums", 'Reaches All Teeth" and "Comfortable To Hold" all at 20%, and 8% stated "Long Lasting" and "Looks Attractive" to be least important. The weighted objectives method, executed as a team by members of the School of Electronic and Manufacturing Systems Engineering Design Group and illustrated in Figure 6.3.2a, painted a similar picture.

6.3.3 Model Construction

Not all physical situations can be modelled using procedural methods. Either the situation is too complex or the mathematical problems are intractable, even by numerical methods. In these cases alternative approaches such as empirical models[8] (Edwards and Hamson 1989) or rule-based models (Lees and Finch 1989-93) have to be used.

The models (**Mod**) used here are empirical linear multi-variable models. The relative weightings are based on expert knowledge and relevant literature. For example the construction

[8] An empirical model is one which is derived from and based entirely on data.

of the attribute model illustrated below was based on expert dental opinion (Appendix III), and published dental knowledge (Delaunay 1982), (Davies et al 1988).

	Filament Length	Filament Diameter	Filament Material	Handle Shape	Tuft Arrangement	Angle Between Head & Handle	Row Totals
Filament Length	X	0.5	1	1	1	1	4.5
Filament Diameter	0.5	X	1	1	1	1	4.5
Filament Material	0	0	X	0.5	1	0.5	2
Handle Shape	0	0	0.5	X	1	0.5	2
Tuft Arrangement	0	0	0	0	X	0	0
Angle Between Head & Handle	0	0	0.5	0.5	1	X	2

Figure 6.3.3a: Weighted Objectives Method: 'removes_plaque_efficiently' Attribute Model (Mod)

The prototype CADET system was tested against a selection of three very different consumer products generally available on the U.K. market. The three products tested were:

(1) Toothbrushes

(2) Cellular Mobile Telephones

(3) System and Disposable Shavers

A complete description (product characteristics) of each product tested within each of the three product categories can be found as follows:

Appendix V - (toothbrush characteristics),

Appendix VI - (mobile phone characteristics), and

Appendix VII - (shaver characteristics).

6.3.4 Example 1: Toothbrush Test Results

The toothbrushes involved in the test were as follows:

(1) Mentadent-P Ultra Professional

(2) Aquafresh Flex

(3) Wisdom Reflex

(4) Jordan 'Le-Brush'

(5) Oral-B Right Angle 'A-35'

(6) Search 3.5

(7) Dual-Texture

(8) Colgate Diamond Head

(9) Reach Anti-Plaque

Following the procedure of the assessment methodology, a selection of attributes, in users' terms, were defined as:

(1) a toothbrush should be "long lasting"

(2) a toothbrush should be "comfortable to hold"

(3) a toothbrush should "remove plaque efficiently"

(4) a toothbrush should "not irritate our gums"

(5) a toothbrush should "reach all teeth"

(6) a toothbrush should "look attractive"

The CADET system results for the assessment of the nine toothbrushes are illustrated in Figure 6.3.4a below.

	reaches all teeth	removes plaque efficiently	comfortable to hold	long lasting	looks attractive	doesn't irritate gums	Combined Total	Rank
Mentadent-P	73.3	84.2	86.4	100	100	100	88.7	7
Aquafresh Flex	46.6	89.5	77.3	100	100	74.1	78.1	9
Wisdom Reflex	100	84.2	100	100	100	100	96.1	2
Oral-B A-35	100	100	100	84.2	100	100	97.6	1
Search 3.5	100	100	86.4	84.2	81.8	100	94.6	3
Colgate Diamond	80	89.5	86.4	100	100	88.8	89.1	6
Reach Anti-Plaque	73.3	84.2	100	100	100	100	90.7	4
Addis Dual	80	100	86.4	84.2	81.8	70.4	84.7	8
Jordan Le-Brush	100	84.2	72.7	84.2	100	100	89.6	5

Figure 6.3.4a: Toothbrush Evaluation Results (CADET System)

The explanations of the CADET system toothbrush test results, based on published literature, for example (Tsujita et al 1988), (Silverstone and Featherstone 1988), (Rawls et al 1989), and expert knowledge (Appendix III) are described in Appendix II.

6.3.5 Example 2: Cellular Mobile Telephone Test Results

The five mobile telephones involved in the CADET test were as follows:

(1) NEC P-4

(2) NEC P-100

(3) ERICSSON Hotline GH-197

(4) SONY CM-H333

(5) MITSUBISHI MT-799

Following the procedure of the assessment methodology, a selection of attributes, in users' terms, were defined as:

(1) a mobile telephone should "not be too heavy"

(2) a mobile telephone should be "comfortable to hold"

(3) a mobile telephone should "fit in a pocket"

(4) a mobile telephone should "fit the face"

(5) a mobile telephone should be "easy to dial"

(6) a mobile telephone should "look attractive"

(7) a mobile telephone should be "operable with one hand"

As was the case in the toothbrush example mentioned previously, the relative weighting for each attribute within the combination function **Cob** were specified using the results of a questionnaire survey carried out by the author, and by adopting the weighted objectives method described earlier. Those questioned as part of the survey were again asked to rate the importance of each attribute on a scale of 1 to 5. The results of this exercise indicated that of the 70 subjects interviewed 27% thought "easy to dial/ use" most important, followed by "comfortable to hold" and "fits in pocket" at 21%, and 11% stated "looks attractive" and "not too heavy" to be least important. It should be noted however, that the attributes "fits face" and "operable with one hand" were omitted from the original questionnaire and therefore no conclusions can be drawn about the relative importance of these two attributes. The results of the weighted objectives method for the mobile telephone are shown in Figure 6.3.5a below.

	Fits in Pocket	Comfortable to Hold	Easy to Dial	Not too Heavy	Fits Face	Looks Attractive	Operable with one Hand	Row Totals
Fits in Pocket	X	0.5	0	0	0.5	1	1	3
Comfortable to Hold	0.5	X	0	0	0.5	1	1	3
Easy to Dial	1	1	X	1	1	1	1	6
Not too Heavy	1	1	0	X	1	1	1	5
Fits Face	0.5	0.5	0	0	X	1	1	3
Looks Attractive	0	0	0	0	0	X	0	0
Operable with one Hand	0	0	0	0	0	1	X	1

Figure 6.3.5a: Weighted Objectives Method: Mobile Phone Attributes Combination Function Cob

The results for the assessment of the five mobile telephones are illustrated in Figure 6.3.5b below.

	operable with one hand	*fits face*	*fits in pocket*	*not too heavy*	*comfortable to hold*	*easy to dial*	*looks attractive*	*Combined Total*	*Rank*
Mitsubishi MT-5	**90.9**	**100**	**100**	**100**	**100**	**51.8**	**100**	**87.7**	**3**
NEC P-100	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**1**
NEC P-4	**77.3**	**61.9**	**78.9**	**88.8**	**77.3**	**81.5**	**100**	**79.6**	**5**
Ericsson Hotline	**100**	**76.2**	**100**	**100**	**100**	**70.1**	**100**	**89.5**	**2**
SONY CM-H333	**81.8**	**85.7**	**100**	**83.3**	**86.4**	**81.5**	**91.3**	**86.3**	**4**

Figure 6.3.5b: Mobile Phone Evaluation Results (CADET System)

The explanations of the mobile telephone evaluations derived from the CADET system explanation facility are given in Appendix VIII.

6.3.6 Example 3: System and Disposable Shaver Test Results

The shavers involved in the CADET system test were grouped into two categories; disposable shavers and system shavers.

Disposable Shavers

(1) Gillette Blue

(2) Gillette Grey

(3) Wilkinson Red

(4) BIC Orange

(5) Wilkinson Green

System Shavers

(1) Gillette Contour

(2) Wilkinson Classic

(3) Gillette Lady Contour

(4) Wilkinson Swivel Profile

(5) Gillette Sensor

(6) Wilkinson Protector

Following the procedure of the assessment methodology, a selection of attributes, in users' terms, were defined as:

(1) a shaver should "not irritate skin"

(2) a shaver should be "comfortable to hold"

(3) a shaver should be "easy to clean"

(4) a shaver should "give a close shave"

(5) a shaver should "remove hair in difficult areas"

(6) a shaver should "look attractive"

(7) a shaver should "be hygienic"

(8) a shaver should "not cut or nick face"

The results for the assessment of the disposable shavers and system shavers are illustrated in

Figure 6.3.6a and Figure 6.3.6b respectively.

	looks attractive	gives a close shave	comfortable to hold	doesn't irritate skin	easy to clean	removes hair in difficult areas	doesn't cut or nick face	is hygienic	Combined Total	Rank
Gillette Blue	**100**	**100**	**82.6**	**100**	**90.9**	**91.6**	**100**	**100**	**96.7**	**2**
Gillette Grey	**85.7**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**99.4**	**1**
Wilkinson Red	**100**	**88.8**	**100**	**100**	**90.9**	**79.1**	**88.2**	**100**	**92.4**	**4**
BIC Orange	**85.7**	**88.8**	**82.6**	**100**	**81.8**	**66.6**	**100**	**100**	**89.9**	**5**
Wilkinson Green	**100**	**100**	**82.6**	**100**	**90.9**	**91.6**	**100**	**100**	**96.7**	**2**

Figure 6.3.6a: Disposable Shaver Evaluation Results (CADET System)

	looks attractive	gives a close shave	comfortable to hold	doesn't irritate skin	easy to clean	removes hair in difficult areas	doesn't cut or nick face	is hygienic	Combined Total	Rank
Gillette Contour	**100**	**88.8**	**100**	**100**	**100**	**83.3**	**100**	**100**	**95.6**	**5**
Wilkinson Classic	**100**	**88.8**	**100**	**100**	**81.8**	**58.3**	**100**	**100**	**90.9**	**6**
Gillette Lady	**85.7**	**100**	**86.9**	**100**	**100**	**100**	**100**	**100**	**98.3**	**4**
Wilkinson Swivel	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**1**
Gillette Sensor	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**1**
Wilkinson Protector	**100**	**100**	**86.9**	**100**	**100**	**100**	**100**	**100**	**98.9**	**3**

Figure 6.3.6b: System Shaver Evaluation Results (CADET System)

The CADET system explanation facility justifications of the disposable shavers and system shavers test results are given in Appendix IX.

6.4.0 CADET System Conformance Testing

To ensure that the *FLEX* relations were an accurate codification of the expert knowledge the results of individual assessments were directly compared with the expert knowledge used in the construction within each attribute model (Appendix II). All of the attribute failings of the conformance testing could be accounted for directly from the expert knowledge. This demonstrated that the attribute models encoded within *FLEX* were an accurate representation of the expert knowledge.

6.5.0 CADET System Performance Testing

The performance of the CADET system has been compared against actual product sales. Product sales are a significant measure of product performance for manufacturers (Duerr 1986) and (Cooper 1984). It is acknowledged that there are additional factors influencing product choice, not considered in the CADET assessment, such as advertising, price, promotions, distributions, availability, packaging, etc. However, Urban & Hauser (1993), have suggested that there is a strong correlation between product success and meeting user needs. Assuming this is the case then the CADET assessment is reasonably consistent with market share. Within a +/- 5% margin the CADET system comparison matches market share with one exception. For example the sales figures of toothbrushes involved in the CADET system test are shown in Table 6.5.0a below.

TOOTHBRUSH	MARKET SHARE[9]	CADET TOTAL (%)	RANK
Oral-B	26.1%	97.6%	1st
Reach	11.4%	90.7%	4th
Wisdom	10.6%	96.1%	2nd
Colgate	8.7%	89.1%	6th

[9] Source: Nielsen Combined Food & Pharmacy Outlets Data 1992

Search	6.9%	94.6%	3rd
Aquafresh	4.0%	78.1%	9th
Mentadent-P	3.2%	88.7%	7th
Jordan	N/A.	89.6%	5th
Addis	N/A.	84.7%	8th

Table 6.5.0a: Market Share of Toothbrushes

Verification of CADET tool Results

Testing of the CADET System indicates that certain designs achieved a higher rating than others. For example in the toothbrush test the Oral-B 'A-35', Wisdom Reflex, Search 3.5, and Reach Anti-Plaque toothbrushes accomplished a higher score than the rest of the toothbrushes tested (see Figure 6.3.1c). The results from the CADET System have been compared and contrasted against the results drawn from carrying out actual product attribute tests.

6.6.0 Actual Product Attribute Tests

The main objective of the actual product tests was to establish if the operator **Mod** is an accurate model of the observations it is intended to predict. The product test results and the model (**Mod**) results are compared in the following section.

6.6.1 Actual Toothbrush Tests

(i) **long_lasting** = "percentage of wear after three months use"
long_lasting **Mod** (see Appendix I)

Test:

In this test the actual observation **Oba** had to be simulated. In doing this each toothbrush is subjected to a test which simulates the brushing action of a typical toothbrush user over a period of approximately three months. The computer-controlled test rig, based on expert dental information (Walsh and Lamb 1993) is shown in Figure 6.6.1a below.

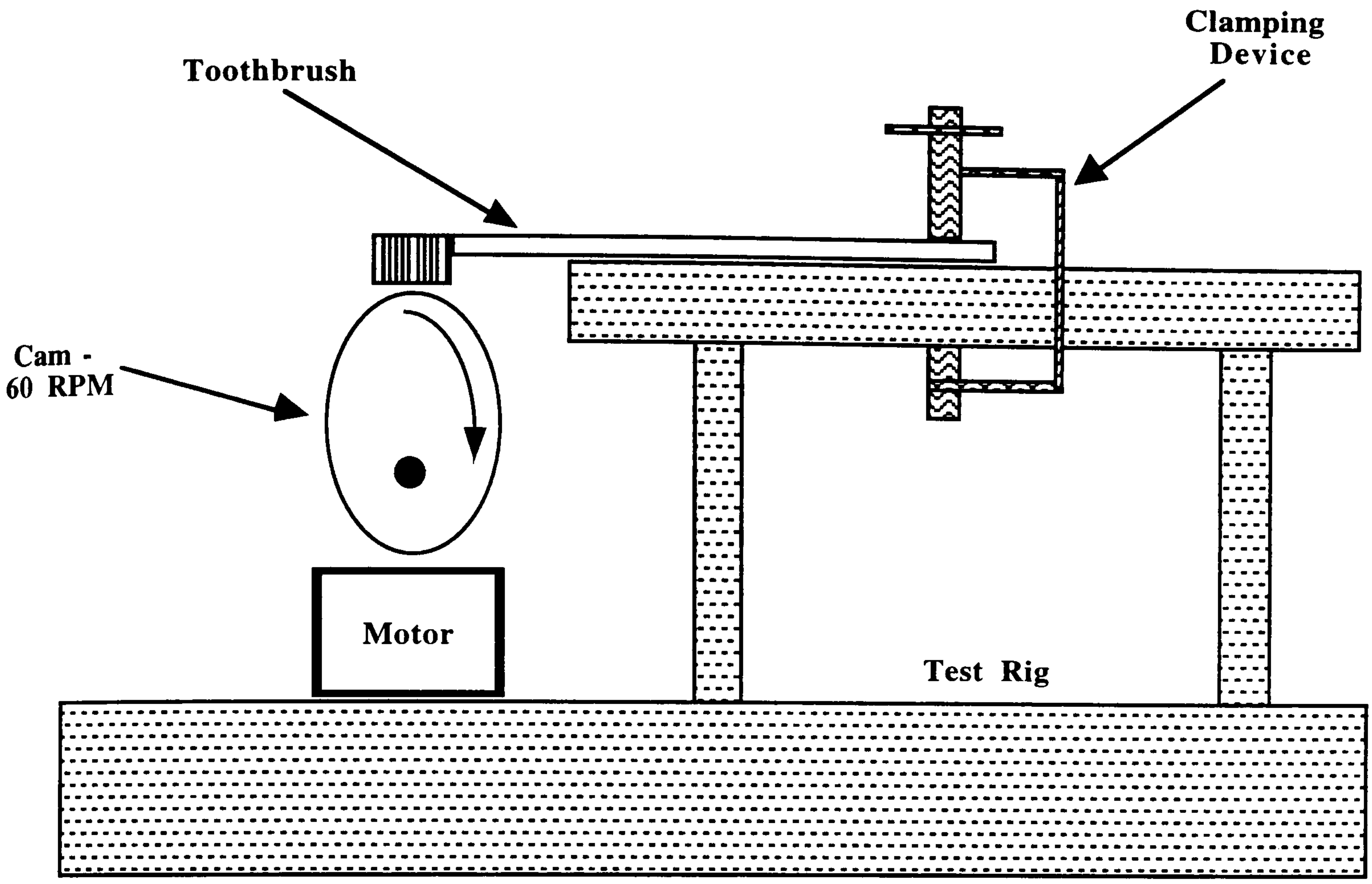


Figure 6.6.1a: Computer-Controlled Test System

Water is applied continuously to the toothbrush during the test. Each test is run for 9 hours. This equates to:

3 minutes brushing twice a day (3 * 2) =	6 minutes
3 months use (90 days) * 6 minutes =	540 minutes
540 minutes / 60 minutes =	9 hours.

A schematic diagram illustrating the relative motion of the toothbrush with respect to the cam is shown in Figure 6.6.1b.

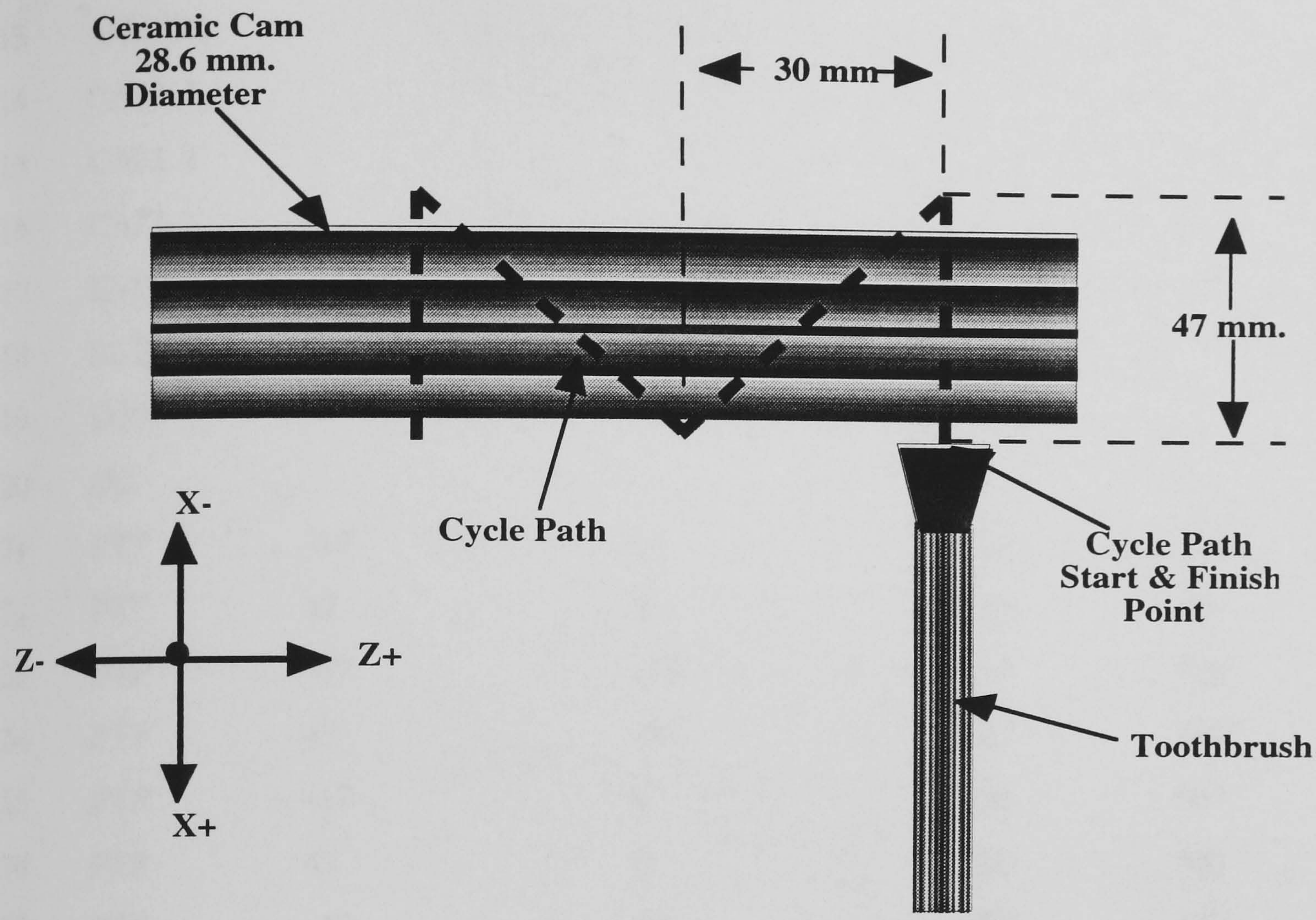


Figure 6.6.1b: Relative Motion of Toothbrush with Respect to Cam

The time taken for one cycle is 1.6875 minutes, and the test is run for 320 cycles. This equates to exactly 9 hours.

The program code listing for the above test is shown below in Table 6.6.1a.

PAGE	FUNCTION	INCREMENTAL-X	INCREMENTAL-Z	FEED	SPEED
1	MM				
2	INC				
3	DATUM	300	250		
4	DO				
5	PTP	-47	0	250	500
6	PTP	47	0	250	500
7	PTP	-47	-30	250	500
8	PTP	47	-30	250	500
9	PTP	-47	0	250	500
10	PTP	47	0	250	500
11	PTP	-47	30	250	500
12	PTP	47	30	250	500

```
END DO
CALL 1
CALL 1
CALL 1
END
SUB 1
INC
DO
PTP     -47     0       250     500
PTP     47      0       250     500
PTP     -47     -30     250     500
PTP     47      -30     250     500
PTP     -47     0       250     500
PTP     47      0       250     500
PTP     -47     30      250     500
PTP     47      30      250     500
END DO
INC
END PROG
```

Table 6.6.1a: ISO Numerically-Controlled Program Code

The measure of whether each toothbrush is 'long lasting' or not is done in two ways. Firstly, each toothbrush is inspected visibly (see Plate 6.6.1c) to ascertain the amount of filament distortion, and secondly the filaments of each toothbrush are measured before and after the test has run.

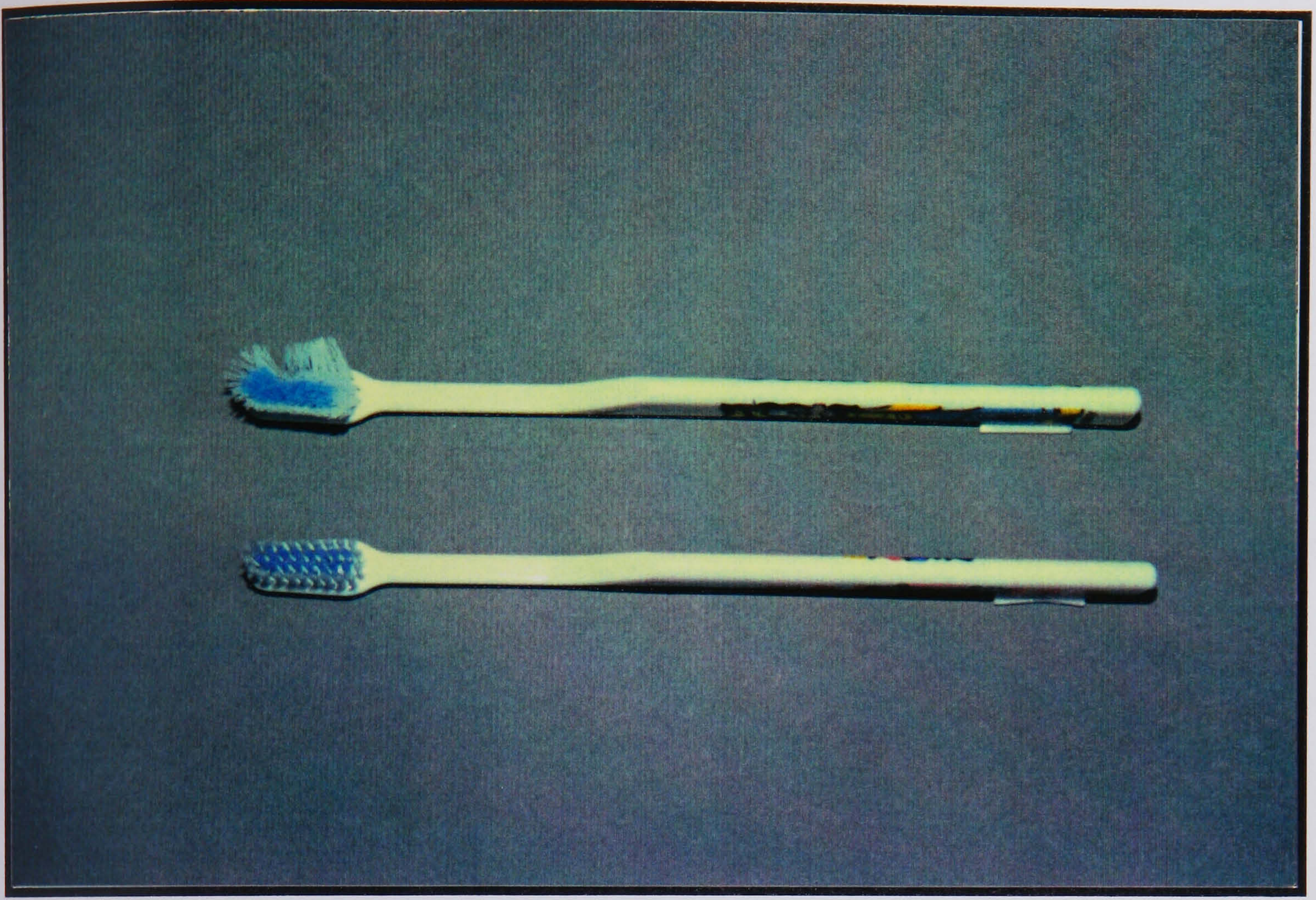


Plate 6.6.1c: Filament Distortion after Test Run

The scores for the amount of filament loss are represented as a percentage, thus:

*length (mm.) of filament "loss" during test / filament length (mm.) before test * 100*

Results:

The comparative results of these tests are presented below:

TOOTHBRUSH	FILAMENT LOSS (%)	'long_lasting' **Mod**
Mentadent-P	1.5%	100%
Colgate Diamond	1.5%	100%
Aquafresh Flex	2%	100%
Addis Dual Texture	8%	84.2%
Jordan Le-Brush	10%	84.2%
Search 3.5	20%	84.2%
Wisdom Reflex	30%	100%
Oral-B A-35	36%	84.2%
Reach Anti-Plaque	55%	100%

*Table 6.6.1b: Comparison of Filament Loss Percentage and 'long_lasting' **Mod** Percentage Scores*

The 'long_lasting' **Mod** evaluation scores compare reasonably consistent with the filament percentage losses, with the exception of the Wisdom Reflex and the Reach Anti-Plaque. One plausible justification for the poor result of the latter is the filament material used (Polybutylene-Terthalate) whereas the majority of the other toothbrushes utilise varying grades of Nylon. An excuse for the disappointing percentage loss of the Wisdom Reflex toothbrush may be attributed to its 30 tufts in the toothbrush head. This figure is slightly less than the other toothbrushes.

(ii) **comfortable_to_hold** = "degree of comfortable to hold whilst brushing teeth"
comfortable_to_hold **Mod** (see Appendix I)

Test:
This test is carried out using the 'hall tests' procedure described in Cross (1994). 'Hall tests' are used in simulating user/customer behaviour. In this instance fifteen typical toothbrush users were asked to rate the toothbrushes on how comfortable they are to hold whilst brushing their teeth using the following scale:
1 - very uncomfortable
2 - poor comfort
3 - average comfort
4 - good comfort
5 - extremely comfortable

Results:
The respondents' scores were then tallied to give a percentage, of which those results, and the 'comfortable_to_hold' **Mod** scores are as follows:

TOOTHBRUSH	HALL TEST (%)	'comfortable_to_hold' **Mod**
Aquafresh Flex	92%	77.3%
Oral-B A-35	88%	100%

Wisdom Reflex	88%	100%
Reach Anti-Plaque	88%	100%
Mentadent-P	82%	86.4%
Addis Dual Texture	78.6%	86.4%
Colgate Diamond	74.6%	86.4%
Jordan Le-Brush	66.6%	72.7%
Search 3.5	64%	86.4%

Table 6.6.1c: Comparison of 'hall test' Scores and 'comfortable_to_hold' ***Mod*** *Scores*

The 'comfortable_to_hold' **Mod** predictions and the 'hall test' scores derived for 'comfortable_to_hold' compare reasonably with one another, with one exception - the Aquafresh Flex toothbrush. This was due to the fact that many of the users questioned found the slightly longer (191 mm.) and slightly thicker (9 - 10 mm.) Aquafresh toothbrush gave them greater purchase whilst brushing their teeth.

(iii) **removes_plaque_efficiently** = "percentage of plaque removed each brushing"
removes_plaque_efficiently **Mod** (see Appendix I)

Test:
In this test the actual observation **Oba** is simulated by using the Tsujita et al (1988) method of measuring the efficiency of plaque removal of toothbrushes. For each toothbrush in the test the plaque score of a typical mouth is measured as follows:

(1) A sample group of typical toothbrush users are required to brush their teeth as usual for a set time of between 2 to 3 minutes.

(2) The plaque score for tooth numbers 16, 21, 24, 36, 41 and 44, selected by (Ramfjord 1958) as being representative of the mouth as a whole (see Figure 6.6.1c below), before and after brushing will be taken by gargling with disclosing solution[10].

[10] Oral-B Laboratories Plaque Check Disclosing Tablets

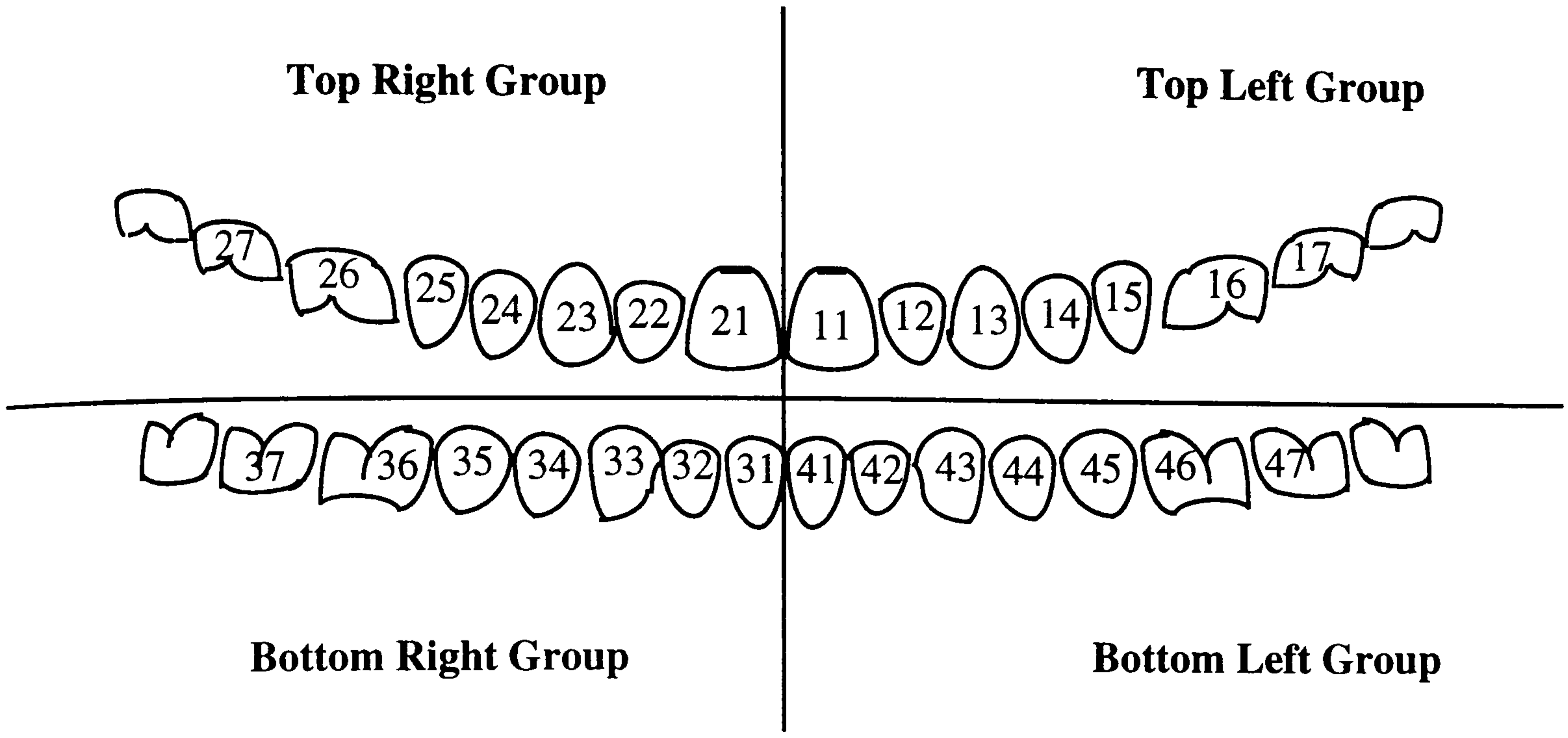


Figure 6.6.1c: Plaque Test Tooth Numbers

(3) The width of dental plaque is measured at six sites for each tooth using a 0.5 millimetre graduation periodontal probe (see Figure 6.6.1d below).

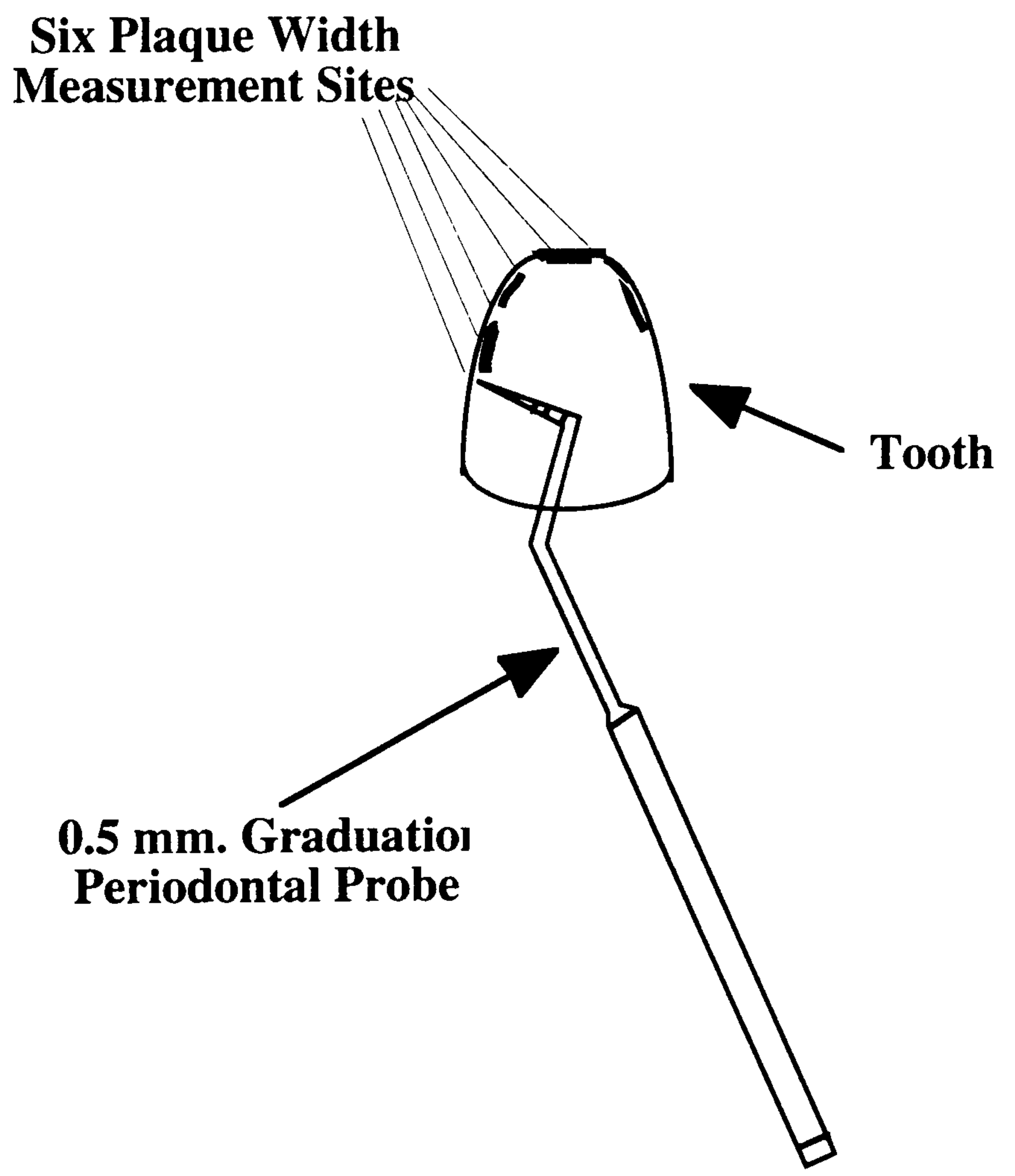


Figure 6.6.1d: Measurement of Plaque Width

(4) The plaque score for each tooth is determined by adding the measurements of plaque width at six sites of each tooth.

(5) The plaque score for the whole mouth is then calculated by adding the plaque scores for all six teeth examined (i.e. tooth numbers 16, 21, 24, 36, 41, and 44).

(6) The rate of plaque removal by brushing is calculated by the following equation:

Plaque Removal (%) = (1 - plaque score after brushing / plaque score before brushing) * 100.

The procedure will be repeated several times over to avoid any 'one-off' results.

Results:

The comparative results of the 'removes_plaque_efficiently' tests are as follows:

TOOTHBRUSH	PLAQUE REM. (%)	'removes_plaque_efficiently' **Mod**
Oral-B A-35	95.5%	100%
Search 3.5	95.5%	100%
Colgate Diamond	93.7%	89.5%
Aquafresh Flex	93.7%	84.2%
Wisdom Reflex	90.6%	89.5%
Reach Anti-Plaque	90.6%	84.2%
Mentadent-P	90.6%	84.2%
Addis Dual Texture	85.9%	100%
Jordan Le-Brush	85.9%	84.2%

*Table 6.6.1d: Comparison of Plaque Removal % Scores and 'removes_plaque_efficiently' **Mod** Scores*

The model predictions and the plaque removal percentage scores derived for 'removes_plaque_efficiently' compare reasonably with one another, with one obvious exception - the Addis Dual Texture toothbrush. This may be due to the slightly longer head (35 mm.), or alternatively, the slightly fewer number of filaments in one tuft (packing density - 22).

(iv) **does_not_irritate_gums** = "degree of gum bleeding and oral irritation"

does_not_irritate_gums **Mod** (see Appendix I)

Test:

In this test the gum health test recommended by Mentadent and the F.D.I.[11] is used to simulate the actual observation **Oba**. The results of this simulation are then compared against the 'does_not_irritate_gums' **Mod** results. The dental chart used in this test shows the six groups of teeth. For each set of teeth (top and bottom) there are three tooth groups: back left (5 teeth), front (6 teeth), and back right (5 teeth).

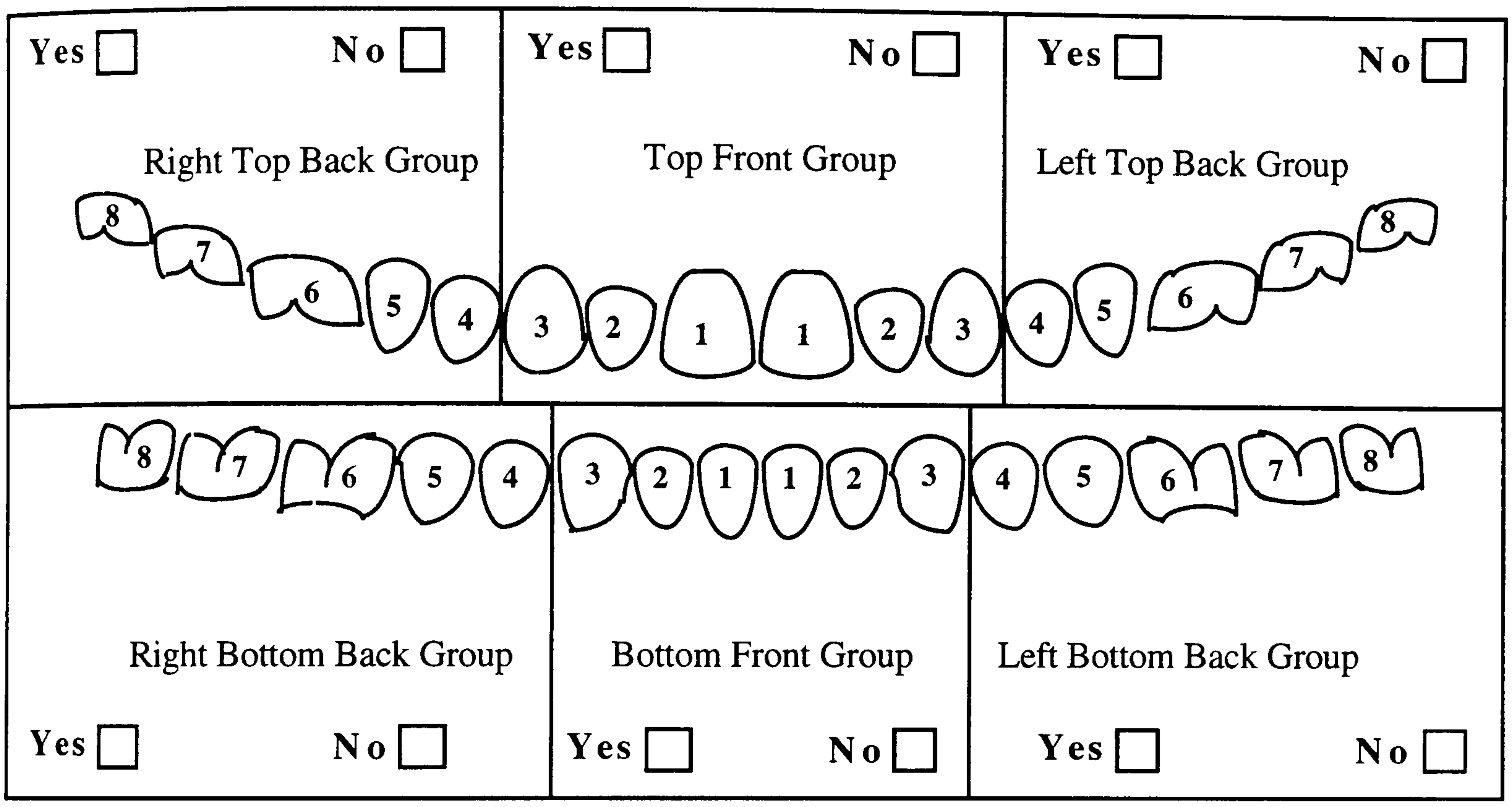


Figure 6.6.1e: 'does_not_irritate_gums' Dental Chart

Few people will have all 32 teeth. Using the chart (see Figure 6.6.1e above) the users involved in the test were given the following instructions:

(1) Look in the mirror and cross off any teeth that are missing. To make the scoring easier, test just one group at a time. Start with the <u>top left group</u>. NOTE: Do not use toothpaste.

(2) First, brush the inner surfaces that face your tongue. Brush firmly, and make sure you get right to the gum edges (hold the toothbrush at a slight angle).

(3) Next, brush the outer surfaces (facing your cheek) of the same group of teeth.

(4) Now spit out - any sign of blood ? Check the group of teeth where you have just brushed for any bleeding from the gums (using the mirror), and also check the toothbrush. If there is any bleeding at all, mark this group 'Yes'.

(5) Now go on to the next group of teeth (<u>top front group</u>). Again, do not forget to brush and check for bleeding on the 'tongue side' as well as the 'lip side' surfaces (using the mirror).

(6) Carry on until you have tested all six tooth groups. Mark the chart 'Yes' or 'No' (bleeding

[11] International Dental Federation (F.D.I.) Gum Health Plan.

or not) for each group as you go along.

(7) Finally, add up the groups where you have marked 'No'. This is your total score (Maximum possible score = 6).

0 - totally useless

1 - very poor

2 - poor

3 - satisfactory

4 - good

5 - very good

6 - perfect / ideal

Results:

The users involved in the test brushed their teeth for a period of one week with each toothbrush involved in the test. The comparison of this test with the 'does_not_irritate_gums' **Mod** results are as follows:

TOOTHBRUSH	IRRITATE GUMS (%)	'does_not_irritate_gums' **Mod**
Wisdom Reflex	100%	100%
Search 3.5	100%	100%
Jordan Le-Brush	100%	100%
Colgate Diamond	100%	88.8%
Reach Anti-Plaque	96.6%	100%
Mentadent-P	93.3%	100%
Aquafresh Flex	93.3%	74.1%
Addis Dual Texture	93.3%	70.4%
Oral-B A-35	76.7%	100%

Table 6.6.1e: Comparison of Irritate Gums (%) and 'does_not_irritate_gums' ***Mod*** *Scores*

The 'does_not_irritate_gums' **Mod** predictions and the F.D.I. gum health test scores correlate moderately well, with one exception - the Oral-B toothbrush. This may be down to the fact that the Oral-B has a lower packing density than the other toothbrushes, however it is more likely due to the small sample of users used in the test.

(v) **reaches_all_teeth** = "percentage of surface area of teeth reached by filament ends of toothbrush"
reaches_all_teeth **Mod** (see Appendix I)

Test:

The actual observation **Oba** is simulated for this test by adopting exactly the same test as is described in Chapter 5.0.0 of this thesis, (5.3.2 - Toothbrush Example).

Results:

The percentage of tooth area results and 'reaches_all_teeth' **Mod** results, reached by each toothbrush, are presented below:

TOOTHBRUSH	TOOTH AREA REACHED (%)	'reaches_all_teeth' **Mod**
Search 3.5	96.87%	100%
Oral-B A-35	93.75%	100%
Aquafresh Flex	93.75%	46.6%
Jordan Le-Brush	87.5%	100%
Reach Anti-Plaque	87.5%	73.3%
Mentadent-P	87.5%	73.3%
Colgate Diamond	84.37%	80%
Wisdom Reflex	81.25%	100%
Addis Dual Texture	81.25%	80%

Table 6.6.1f: Comparison of Tooth Area Reached (%) and 'reaches_all_teeth' ***Mod*** *Scores*

Comparisons between the two results are not credible. In particular, the results of the Aquafresh Flex are hugely inaccurate. The percentage of tooth area reached, using the test described in Chapter 5.0.0, is double that of the attribute model rating. This is probably due to the 'flexible' neck of the toothbrush. Consequently, the model (**Mod**) of "reaches_all_teeth" will need to be altered to include clauses relating to neck dimensions, and perhaps a sub-relation pertaining to flexural properties.

(vi) **looks_attractive** = "degree of attractiveness within a bathroom environment"
looks_attractive **Mod** (see Appendix I)

Test:

The actual observation **Oba** in this test is simulated by adopting the 'hall tests' procedure described in Cross (1994) as reported previously. Fifteen typical toothbrush users were asked to rate the toothbrushes on how attractive they would look in their local environment (i.e. a bathroom) by using the following measure:

1 - very unattractive

2 - unattractive

3 - attractive

4 - very attractive

5 - extremely attractive

Results:

The respondents' scores were then tallied to give a percentage. The table below shows the comparison of 'hall test' results against the 'looks_attractive' **Mod** results:

TOOTHBRUSH	HALL TEST (%)	'looks_attractive' **Mod**
Aquafresh Flex	92%	100%
Mentadent-P	89%	100%
Wisdom Reflex	86.6%	100%
Oral-B A-35	84%	100%
Colgate Diamond	81.3%	100%
Reach Anti-Plaque	80%	100%
Search 3.5	65.3%	81.8%
Jordan Le-Brush	64%	100%
Addis Dual Texture	57.3%	81.8%

Table 6.6.1g: Comparison of 'hall test' Scores and 'looks_attractive' ***Mod*** *Scores*

The 'looks_attractive' **Mod** results compare fairly consistent with the 'hall test' results for the 'looks_attractive' test. Apart from the Search and the Addis Dual Texture every toothbrush achieved the highest possible score. The single reason for both these toothbrushes not scoring the maximum was of the toothbrush colour applied.

6.6.2 Actual Mobile Telephone Tests

(i) **operable_with_one_hand** = "user can operate completely the telephone by using only **one hand** to switch-on, dial, send, end, and switch-off the mobile telephone"

operable_with_one_hand **Mod** (see Appendix I)

Test:

This test measures the ease of operating a cellular telephone with one hand only (see Plate 6.6.2a below) which is intended to simulate the actual observation **Oba**.

Plate 6.6.2a: 'operable_with_one_hand'

The test is as follows:

(1) Users are given a selection of cellular mobile telephones and a random list of 25 telephone numbers.

(2) The users are asked to switch the telephone on, dial the telephone number, send and end the communication, and switch the telephone off for each number on the list.

(3) Users rate the ease of operation with one hand for each number (e.g. on a scale of 1 to 5) using the following scale of measurement:

1 - very uneasy to operate

2 - poor ease of operation

3 - average ease of operating

4 - easy to operate

5 - extremely easy to operate

Results:

The users involved in the test rated each phone (rounded up to the nearest percentage). Those results and the 'operable_with_one_hand' **Mod** are as follows:

MOBILE PHONE	1-HAND TEST (%)	'operable_with_one_hand' **Mod**
Sony CM-H333	85%	81.8%
NEC P-4	64%	77.3%
NEC P-100	54%	100%
Ericsson Hotline	52%	100%
Mitsubishi MT-5	48%	90.9%

*Table 6.6.2a: Comparison of 1-Hand Test Scores and 'operable_with_one_hand' **Mod** Scores*

The attribute model (**Mod**) results do not compare with the one hand test results. As with some of the other simulated 'physical' tests, the sample size used was probably too small to provide any accurate evidence of the attribute model's accuracy. The poor **Mod** results of the Sony and NEC P-4 phones can be directly accounted for from within the attribute model "operable_with_one_hand". The single clause, phone_thickness, of the Sony phone was deemed too great to be operable with one hand. The cross-section of the NEC P-4 phone was deemed unsuitable. This latter point is discussed briefly in Section 6.6.4 (Test Conclusions). The model **Mod** of "operable_with_one_hand" has been adjusted to include these findings.

(ii) **fits_face** = "telephone fits the facial contours of the user, and the telephones ear piece to mouthpiece distance is suited to the user"

fits_face **Mod** (see Appendix I)

Test:

In this test the actual observation **Oba** was simulated by conducting a test which involved a number of typical cellular phone users checking whether or not the cellular phone fits the contours of their faces (see Plate 6.6.2b below).

Plate 6.6.2b: 'fits_face'

The users score each telephone on how well it fits the contours of their faces on a scale of 1 to 5 by adopting the following ratings:

1 - very bad fit

2 - poor fit

3 - average fit

4 - good fit

5 - excellent fit

Results:

The comparative results gained from conducting this test are given below:

MOBILE PHONE	FACE TEST (%)	'fits_face' **Mod**
Sony CM-H333	80%	85.7%
NEC P-100	74%	100%
Ericsson Hotline	70%	76.2%
Mitsubishi MT-5	62%	100%
NEC P-4	46%	61.9%

Table 6.6.2b: Comparison of Face Test Scores and 'fits_face' ***Mod*** *Scores*

The 'fits_face' **Mod** results do not match accurately with the fits face test results. As mentioned earlier, the sample size of users involved in the test was small (15 users) and this does not really assist in determining the validity of the model.

(iii) **fits_in_pocket** = "telephone will fit, and has the potential to be carried, within a typical-size of pocket"
fits_in_pocket **Mod** (see Appendix I)

Test:

This test will be carried out using the 'hall tests' procedure described in (Cross 1994), this method of testing is used to simulate an actual observation **Oba**. Fifteen typical mobile phone users were asked to rate the mobile phones on how well they fitted into their pockets using the following scoring system:

1 - very bad fit

2 - poor fit

3 - average fit

4 - good fit

5 - excellent fit

Results:

The table below illustrates comparatively the 'hall test' results against the 'fits_in_pocket' **Mod** results:

MOBILE PHONE	HALL TEST (%)	'fits_in_pocket' **Mod**
Sony CM-H333	84%	100%
NEC P-4	82.6%	78.9%
Ericsson Hotline	76%	100%
NEC P-100	72%	100%
Mitsubishi MT-5	68%	100%

Table 6.6.2c: Comparison of 'hall test' Results and 'fits_in_pocket' ***Mod*** *Results*

The above results are pretty inconclusive. As can be seen from the above table, apart from the NEC P-4 mobile phone, every phone achieved a perfect rating (100%). The solitary reason for the NEC P-4 failing (**Mod**) was its cross-section shape. The 'hall test' results portray a distinct preference for the Sony and the NEC P-4 phones.

(iv) **comfortable_to_hold** = "comfortable to hold whilst using"
comfortable_to_hold **Mod** (see Appendix I)

Test:

In this test the actual observation **Oba** is simulated using the 'hall tests' procedure described by Cross (1994). Fifteen average consumers were asked to rate the mobile telephones on how comfortable they were to hold whilst in use, by using the following scale:

1 - very uncomfortable
2 - poor comfort
3 - average comfort
4 - good comfort
5 - extremely comfortable

Results:

The respondents' scores were then tallied to give a percentage. The comparative results of both tests are as follows:

MOBILE PHONE	HALL TEST (%)	'comfortable_to_hold' **Mod**
Sony CM-H333	86.6%	86.4%
NEC P-4	77.3%	77.3%
NEC P-100	73.3%	100%
Ericsson Hotline	72%	100%
Mitsubishi MT-5	70.6%	100%

Table 6.6.2d: Comparison of 'hall test' Results and Mobile Phone 'comfortable_to_hold' ***Mod*** *Results*

Again the results of the 'hall tests' and the attribute model do not compare positively. The product users questioned found the Sony and the NEC P-4 phones the most comfortable to hold. This is in total contrast to the results gained from the 'comfortable_to_hold' **Mod**. The failings of the Sony and the NEC P-4 phones are the phone thickness being too great and the phone cross-sectional shape being unsuitable respectively.

(v) **easy_to_dial** = "user can dial easily and accurately (no mis-dials)"
easy_to_dial **Mod** (see Appendix I)

Test:
The actual observation **Oba** is simulated in this test. The aim of this test is to examine the ease of dialling and the accuracy of dialling, or in other words the frequency of dialling error.
(1) Users are given a random list of 25 telephone numbers and will be asked to switch the telephone on, dial the telephone number, send and end the communication, and switch the telephone off for each number on the list.
(2) Users will then be asked to note the number of mis-dials and tally the total to give a score for each cellular phone tested.

Results:
The number of mis-dials of each mobile phone are tallied to give a percentage rating. The results of this test and the results of 'easy_to_dial' **Mod** are:

MOBILE PHONE	EASY TO DIAL TEST (%)	'easy_to_dial' **Mod**
NEC P-100	82%	100%
Ericsson Hotline	81%	70.1%
Sony CM-H333	71%	81.5%
Mitsubishi MT-5	45%	51.8%
NEC P-4	44%	81.5%

Table 6.6.2e: Comparison of 'hall test' Results and 'easy_to_dial' ***Mod*** *Results*

The results of the 'easy_to_dial' simulated test agree in part with the 'easy_to_dial' **Mod** results. The attribute model failings of the Ericsson phone were down to the button spacing and the button digit size being too small. Once more however, the sample of users is too small to discern certain proof of the validity of the model (**Mod**).

(vi) **looks_attractive** = "looks attractive within the environment(s) it will be used in"
looks_attractive **Mod** (see Appendix I)

Test:

This test will be carried out using the 'hall tests' procedure described in (Cross 1994). The actual observation **Oba** is simulated here by the 'hall test'. In this example fifteen typical users were requested to rate the mobile telephones on how attractive they looked. The phones were rated using the following scale:

1 - very unattractive

2 - unattractive

3 - attractive

4 - very attractive

5 - extremely attractive

Results:

The scores of those questioned were then tallied to give a percentage result, which are compared with the 'looks_attractive' **Mod** results:

MOBILE PHONE	HALL TEST (%)	'looks_attractive' **Mod**
Sony CM-H333	85.3%	91.3%
NEC P-100	78.6%	100%
NEC P-4	74.6%	100%
Mitsubishi MT-5	66.6%	100%
Ericsson Hotline	64%	100%

Table 6.6.2f: Comparison of 'hall test' Results and 'looks_attractive' ***Mod*** *Results*

Similar to the other comparisons of 'hall test' and attribute model results for mobile phones, the percentage scores are at best inconclusive. The Sony mobile phone was thought to be the most attractive of the five phones tested by the panel of fifteen typical phone users. However, the Sony was the only phone tested using the 'looks_attractive' **Mod** that did not achieve a 100% rating, because of its thickness (40 mm.). The value of this clause (i.e. phone_thickness) has now been enlarged in the attribute model (**Mod**).

6.6.3 Actual System and Disposable Shaver Tests

(i) **easy_to_clean** = "the shaver can be cleaned easily of hair that has been removed during shaving"

easy_to_clean **Mod** (see Appendix I)

Test:

The actual observation **Oba** is simulated in this test. This test examines the users' ratings after shaving with each shaver on how easy to clean they were by adopting the following scale of measurement: (see Plate 6.6.3a below)

Plate 6.6.3a: 'easy_to_clean'

1 - extremely difficult to clean

2 - difficult to clean

3 - average

4 - easy to clean

5 - extremely easy to clean

Results:

The comparative results of the 'hall test' and 'easy_to_clean' **Mod** test are presented below:

DISPOSABLE SHAVER	HALL TEST (%)	'easy_to_clean' **Mod**
Bic Orange	60%	81.8%
Wilkinson Red	49%	90.9%
Wilkinson Green	46%	90.9%
Gillette Blue	46%	90.9%
Gillette Grey	45%	100%

SYSTEM SHAVER	HALL TEST (%)	'easy_to_clean' **Mod**
Gillette Sensor	68%	100%
Wilkinson Classic	57%	81.8%
Wilkinson Protector	54%	100%
Gillette Contour	50%	100%
Wilkinson Swivel	48%	100%
Gillette Lady Contour	39%	100%

Table 6.6.3a: Comparison of 'hall test' Results and 'easy_to_clean' ***Mod*** *Results for both shaver types*

As can be observed from the table above, the sample group concerned found the BIC disposable shaver to be the easiest to clean. This is totally opposite to the 'easy_to_clean' **Mod**, which is based on expert opinion (see Appendix IV). The deficiency of the BIC shaver is its head length (44 mm.) and head width (15 mm.) being oversize. In the case of the system shaver tests, the results illustrate some uniformity, with one exception - the Wilkinson Classic. The head length (48 mm.) and the head width (24 mm.) of this shaver are deemed too large by the attribute model. However, the attribute model (**Mod**) neglected the detachable feature of the head on the Wilkinson Classic shaver. The 'easy_to_clean' model **Mod** will have to be modified to rectify this omission.

(ii) **comfortable_to_hold** = "comfortable to hold whilst shaving"

comfortable_to_hold **Mod** (see Appendix I)

Test:

The actual observation **Oba** is simulated in this test by using the 'hall tests' procedure (Cross 1994). In this case the users will rate the shavers on how comfortable they are to hold while shaving on the following scale: (see Plate 6.6.3b below)

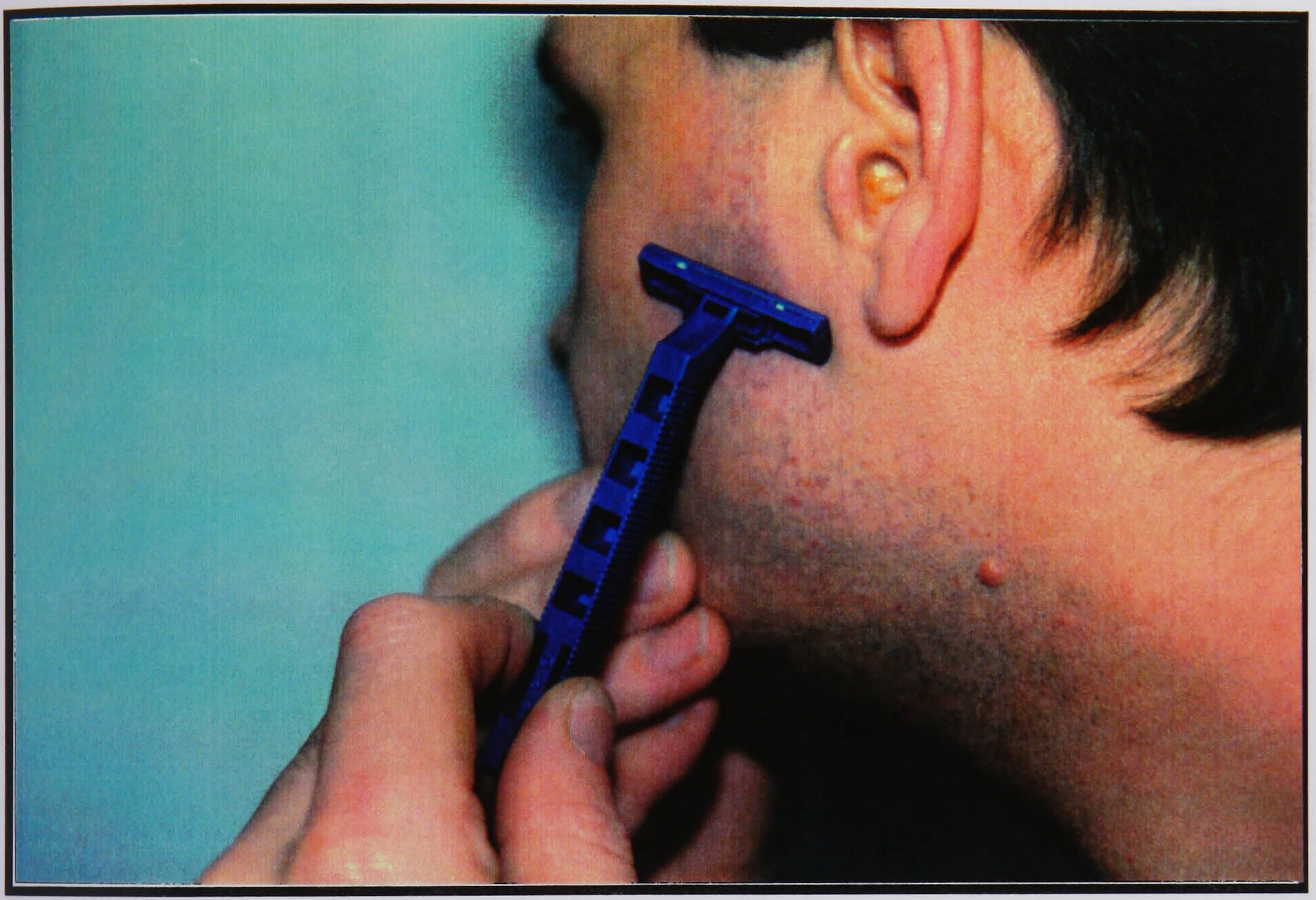


Plate 6.6.3b: Shaver 'comfortable_to_hold'

1 - very uncomfortable

2 - poor comfort

3 - average comfort

4 - good comfort

5 - extremely comfortable

Results:

The comparative scores of both tests are as follows:

DISPOSABLE SHAVER	HALL TEST (%)	'comfortable_to_hold' **Mod**
Wilkinson Green	76%	82.6%

Wilkinson Red	72%	100%
Gillette Blue	68%	82.6%
Gillette Grey	68%	100%
Bic Orange	64%	82.6%

SYSTEM SHAVER	HALL TEST (%)	'comfortable_to_hold' **Mod**
Gillette Sensor	86.6%	100%
Wilkinson Protector	74.6%	86.9%
Gillette Contour	73.3%	100%
Wilkinson Swivel	73.3%	100%
Wilkinson Classic	68%	100%
Gillette Lady Contour	56%	86.9%

Table 6.6.3b: Comparison of 'hall test' Results and 'comfortable_to_hold' ***Mod*** *Results*

There is little difference in the 'hall test' results of the disposable shavers (high - 76%, low - 64%). Many of the users questioned found little difference between the disposable shavers in terms of comfort. The system shaver 'hall test' and model **Mod** results compare well with the exception of the Wilkinson Protector. Those queried found the slightly larger dimensioned handle of the Protector comfortable to hold. The 'comfortable_to_hold' **Mod** will be altered to include this preference.

(iii) **looks_attractive** = "looks attractive within the environment(s) it will be used in"
looks_attractive **Mod** (see Appendix I)

Test:

This test will be carried out using the 'hall tests' procedure (Cross 1994). 'Hall tests' are widely used for simulation purposes. In this case the 'hall test' is used to simulate the actual observation **Oba**. Users will rate the shavers on how attractive they look using the following scale of measurement:

1 - very unattractive

2 - unattractive

3 - attractive

4 - very attractive

5 - extremely attractive

Results:

The comparative scores for the 'hall test' and the 'looks_attractive' **Mod** are as follows:

DISPOSABLE SHAVER	HALL TEST (%)	'looks_attractive' **Mod**
Wilkinson Red	78.6%	100%
Wilkinson Green	72%	100%
Gillette Blue	70.6%	100%
Gillette Grey	66.6%	85.7%
Bic Orange	61.3%	85.7%

SYSTEM SHAVER	HALL TEST (%)	'looks_attractive' **Mod**
Gillette Sensor	86.6%	100%
Wilkinson Swivel	74.6%	100%
Gillette Contour	73.3%	100%
Wilkinson Protector	73.3%	100%
Wilkinson Classic	65.3%	100%
Gillette Lady Contour	54.6%	85.7%

Table 6.6.3c: Comparison of 'hall test' Results and 'looks_attractive' ***Mod*** *Results*

The above 'hall test' and 'looks_attractive' **Mod** results compare accurately with respect to one another. Those involved in the 'hall test' found the three shavers that performed badly in the attribute model (**Mod**) test unattractive.

6.6.4 Test Conclusions

(i) Attribute Selection

The three product examples described previously, only deal with a limited selection of attributes. However, for a certain prediction of the product's performance, a complete set of attributes would have to be defined at the outset. Many authors now question the feasibility of this approach as many attributes are quite likely to occur to the designer during and after the synthesis of design solutions. The assessment procedure described in this work, thus far, needs to be extended in two ways to deal with this problem.

Firstly, the designer should be able to modify the attribute definition during the design process. In terms of the design model (Figure 4.1.5a), the system implementation of the operator **Exp•For** needs to be available to the designer throughout the process. Maintaining the history of the entity **C3** provides the design audit trail (Ganeshan et al 1994).

Secondly, the system must be capable of updating based on the experience of the actual product in context. It is intended to address this problem by treating the CADET system as an **evolutionary** system by allowing attributes, their combination, and their models to be updated in response to new knowledge and understanding of product use and requirements.

(ii) Individual Preference in Mass Consumption

One major difficulty as observed by Cross (1994) in establishing product success is the potential maverick behaviour of individual consumers and their preferences. This problem has been overcome by the definition of actual form, context and ensemble as the totality of the product in use respectively. Formulation of attributes are **summaries** of the behaviour or requirements of large numbers of potential consumers in which the maverick is statistically inconsequential.

(iii) Verification of CADET System Testing

The purpose of the tests was to determine if:

(a) the evaluations are equivalent;

(b) they are equivalent for the same reasons as those embodied within the system;

or otherwise.

Formally in terms of the CADET system description, the main objective of the tests was to establish if the operator **Mod** is an accurate model of the observations it is intended to predict. The test results presented indicate varying degrees of accuracy. For example the model (**Mod**) of 'long_lasting' was found to be grossly inaccurate. The reason for this defect is most likely down to an oversight in the sub-relation *long_lasting_material*.

The sub-relation *long_lasting_material* is is as follows:

relation 'long_lasting_material'
if the density is greater than 0.9 and the density is less than 2.0 and
the water_absorption is less than 7.0 and
the tensile_strength is greater than 25 and
the impact_strength is greater than 25 and
the ball_indentation_hardness is greater than 50 and
the melting_temperature is greater than 160.

The obvious justification for the inaccuracy of this model is that it does not contain sufficient information. The model, as it stands, omits several critical properties, (e.g. flexural_strength and flexural_modulus). A possible reason for the bad performance of the PBT filaments lies in the case of the latter property. The flexural modulus of PBT is almost 3 times as great as nylon ("grade-6"). The lower flexural modulus of nylon means that it is going to be more flexible, tougher and have greater resilience than PBT. In fact Hoechst Celanese Advanced Materials Group[12](1994) state:

"Since most plastic parts must be analysed in bending, flexural values should lead to more accurate results".

Consequently the CADET system will be updated to incorporate the results of this test. Specifically the results of this physical test will be added to the *Explanation Facility*, and the model (**Mod**) of 'long_lasting', and the sub-relation 'long_lasting_material' in particular, will be updated to include the property 'flexural_modulus'. The model now appears as follows:

relation 'long_lasting_material'
if the density is greater than 0.9 and the density is less than 2.0 and
the water_absorption is less than 7.0 and

[12]Hoechst Celanese Advanced Materials Group, *Designing With Plastics: The Fundamentals*, Design Manual (TDM-1), 1994

the flexural_modulus is less than 2.5 and

the tensile_strength is greater than 25 and

the impact_strength is greater than 25 and

the ball_indentation_hardness is greater than 50 and

the melting_temperature is greater than 160.

The reasons for failure or inaccuracy of the CADET system can be directly accounted for from the *FLEX* code listings. Several of the other attribute models that failed did so as a result of not containing enough information. For example the reason for the following mobile phone attributes:
'fits_in_pocket', 'operable_with_one_hand', 'comfortable_to_hold' and 'looks_attractive' was directly due to the insufficient CADET cross-sectional database.

The 'comfortable_to_hold' CADET scores for both the toothbrush and shaver did not compare favourably with the 'hall test' scores. It is acknowledged that the 'hall test' sample was rather small, and therefore may be misleading. However, the reasons for the scores not being equivalent are wholly justifiable. The users involved in the 'hall tests' generally agreed that they preferred larger dimensioned handles to smaller ones. The upshot of this evidence means modification of the 'comfortable_to_hold' attribute models, both shaver and toothbrush, and inclusion of this documentation in the *Explanation Facility* of the CADET system.

The perfect ratings (i.e. combined total of 100%) of the NEC P-100 phone and the Wilkinson Swivel and Gillette Sensor shavers suggests that these particular examples are optimum or perfect solutions. This is highly unlikely to be the case however. As Pye (1988) points out:

"Nothing we design or make ever really works. We can always say what it ought to do, but that it never does. Our dinner table ought to be variable in size and height, removable altogether, impervious to scratches, self-cleaning, and having no legs....Never do we achieve a satisfactory performance....Every thing we design and make is an improvisation, a lash-up, something inept and provisional."

Pye is implying that nothing is ever perfect. He says that because design requirements are always in conflict, they can never be completely reconciled. He goes on further to say:

"All designs for devices are in some degree failures, either because they flout one or another of the requirements or because they are compromises, and compromise implies a degree of failure...."

The flawless rating of the product examples mentioned previously does not necessarily mean they are perfect, rather it indicates that the CADET system has failed to identify any failures within them.

Chapter 7.0.0 Conclusions and Recommendations for Future Work

7.1.0 Summary of Key Features

The product performance assessment methodology described previously comprises three major stages:

(1) Definition of the attributes, in users' terms.

It is important to note that an attribute is **defined** as an observation that **could** be made of an actual ensemble. The designer's problem at the conceptual stage of the design process is to **predict** this observation, since the actual ensemble does not exist. In order to do this a notation has been introduced that represents the design process.

In this notation an attribute observation Oba is declared as a function from an actual ensemble **E1** to an attribute value A.

$$\text{Oba} \mid \mathbf{E1} \rightarrow \text{A}$$

An attribute is the observation of an element of performance of an actual form **F1** within an actual ensemble **E1**, i.e. of the product in use. Notice the following ensembles **E1**, for example:

"a kettle should not burn ones hand whilst pouring",
"a toothbrush should remove enough plaque each brushing to prevent tooth decay",
"a hand drill should be comfortable to hold whilst using".

The attribute variables define the relevant aspects of the product in use. It is extremely doubtful, however, whether a comprehensive list of requirements (attributes) can ever be defined at the beginning of a design project. Many attributes of products only become apparent through the process of analysing design proposals. Indeed, in some cases many product attributes may only manifest themselves once the product is placed on the market.

(2) Determining the model **Mod** of each attribute.

Whilst the problem of product attribute definition is in determining an acceptable, even if incomplete, list of attributes, the possible difficulty in the model is in accurately simulating or predicting those attributes that have been defined. The novel approach taken here addresses this difficulty by formally linking the physical characteristics of the product to a clear statement of the user requirements. For example in the case of the toothbrush the attribute and its observation,

> reaches_all_teeth = "percentage of surface area of teeth reached by filament ends of toothbrush",

clearly reflect the user requirement whilst the model links the relevant characteristics of spatial occupancy.

The model of each attribute consists of a collection of clauses based on either product characteristics or sub-relations. For example clauses contained within the model **Mod** "comfortable_to_hold" for a mobile phone include:

"if ***cellular_phone_width*** *is greater than 29 and less than 66 and*
if ***cellular_phone_thickness*** *is less than 36 and*
if ***cellular_phone_shape*** *is some instance of comfortable_handle_shape and*
if ***cellular_phone_cross_section*** *is some instance of comfortable_handle_cross_section"*

Numerical weighting (*FLEX* command "Score") is assigned to each clause within the model to reflect their relative importance with one another, for example:

"if cellular_phone_width is greater than 29 and less than 66 ***Score 5*** *and*
if cellular_phone_thickness is less than 36 ***Score 2****"*

Characteristics are inherent properties of any product, independent of the product's use, and can be determined purely from the representation of the product. Product characteristic examples include mass, colour, material specifications, dimensional information (for example length, width, height, etc.) and a symbolic notation to represent properties of this nature has been illustrated. Sub-relations, such as {non_irritate_oral_material}, are intended to be applicable to any item which is placed in the mouth. The CADET system contains a library of similar sub-relations.

The operator **Ext** is a function from form **F3** to characteristics **Ch**.

Ext | **F3** $\rightarrow$ **Ch**

and the model **Mod** a function from characteristics **Ch** to attributes **A**.

Mod | **Ch** $\rightarrow$ **A**.

(3) Defining the combination function **Cob**.

The relative weighting for both the product characteristics within each attribute model, and of each attribute within the combination function can be defined using questionnaire results, for example, or by adopting the weighted objectives method described in Cross (1994). This aspect has been a consistent area of interest over many years and the CADET system provides a practical solution.

The combination function in this case is a linear weighting of the attributes,

$$\textbf{Cob}\ (a) = \Sigma_{1 \leq i \leq 6}\ w_i\ a_i.$$

For example the combination function **Cob** of the toothbrush example is as follows:

"toothbrush_combination;
looks_attractive(Score 1)
reaches_all_teeth(Score 4)
comfortable_to_hold(Score 3)
does_not_irritate_gums(Score 4)
lasts_long(Score 3)
removes_plaque_efficiently(Score 5)
*toothbrush_combination_total = (looks_attractive *(Score 1) + reaches_all_teeth *(Score 4) + comfortable_to_hold *(Score 3) + does_not_irritate_gums *(Score 4) + lasts_long *(Score 3) + removes_plaque_efficiently *(Score 5)) / 600 *(100))."*

CADET Test Conclusions

The CADET models (**Mod**) described in this work, thus far, need to be modified in two ways.

Firstly, the designer must be able to modify the attribute definition during the design process, i.e. the composite operator **Exp•For** (problem definition) must be available for the designer to apply during as well as before the synthesis of new forms. Secondly, although not helpful for the current design the system must be capable of updating based on the experience of the actual product in context. It is intended to address this problem by treating the CADET system as an **evolutionary** system that may be updated in response to new knowledge and understanding of product use and requirements.

7.2.0 Conclusions

The subject area recognised as "design" generally contains the type of tasks which require the most important human problem solving processes to solve them, yet at the same time it is one of the least understood areas of study. Many stimulating and diverse definitions of design have been postulated over time, as have many formal models of what is involved in the design process (see Chapter 2.0.0). One may argue that many of the design models that have been formulated are too abstract and general and this ultimately results in their limited use. However, by adopting a formal model of the design process, all the decisions, judgments, etc. that are taken by the designer can be made explicit and subject to rigorous examination.

This work makes the following contributions to knowledge:

(I) The work presents a novel methodology for assessing product performance at the conceptual stage of the design process. Specifically, the methodology formally defines and requires the user to formally state the observable elements of success of a product in use. A product in use is formally defined as an actual ensemble and an attribute is formally defined as a method of observation of that ensemble. The requirements are formally defined avoiding the type of conflict reported by Bucciarelli (1994).

(II) In this method product performance assessment is directly related to stated users' needs and does not require the introduction of further evaluation criteria "deduced" by the design team from a Product Design Specification, as suggested by Pugh (1990).

(III) Since an attribute is defined as a measure of an actual physical situation, its prediction at the design stage requires a model of that physical situation. The construction of this model is the computable equivalent of defining engineering characteristics in QFD which are now a derivative of the model rather than an objective of the exercise. The rationale, information, data used in the model construction is retained as the basis of the design audit (within the CADET explanation facility). Since this is now computable, product performance can be directly assessed against the originally stated user/ customer requirements (King 1989). Further, the designer is not tied to target values of engineering characteristics but simply in improving overall performance.

(IV) Like Alexander (1964) the methodology is constructed in abstract terms making its problem independent. It is equally applicable to any problem. The model of the design process on which it is based is equally generic and abstract and, subject to including process design, can be used to form the building blocks of a truly integrated concurrent engineering (CE) system. Most proposals for computer-based concurrent engineering systems are domain specific rather than as an architecture that integrates available domain specific software. This thesis has highlighted where engineering analysis packages and visualisation packages would be incorporated within a computerised implementation of the methodology.

(V) The attribute assessment methodology has been incorporated and tested in a prototype Computer Aided Design Evaluation Tool (CADET) that can quickly and accurately assess product performance in the early stages of design. Admittedly the time taken to initially define a problem must at least be similar to that of forming QFD matrices. However, it is anticipated that general or universal attributes can be defined and a library established that would speed up future assessments. Like most computer systems, most benefit comes with later editing rather than initial input. The CADET enables the designer to modify easily performance criteria as new knowledge and understanding emerges, and to retain an audit of these changes.

(VI) Like QFD, the method provides a clear distinction between what is significant to a user/ customer and their relative importance to the user/ customer, a major failing in Alexander's approach. Attributes should be value neutral and their relative value to the user/ customer should be described through the combination function. In many examples within this thesis, this is not the case and elements of relative value have been built into attribute definitions.

7.3.0 Recommendations for Future Work

The thesis has developed a diagrammatic methodology for assessing product performance in user rather than product terms, that can be implemented into a computer based tool. The methodology addresses the problem of predicting the performance of product design proposals at the conceptual stage of the design process.

Recently, there has been an explosion of interest in the relationship between product users and product designers and manufacturers. This has been reflected by the number of conferences and workshops dedicated to this area. For example there has been much activity recently in subjects such as "Customer Driven Product Design" - IEE Colloquium, 6th May 1994, "Participatory Design" - Brighton Design Forum, 9th February 1995, "Wealth Creation from Design" - IEE Colloquium, 8th March 1995, and so on.

The primary motivation for this interest is the continual attempt to provide customers with products that will completely satisfy their requirements. Product designers and manufacturers alike are well aware of the increasing importance of the customer. The expanding development of information technology and computer based tools will increase the scope for participation and will force designers into a new relationship with users, one based on facilitation and empowerment rather than service. Moreover, the new manufacturing technologies of the post mass-production era will enable product users to customise their own futures.

Recommendations for future study are to consolidate and further expand this approach. Further testing of other product examples is required. A great deal of design work in practice is concerned not with the creation of radical new design concepts but with the making of modifications to existing product designs. These modifications seek to improve a product - to improve its performance, to enhance its appearance, and provide superior user performance characteristics.

Further evaluation of the prototype CADET system will need to consider established classes of product design, particularly consumer products whose purpose and use is well defined, for example audio/ video equipment, kettles, hair-driers, calculators, screwdrivers, irons, etc. This type of product has evolved through several generations of products as user needs have developed.

The prototype CADET system can be integrated with other CAD systems, for example, in the current implementation the extraction of product data in the CADET system is performed manually, in the majority of CAD systems product characteristic data extraction is an automated feature and is well understood. Integration of the CADET system with other computer based packages such as materials databases (CAMPUS®[13]) and ergonomic databases etc. will furnish designers with vast amounts of information within a single Computer Aided Design system. The implementation of such a single system would be a matter of resolving data exchange protocols between packages.

For the designer the CADET assessment of product performance is an optimisation criteria s/he is working towards, i.e. s/he is attempting to maximise the rated performance of the concept. At present the design model developed has deliberately not had a chronological element, it has only demonstrated the relationship between defined operations. Further work is required to develop the existing model into a chronological model by treating it as an optimisation problem of performance.

Future development of the CADET system should include the facility for easy input of data by both designers and users alike. This would involve building a series of user interfaces for the following elements:

(i) Definition and listing of attributes into the CADET system. For example the user (of the CADET system) would be asked to define and register the attribute (string of characters) into a dialog box in their own terms.

(ii) Determining the model **Mod** of each attribute, including relative weighting of product characteristics and sub-relations.

[13] CAMPUS® DU PONT Plastics Database 1991 Version 2.0

(iii) Defining and specifying the combination function **Cob**, including the relative weighting of each attribute.

(iv) Construction of the explanation facility which relates to the attribute in question. Input of expert data, knowledge, information, etc.

Over the last couple of years, the use of multimedia and hypermedia techniques have been introduced to assist in many practical cases, for example mechanical engineering, building design, etc. Because product design is predominately a three dimensional activity, the CADET system should be developed in the future to contain not only graphical information, but by utilising multimedia methods include video, still photographic image, and sound data, within the explanation facility.

8.0.0

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8.0.0 References

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9.0.0

Appendices

9.0.0 Appendices

9.1.0 Appendix I - CADET System Code Listings (*FLEX* / PROLOG)

(1) TOOTHBRUSH

/* TOOTHBRUSH SELECT ATTRIBUTE CODE */

```
'Toothbrush'('looks attractive'):- toothbrush_attractive(S1).
'Toothbrush'('reaches all teeth') :- reaches(S2).
'Toothbrush'('comfortable to hold'):- toothbrush_comfortable(S3).
'Toothbrush'('does not irritate gums') :- gums(S4).
'Toothbrush'('long lasting') :- lasts(S5).
'Toothbrush'('removes plaque efficiently') :- plaque(S6).
'Toothbrush'('total evaluation'):- toothbrush_total.
```

/* TOOTHBRUSH EVALUATION - GRAPHICAL INTERFACE DIALOG CODE */

```
toothbrush_mydialog(Message,Name,Score) :-!,
        beep(1),
        screen(D,W),
        T is D - 140,
        L is W - 520,
        dialog(Message,T,L,120,360,
        [button(16,280,25,60,'OK'),
        button(52,280,20,60,'Cancel'),
        button(88,280,20,60,'Explain'),
        text(20,10,26,150, 'TOOTHBRUSH CONCEPT: '),
        text(20,160,20,100,Name),
        text(50,10,20,260, Message),
        text(80,10,20,60, 'SCORE: '),
        text(80,80,20,60, writeq(Score))],
        Btn,
```

```
        toothbrush_explain(Message)).

toothbrush_explain(D, 3, Message) :-!,
        help(cadet_tooth_file, 'Explain Evaluation', Message),
        fail.
        toothbrush_explain(_,_,_).

toothbrush_total_dialog(Name,Score) :-!,
        beep(1),
        screen(D,W),
        T is D - 140,
        L is W - 520,
        dialog('Total Evaluation Result',T,L,120,360,
        [button(16,280,25,60,'OK'),
        button(52,280,20,60,'Cancel'),
        text(20,10,20,150, 'TOOTHBRUSH CONCEPT: '),
        text(20,160,20,100, writeq(Name)),
        text(80,10,20,160, 'TOTAL SCORE: '),
        text(80,120,20,100, writeq(Score))],
        Btn).
```

/* TOOTHBRUSH TOTAL EVALUATION CODE */

```
action toothbrush_total_output(Name,Score);
        if Score = 100 then
        pass_result_toothbrush_total(Name,Score) else
        fail_result_toothbrush_total(Name,Score)
        end if.

action pass_result_toothbrush_total(Name,Score);
        toothbrush_total_dialog(Name,Score).

action fail_result_toothbrush_total(Name,Score);
```

toothbrush_total_dialog(Name,Score).

/* CODE FOR EVALUATING EVERY ATTRIBUTE IN TURN */

```
action toothbrush_total;
do restart
and toothbrush_attractive(S1)
and reaches(S2)
and toothbrush_comfortable(S3)
and gums(S4)
and lasts(S5)
and plaque(S6)
and toothbrush_total_output(Name,(S1 + S2 + S3 + S4 + S5 + S6) / 600 *(100)).
```

/* DOES NOT IRRITATE GUMS CODE */

/* ATTRIBUTE MODEL */

```
relation does_not_irritate_gums(Name,Score)
if Name is an instance of toothbrush
and the Score1 is
if the head_length of Name is greater than 18 and the head_length of Name is less than 31 then
1 else 0
and the Score2 is
if the head_width of Name is greater than 6 and the head_width of Name is less than 13 then 1
else 0
and the Score3 is
if the filament_diameter of Name is greater than 0.15 and the filament_diameter of Name is less
than 0.31 then 1 else 0
and the Score4 is
if the filament_material of Name is some instance of safe_material_for_mouth then 1 else 0
and the Score5 is
if the toothbrush_material of Name is some instance of safe_material_for_mouth then 1 else 0
and the Score6 is
if the head_shape of Name is some instance of shape_safe_for_mouth then 1 else 0
```

```
and the Score7 is
if the head_cross_section of Name is some instance of non_irritate_section then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6 + Score7) / 7 *(100).

relation check_irritate(Name,Score)
if does_not_irritate_gums(Name,Score)
and gums_output(Name,Score).

action gums(Score);
        do restart
        and enter_toothbrush_gums(Name,Score)
        and check_irritate(Name,Score) .

action gums_output(Name,Score);
        if Score = 100 then
        pass_result_gums(Name,Score) else
        fail_result_gums(Name,Score)
        end if.

/*action gums_outputfail(Name,Score);
comparison(<, Score, 100) and
fail_result_gums(Name,Score).*/

action gums_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* LONG LASTING CODE */

/* ATTRIBUTE MODEL */

```
relation long_lasting(Name,Score)
if Name is an instance of toothbrush
```

```
and the Score1 is
if the filament_length of Name is greater than 9 and the filament_length of Name is less than 13
then 1 else 0
and the Score2 is
if the filament_diameter of Name is greater than 0.15 and the filament_diameter of Name is less
than 0.31 then 1 else 0
and the Score3 is
if the filament_number of Name is greater than 29 and the filament_number of Name is less
than 51 then 1 else 0
and the Score4 is
 if the filament_material of Name is some instance of long_lasting_material then 1 else 0
and the Score5 is
if the toothbrush_material of Name is some instance of long_lasting_material then 1 else 0
and the Score6 is
if the filament_end_shape of Name is end_rounded then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6) / 6 *(100).

relation check_lasts_long(Name,Score)
if lasts_long(Name,Score)
        and lasts_output(Name,Score).

action lasts(Score);
        do restart
        and enter_toothbrush_lasts(Name,Score)
        and check_lasts_long(Name,Score) .

action lasts_output(Name,Score);
if Score = 100 then
pass_result_lasts(Name,Score) else
fail_result_lasts(Name,Score)
end if.
```

```
/*action lasts_outputfail(Name,Score);
fail_result_lasts(Name,Score).*/

action lasts_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* REACHES ALL TEETH CODE */

/* ATTRIBUTE MODEL */

```
relation reaches_all_teeth(Name,Score)

if Name is an instance of toothbrush
and the Score1 is
if the toothbrush_length of Name is greater than 154 and the toothbrush_length of Name is less
than 191 then 1 else 0
and the Score2 is
if the head_length of Name is greater than 18 and the head_length of Name is less than 31 then
1 else 0
and the Score3 is
if the filament_length of Name is greater than 9 and the filament_length of Name is less than 13
then 1 else 0
and the Score4 is
if the head_shape of Name is some instance of shape_safe_for_mouth then 1 else 0
and the Score5 is
if the angle of Name is greater than -6 and the angle of Name is less than 16 then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5) / 5 *(100).

relation check_reaches_all_teeth(Name,Score)
if reaches_all_teeth(Name,Score)
        and reaches_output(Name,Score).
```

```
action reaches(Score) ;
        do restart
        and enter_toothbrush_reaches(Name,Score)
        and check_reaches_all_teeth(Name,Score) .

action reaches_output(Name,Score);
if Score = 100 then
pass_result_reaches(Name,Score)else
fail_result_reaches(Name,Score)
end if.

/*action reaches_outputfail(Name,Score);
fail_result_reaches(Name,Score).*/

action reaches_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* REMOVES PLAQUE EFFICIENTLY CODE */

/* ATTRIBUTE MODEL */

```
relation removes_plaque_efficiently(Name,Score)

if Name is an instance of toothbrush
and the Score1 is
if the filament_length of Name is greater than 9 and the filament_length of Name is less than 13
then 1 else 0
and the Score2 is
if the filament_diameter of Name is greater than 0.15 and the filament_diameter of Name is less
than 0.31 then 1 else 0
and the Score3 is
if the filament_material of Name is some instance of long_lasting_material then 1 else 0
```

```
and the Score4 is
if the handle_shape of Name is contoured then 1 else 0
and the Score5 is
if the tuft_arrangement of Name is rectangular then 1 else 0
and the Score6 is
if the angle of Name is greater than -6 and the angle of Name is less than 16 then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6) / 6 *(100).

relation check_removes_plaque(Name,Score)
if removes_plaque_efficiently(Name,Score)
        and plaque_output(Name,Score).

action plaque(Score);
        do restart
        and enter_toothbrush_plaque(Name,Score)
        and check_removes_plaque(Name,Score) .

action plaque_output(Name,Score);
if Score = 100 then
pass_result_plaque(Name,Score) else
fail_result_plaque(Name,Score)
end if.

/*action plaque_outputfail(Name,Score);
fail_result_plaque(Name,Score).*/

action plaque_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* **TOOTHBRUSH LOOKS ATTRACTIVE CODE** */

/* **ATTRIBUTE MODEL** */

```
relation looks_toothbrush_attractive(Name,Score)

if Name is an instance of toothbrush
and the Score1 is
if the toothbrush_material of Name is some instance of attractive_material then 1 else 0
and the Score2 is
if the head_shape of Name is some instance of attractive_shape then 1 else 0
and the Score3 is
if the handle_shape of Name is some instance of attractive_shape then 1 else 0
and the Score4 is
if the handle_cross_section of Name is some instance of attractive_shape then 1 else 0
and the Score5 is
if the head_cross_section of Name is some instance of attractive_shape then 1 else 0
and the Score6 is
if the toothbrush_colour of Name is some instance of attractive_toothbrush_colour then 1 else 0
and the Score7 is
if the filament_colour of Name is some instance of attractive_toothbrush_colour then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6 + Score7) / 7 *(100).

relation check_looks_toothbrush_attractive(Name,Score)
if looks_toothbrush_attractive(Name,Score)
    and toothbrush_attractive_output(Name,Score).

action toothbrush_attractive(Score);
    do restart
    and enter_toothbrush_attractive(Name,Score)
    and check_looks_toothbrush_attractive(Name,Score) .

action toothbrush_attractive_output(Name,Score);
if Score = 100 then
```

```
pass_result_toothbrush_attractive(Name,Score) else
fail_result_toothbrush_attractive(Name,Score)
end if.


action toothbrush_attractive_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* TOOTHBRUSH COMFORTABLE TO HOLD CODE */

/* ATTRIBUTE MODEL */

```
relation toothbrush_comfortable_to_hold(Name,Score)

if Name is an instance of toothbrush
and the Score1 is
if the toothbrush_length of Name is greater than 154 and the toothbrush_length of Name is less
than 191 then 1 else 0
and the Score2 is
if the handle_length of Name is greater than 99 and the handle_length of Name is less than 156
then 1 else 0
 and the Score3 is
if the handle_width of Name is greater than 9 and the handle_width of Name is less than 14
then 1 else 0
and the Score4 is
if the handle_thickness of Name is greater than 4 and the handle_thickness of Name is less than
8 then 1 else 0
and the Score5 is
if the handle_shape of Name is some instance of comfortable_handle_shape then 1 else 0
and the Score6 is
if the handle_cross_section of Name is some instance of comfortable_handle_cross_section
then 1 else 0
```

```
and the Score7 is
if the texture_finish of Name is some instance of comfortable_handle_texture then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6 + Score7) / 7 *(100).

relation check_toothbrush_comfort(Name,Score)
if toothbrush_comfortable_to_hold(Name,Score)
 and toothbrush_comfortable_output(Name,Score).

action toothbrush_comfortable(Score);
        do restart
        and enter_toothbrush_comfortable(Name,Score)
        and check_toothbrush_comfort(Name,Score) .

action toothbrush_comfortable_output(Name,Score);
if Score = 100 then
 pass_result_toothbrush_comfortable(Name,Score) else
 fail_result_toothbrush_comfortable(Name,Score)
end if.

action toothbrush_comfortable_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* TOOTHBRUSH ATTRIBUTE GRAPHICAL INTERFACE DIALOG CODE (EXAMPLE) */

```
enter_toothbrush_gums(Name,Score) :-
        create_toothbrush_dialog_gums([Name,HL,HW,FD,FM,TM,HS,HCS]),
        convert_to_number_gums([HL,HW,FD],
        [HL1,HW1,FD1]),
        new_instance(Name,toothbrush),
        new_slot(head_length,Name,HL1),
```

```
        new_slot(head_width,Name,HW1),
        new_slot(filament_diameter,Name,FD1),
        new_slot(filament_material,Name,FM),
        new_slot(toothbrush_material,Name,TM),
        new_slot(head_shape,Name,HS),
        new_slot(head_cross_section,Name,HCS).

create_toothbrush_dialog_gums([Name,HL,HW,FD,FM,TM,HS,HCS]) :-
            dialog('Does not irritate gums Evaluation',40,5,430,300,
            [button(400,230,25,60,'OK'),
            button(400,160,20,60,'Cancel'),
            text(10,10,20,140,'Toothbrush Name:'),
            edit(10,140,20,140,'',Name),
            text(50,10,20,220,'Head Length (mm):'),
            edit(70,140,20,140,'',HL),
            text(100,10,20,160,'Head Width (mm):'),
            edit(120,140,20,140,'',HW),
            text(150,10,20,160,'Filament Diameter (mm):'),
            edit(170,140,20,140,'',FD),
            text(200,10,20,160,'Filament Material:'),
            edit(220,140,20,140,'',FM),
            text(250,10,20,160,'Toothbrush Material:'),
            edit(270,140,20,140,'',TM),
            text(300,10,20,210,'Head Shape:'),
            edit(320,140,20,140,'',HS),
            text(350,10,20,150,'Head Cross Section:'),
            edit(370,140,20,140,'',HCS)
            ],
            Btn).

convert_to_number_gums([],[]).
convert_to_number_gums([H|W],[H1|W1]) :-
```

```
name(H,L),
name(H1,L),
convert_to_number_gums(W,W1).

pass_result_gums(Name,Score) :-
        toothbrush_mydialog('WOULD NOT IRRITATE GUMS',Name,Score).

fail_result_gums(Name,Score) :-
        toothbrush_mydialog('WOULD IRRITATE GUMS',Name,Score).
```

/* TOOTHBRUSH EXPLANATION FACILITY */

Explain Evaluation 'WOULD NOT REACH ALL TEETH' /* Toothbrush concept would not reach all teeth!

(1) The overall toothbrush length should range between 155-190 mm. (Oral-B Technical Report, 1992) (Chong and Beech, 1983).

(2) The toothbrush head length should be between 19-30 mm. (Walsh and Lamb, 1992/93) (Silverstone and Featherstone, 1988).

(3) The length of the filaments should range between 10-12 mm. (Tsujita et al, 1988) (Rawls et al, 1989).

(4) The preferred head shape is rectangular with rounded corners or a similar variation, eg. elliptical, oval etc. (Walsh and Lamb, 1992/93).

(5) The angle between head and handle should range between -5 degrees and +15 degrees (Walsh and Lamb, 1993).

Explain Evaluation 'WOULD REACH ALL TEETH' /* Toothbrush concept would reach all teeth because:

(1) The concept's overall toothbrush length ranges between 155-190 mm. (Oral-B Technical Report, 1992) (Chong and Beech, 1983).

(2) The concept's toothbrush head length lies between 19-30 mm. (Walsh and Lamb, 1992/93) (Silverstone and Featherstone, 1988).

(3) The length of the concept's filaments range between 10-12 mm. (Tsujita et al, 1988) (Rawls et al, 1989).

(4) The concept's head shape is either rectangular with rounded corners or a similar variation, eg. elliptical, oval etc. in accordance with (Walsh and Lamb, 1992/93).
(5) The angle between the concept's head and handle ranges between -5 degrees and +15 degrees (Walsh and Lamb, 1993).

Explain Evaluation 'WOULD NOT LOOK ATTRACTIVE' /* Toothbrush concept would not look attractive!
(1) The toothbrush handle material should be made from either cellulose acetate, styrene acrylo-nitrile(SAN), cellulose propionate, polypropylene, polyamide, acetyl butyl-stearate(ABS) or similar polymers. Materials such as wood, acrylic, metal also look attractive. (Delaunay, 1982).
(2) The head shape should be either rectangular, elliptical, diamond, oval or similar shapes (Golding, 1982).
(3) The handle shape may be either contoured (varying width and thicknesses), straight, irregular or a similar style (Davies et al, 1988).
(4) The handle cross-section should not have sharp edges, suitable cross-sections include rectangular, oval, elliptical, circular or similar cross-sections (Golding, 1982).
(5) The head cross-section should preferably be rectangular(rounded corners), or similar, eg. elliptical or oval (Walsh and Lamb, 1993).
(6) The toothbrush colour(s) should project the image of 'health', 'fitness' or 'cleanliness', for example red, yellow, green, clear, blue, white and variations of these hues (Kobayashi, 1990).
(7) The filament colour(s) should project the image of 'health', 'fitness' or 'cleanliness', for example red, yellow, green, clear, blue, white and variations of these hues (Kobayashi, 1990).

Explain Evaluation 'WOULD LOOK ATTRACTIVE' /* Toothbrush concept would look attractive because:
(1) The toothbrush concept's handle material is made from either cellulose acetate, styrene acrylo-nitrile(SAN), cellulose propionate, polypropylene, polyamide, acetyl butyl-stearate(ABS) or similar polymers, or indeed wood, metal, acrylic, or perspex variations (Delaunay, 1982).
(2) The concept's head shape is either rectangular, elliptical, diamond, oval or a similar shape (Golding, 1982).
(3) The concept's handle shape is either contoured (varying width and thicknesses), straight,

irregular or a similar style (Davies et al, 1988).

(4) The concept's handle cross-section does not have sharp edges, but a suitable cross-section, eg. rectangular, oval, elliptical, circular or similar cross-sections (Golding, 1982).

(5) The concept's head cross-section is either rectangular(rounded corners), or similar, eg. elliptical or oval (Walsh and Lamb, 1993).

(6) The toothbrush concept's colour(s) projects the image of 'health', 'fitness' or 'cleanliness', for example red, yellow, green, clear, blue, white or variations of these hues (Kobayashi, 1990).

(7) The concept's filament colour(s) projects the image of 'health', 'fitness' or 'cleanliness', for example red, yellow, green, clear, blue, white or variations of these hues (Kobayashi, 1990).

Explain Evaluation 'WOULD NOT LAST LONG' /* Toothbrush concept would not be long lasting!

(1) The length of filaments should be between 10-12 mm. (Chong and Beech, 1983).

(2) The diameter of the filaments should be between 0.16-0.3 mm. (Davies et al, 1988).

(3) The number of filaments in one tuft should range between 30-50 (Silverstone and Featherstone, 1988).

(4) Filaments should have filament material such as; nylon, polyamide or zytel (Walsh and Lamb, 1992/93).

(5) The toothbrush handle material should be made from either cellulose acetate, styrene acrylo-nitrile(SAN), cellulose propionate, polypropylene, polyamide, acetyl butyl-stearate(ABS) or similar polymers (Delaunay, 1982).

(6) The filaments' end-shape should be end-rounded to avoid gingival trauma (Silverstone and Featherstone, 1988).

Explain Evaluation 'WOULD LAST LONG' /* Toothbrush concept would be long lasting because:

(1) The length of the concept's filaments are between 10-12 mm. (Chong and Beech, 1983).

(2) The diameter of the concept's filaments are between 0.16-0.3 mm. (Davies et al, 1988).

(3) The number of filaments in one tuft of the concept's design range between 30-50 (Silverstone and Featherstone, 1988).

(4) The concept's filament material is one of either nylon, polyamide or zytel (Walsh and Lamb,

1992/93).

(5) The toothbrush concept's handle material is made from either cellulose acetate, styrene acrylo-nitrile(SAN), cellulose propionate, polypropylene, polyamide, acetyl butyl-stearate(ABS) or a similar polymer (Delaunay, 1982).

(6) The filaments' end-shape of the concept design are end-rounded to avoid gingival trauma (Silverstone and Featherstone, 1988).

Explain Evaluation 'WOULD NOT IRRITATE GUMS' /* Toothbrush concept would not irritate gums because:

(1) The length of the toothbrush head lies between the acceptable range 19-30 mm. (Delaunay, 1982).

(2) The width of the toothbrush head is between 7-12 mm. (Chong and Beech, 1983).

(3) The diameter of the filaments are between 0.16-0.3 mm. (Davies et al, 1988) (Rawls et al, 1990).

(4) The filaments of the concept design propose a filament material of either; nylon, polyamide or zytel (Walsh and Lamb, 1992/93) (Rawls et al, 1990).

(5) The toothbrush concept's handle material is made from either cellulose acetate, styrene acrylo-nitrile(SAN), cellulose propionate, polypropylene, polyamide, acetyl butyl-stearate(ABS) or similar polymers (Delaunay, 1982) (Golding, 1982).

(6) The head shape of the concept design is either rectangular, elliptical, oval or a similar 'rounded' shape (Golding, 1982) (Walsh and Lamb, 1993).

(7) The concept's head cross-section is rectangular(rounded corners), or similar, eg. elliptical or oval (Walsh and Lamb, 1993).

Explain Evaluation 'WOULD IRRITATE GUMS' /* Toothbrush concept would irritate gums!

(1) The length of the toothbrush head should be between 19-30 mm. (Delaunay, 1982).

(2) The width of the toothbrush head should range between 7-12 mm. (Chong and Beech, 1983).

(3) The diameter of the filaments should be between 0.16-0.3 mm. (Davies et al, 1988) (Rawls et al, 1990).

(4) Filaments should have filament material such as; nylon, polyamide or zytel (Walsh and Lamb, 1992/93) (Rawls et al, 1990).

(5) The toothbrush handle material should be made from either cellulose acetate, styrene acrylonitrile(SAN), cellulose propionate, polypropylene, polyamide, acetyl butyl-stearate(ABS) or similar polymers (Delaunay, 1982) (Golding, 1982).
(6) The head shape should be either rectangular, elliptical, oval or a similar 'rounded' shape (Golding, 1982) (Walsh and Lamb, 1993).
(7) The head cross-section should preferably be rectangular(rounded corners), or similar, eg. elliptical or oval (Walsh and Lamb, 1993).

Explain Evaluation 'WOULD NOT BE COMFORTABLE TO HOLD' /* Toothbrush concept would not be comfortable to hold!
(1) The overall toothbrush length should range between 155-190 mm. (Oral-B Technical Report, 1992) (Chong and Beech, 1983).
(2) The handle length of the toothbrush should be between 100-155 mm. (Davies et al, 1988).
(3) The width of the toothbrush handle should range between 10-13 mm. (Walsh and Lamb, 1993).
(4) The thickness of the handle should be between 5-7 mm. (Walsh and Lamb, 1993).
(5) The shape of the toothbrush handle may be straight, but ideally it should be contoured (varying width and thickness) (Davies et al, 1988).
(6) The handle cross-section should not have sharp edges, suitable cross-sections include rectangular, oval, elliptical, circular or similar cross-sections (Golding, 1982).
(7) The texture or finish of the toothbrush should be smooth all over, and have an opaque, matt or ideally transparent finish (Walsh and Lamb, 1993).

Explain Evaluation 'WOULD BE COMFORTABLE TO HOLD' /* Toothbrush concept would be comfortable to hold because:
(1) The overall toothbrush length of the concept proposed falls between 155-190 mm. (Oral-B Technical Report, 1992) (Chong and Beech, 1983).
(2) The handle length of the toothbrush concept lies between 100-155 mm. (Davies et al, 1988).
(3) The width of the toothbrush handle concept is between 10-13 mm. (Walsh and Lamb, 1993).
(4) The thickness of the concept design's handle lies between 5-7 mm. (Walsh and Lamb,

1993).

(5) The shape of the toothbrush concept's handle is either straight, or ideally, contoured (Davies et al, 1988).

(6) The handle cross-section of the concept does not have sharp edges, it has a suitable cross-sections of either rectangular, oval, elliptical, circular or similar cross-sections (Golding, 1982).

(7) The texture or finish of the toothbrush concept is smooth all over, and has an opaque, matt or ideally transparent finish (Walsh and Lamb, 1993).

Explain Evaluation 'WOULD NOT REMOVE PLAQUE EFFICIENTLY' /* Toothbrush concept would not remove plaque efficiently!

(1) The length of filaments should be between 10-12 mm. (Chong and Beech, 1983) (Tsujita et al, 1988).

(2) The diameter of the filaments should be between 0.16-0.3 mm. (Davies et al, 1988) (Rawls et al, 1990).

(3) Filaments should have filament material such as; nylon, polyamide or zytel (Rawls et al, 1990) (Walsh and Lamb, 1992/93).

(4) The shape of the toothbrush handle should be contoured as contoured-handles were found to be significantly more efficient at plaque removal (Davies et al, 1988).

(5) The tuft arrangement of the toothbrush should be rectangular or elliptical (Walsh and Lamb, 1993).

(6) The angle between head and handle should range between -5 degrees and +15 degrees (Walsh and Lamb, 1993) (Davies et al, 1988).

Explain Evaluation 'WOULD REMOVE PLAQUE EFFICIENTLY' /* Toothbrush concept would remove plaque efficiently because:

(1) The length of the concept's filaments are between 10-12 mm. (Chong and Beech, 1983) (Tsujita et al, 1988).

(2) The diameter of the concept's filaments are between 0.16-0.3 mm. (Davies et al, 1988) (Rawls et al, 1990).

(3) The concept's filaments have a suitable filament material such as; nylon, polyamide or zytel (Rawls et al, 1990) (Walsh and Lamb, 1992/93).

(4) The shape of the concept design's toothbrush handle is contoured as contoured-handles were found to be significantly more efficient at plaque removal (Davies et al, 1988).
(5) The tuft arrangement of the toothbrush concept is either rectangular or elliptical (Walsh and Lamb, 1993).
(6) The angle between head and handle of the concept design lies between the acceptable range -5 degrees and +15 degrees (Walsh and Lamb, 1993) (Davies et al, 1988).

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WALSH, T.F. and LAMB, D.J., Knowledge Acquisition Exercise, Department of Restorative Dentistry, School of Clinical Dentistry, Sheffield University Dental School, March 19th. 1993
WALSH, T.F. and LAMB, D.J., "Update of oral hygiene aids: Toothbrushes", Dental Health, 1992/93, Vol. 31, No. 6, pp 3-5 */

(2) MOBILE PHONE

/* MOBILE PHONE SELECT ATTRIBUTE CODE */

```
'Phone'('looks attractive'):- phone_attractive(S1).
'Phone'('easy to dial') :- easy(S2).
'Phone'('comfortable to hold'):- phone_comfortable(S3).
'Phone'('not too heavy') :- heavy(S4).
'Phone'('fits in pocket') :- pocket(S5).
'Phone'('fits face'):- face(S6).
'Phone'('operable with one hand'):- operable(S7).
'Phone'('total evaluation'):- phone_total.
```

/* MOBILE PHONE EVALUATION - GRAPHICAL INTERFACE DIALOG CODE *

```
    phone_mydialog(Message,Name,Score) :-!,
    beep(1),
    screen(D,W),
    T is D - 140,
    L is W - 520,
    dialog(Message,T,L,120,360,
        [button(16,280,25,60,'OK'),
        button(52,280,20,60,'Cancel'),
        button(88,280,20,50,'Explain'),
        text(20,10,16,220, 'PHONE CONCEPT: '),
        text(20,160,16,100,Name),
        text(50,10,16,260, Message),
        text(80,10,16,60, 'SCORE: '),
        text(80,80,16,60, writeq(Score))],
        Btn,
        phone_explain(Message)).

phone_explain(D, 3, Message) :-!,
```

```
help(cadet_phone_file, 'Explain Evaluation', Message),
        fail.
phone_explain(_,_,_).

phone_total_dialog(Name,Score) :-!,
        beep(1),
        screen(D,W),
    T is D - 140,
        L is W - 520,
        dialog('Total Evaluation Result',T,L,120,360,
    [button(16,280,25,60,'OK'),
        button(52,280,20,60,'Cancel'),
        text(20,10,16,220, 'PHONE CONCEPT: '),
        text(20,160,16,100, writeq(Name)),
        text(80,10,16,160, 'TOTAL SCORE: '),
        text(80,120,16,100, writeq(Score))],
        Btn).
```

/* MOBILE PHONE TOTAL EVALUATION CODE */

```
action phone_total_output(Name,Score);
if Score = 100 then
pass_result_phone_total(Name,Score) else
fail_result_phone_total(Name,Score)
end if.

action pass_result_phone_total(Name,Score);
    phone_total_dialog(Name,Score).

action fail_result_phone_total(Name,Score);
        phone_total_dialog(Name,Score).
```

/* CODE FOR EVALUATING EVERY ATTRIBUTE IN TURN */

```
action phone_total;
do restart
and phone_attractive(S1)
and easy(S2)
and phone_comfortable(S3)
and heavy(S4)
and pocket(S5)
and face(S6)
and operable(S7)
and phone_total_output(Name,(S1 + S2 + S3 + S4 + S5 + S6 + S7) / 700 *(100)).
```

/* NOT TOO HEAVY CODE */

/* ATTRIBUTE MODEL */

```
relation not_too_heavy(Name,Score)

if Name is an instance of cellular_phone
and the Score1 is
if the cellular_phone_material of Name is some instance of not_heavy_material then 1 else 0
and the Score2 is
if the cellular_phone_button_material of Name is some instance of not_heavy_material then 1
else 0
and the Score3 is
if the cellular_phone_length of Name is greater than 129 and the cellular_phone_length of
Name is less than 211 then 1 else 0
and the Score4 is
if the cellular_phone_width of Name is greater than 29 and the cellular_phone_width of Name
is less than 66 then 1 else 0
and the Score5 is
if the cellular_phone_thickness of Name is less than 36 then 1 else 0
and the Score6 is
if the cellular_phone_cross_section of Name is some instance of
comfortable_handle_cross_section then 1 else 0
```

```
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6) / 6 *(100).

relation check_heavy(Name,Score)
if not_too_heavy(Name,Score)
and heavy_output(Name,Score).

action heavy (Score);
        do restart
        and enter_cellular_phone_heavy(Name,Score)
        and check_heavy(Name,Score) .

action heavy_output(Name,Score);
if Score = 100 then
pass_result_heavy(Name,Score) else
fail_result_heavy(Name,Score)
end if.

/*action heavy_outputfail(Name,Score);
comparison(<, Score, 100) and
fail_result_heavy(Name,Score).*/

action heavy_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* OPERABLE WITH ONE HAND CODE */

/* ATTRIBUTE MODEL */

```
relation operable_with_one_hand(Name,Score)

if Name is an instance of cellular_phone
and the Score1 is
```

```
if the cellular_phone_width of Name is greater than 29 and the cellular_phone_width of Name
is less than 66 then 1 else 0
and the Score2 is
if the cellular_phone_cross_section of Name is some instance of
comfortable_handle_cross_section then 1 else 0
and the Score3 is
if the cellular_phone_shape of Name is some instance of comfortable_handle_shape then 1 else
0
and the Score4 is
if the cellular_phone_thickness of Name is less than 36 then 1 else 0
and the Score5 is
if the button_shape of Name is some instance of easy_dial_button_shape then 1 else 0
and the Score6 is
if the button_length of Name is greater than 5 and the button_length of Name is less than 18
then 1 else 0
and the Score7 is
if the button_width of Name is greater than 5 and the button_width of Name is less than 18 then
1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6 + Score7) / 7 *(100).

relation check_operable(Name,Score)
if operable_with_one_hand(Name,Score)
and operable_output(Name,Score).

action operable (Score);
        do restart
        and enter_cellular_phone_operable(Name,Score)
        and check_operable(Name,Score) .

action operable_output(Name,Score);
if Score = 100 then
pass_result_operable(Name,Score) else
```

```
fail_result_operable(Name,Score)
end if.

/*action operable_outputfail(Name,Score);
comparison(<, Score, 100) and
fail_result_operable(Name,Score).*/

action operable_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* PHONE COMFORTABLE TO HOLD CODE */

/* ATTRIBUTE MODEL */

```
relation phone_comfortable_to_hold(Name,Score)

if Name is an instance of cellular_phone
and the Score1 is
if the cellular_phone_length of Name is greater than 129 and the cellular_phone_length of
Name is less than 211 then 1 else 0
and the Score2 is
if the cellular_phone_width of Name is greater than 29 and the cellular_phone_width of Name
is less than 66 then 1 else 0
and the Score3 is
if the cellular_phone_thickness of Name is less than 36 then 1 else 0
and the Score4 is
if the cellular_phone_shape of Name is some instance of comfortable_handle_shape then 1 else
0
and the Score5 is
if the cellular_phone_cross_section of Name is some instance of
comfortable_handle_cross_section then 1 else 0
and the Score6 is
```

```
if the cellular_phone_material of Name is some instance of long_lasting_material then 1 else 0
and the Score7 is
if the cellular_phone_handle_texture of Name is some instance of comfortable_handle_texture
then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6 + Score7) / 7 *(100).

relation check_phone_comfort(Name,Score)
if phone_comfortable_to_hold(Name,Score)
 and phone_comfortable_output(Name,Score).

action phone_comfortable(Score) ;
        do restart
        and enter_cellular_phone_comfortable(Name,Score)
        and check_phone_comfort(Name,Score) .

action phone_comfortable_output(Name,Score);
if Score = 100 then
 pass_result_phone_comfortable(Name,Score) else
 fail_result_phone_comfortable(Name,Score)
end if.

action phone_comfortable_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* PHONE LOOKS ATTRACTIVE CODE */

/* ATTRIBUTE MODEL */

```
relation looks_phone_attractive(Name,Score)

if Name is an instance of cellular_phone
and the Score1 is
```

```
if the cellular_phone_length of Name is greater than 129 and the cellular_phone_length of
Name is less than 211 then 1 else 0
and the Score2 is
if the cellular_phone_width of Name is greater than 29 and the cellular_phone_width of Name
is less than 66 then 1 else 0
and the Score3 is
if the cellular_phone_thickness of Name is less than 36 then 1 else 0
and the Score4 is
if the cellular_phone_colour of Name is some instance of attractive_phone_colour then 1 else 0
and the Score5 is
if the cellular_phone_button_colour of Name is some instance of attractive_phone_colour then
1 else 0
and the Score6 is
if the cellular_phone_shape of Name is some instance of attractive_shape then 1 else 0
and the Score7 is
if the cellular_phone_button_shape of Name is some instance of attractive_shape then 1 else 0
and the Score8 is
if the cellular_phone_cross_section of Name is some instance of attractive_shape then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6 + Score7 + Score8) / 8
*(100).

relation check_looks_phone_attractive(Name,Score)
if looks_phone_attractive(Name,Score)
        and phone_attractive_output(Name,Score).

action phone_attractive(Score) ;
        do restart
        and enter_cellular_phone_attractive(Name,Score)
        and check_looks_phone_attractive(Name,Score) .

action phone_attractive_output(Name,Score);
if Score = 100 then
```

```
pass_result_phone_attractive(Name,Score) else
fail_result_phone_attractive(Name,Score)
end if.

action phone_attractive_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* EASY TO DIAL CODE */

/* ATTRIBUTE MODEL */

```
relation easy_to_dial(Name,Score)

if Name is an instance of cellular_phone
and the Score1 is
if the button_shape of Name is some instance of easy_dial_button_shape then 1 else 0
and the Score2 is
if the button_length of Name is greater than 5 and the button_length of Name is less than 18
then 1 else 0
and the Score3 is
if the button_width of Name is greater than 5 and the button_width of Name is less than 18 then
1 else 0
and the Score4 is
if the button_configuration of Name is some instance of easy_dial_button_configuration then 1
else 0
and the Score5 is
if the button_spacing of Name is greater than or equal to 6 and the button_spacing of Name is
less than or equal to 20 then 1 else 0
and the Score6 is
if the button_material of Name is some instance of easy_dial_button_material then 1 else 0
and the Score7 is
if the button_number_size of Name is greater than 3 and the button_number_size of Name is
```

```
less than 16 then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6 + Score7) / 7 *(100).

relation check_easy_to_dial(Name,Score)
if easy_to_dial(Name,Score)
        and easy_output(Name,Score).

action easy (Score);
        do restart
        and enter_cellular_phone_easy(Name,Score)
        and check_easy_to_dial(Name,Score) .

action easy_output(Name,Score);
if Score = 100 then
pass_result_easy(Name,Score) else
fail_result_easy(Name,Score)
end if.

/*action easy_outputfail(Name,Score);
fail_result_easy(Name,Score).*/

action easy_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* FITS FACE CODE */

/* ATTRIBUTE MODEL */

```
relation fits_face(Name,Score)

if Name is an instance of cellular_phone
and the Score1 is
```

```
if the cellular_phone_distance of Name is greater than 128 and the cellular_phone_distance of
Name is less than 147 then 1 else 0
and the Score2 is
if the cellular_phone_shape of Name is some instance of comfortable_handle_shape then 1 else
0
and the Score3 is
if the cellular_phone_length of Name is greater than 129 and the cellular_phone_length of
Name is less than 211 then 1 else 0
and the Score4 is
if the cellular_phone_width of Name is greater than 29 and the cellular_phone_width of Name
is less than 66 then 1 else 0
and the Score5 is
if the cellular_phone_thickness of Name is less than 36 then 1 else 0
and the Score6 is
if the cellular_phone_cross_section of Name is some instance of
comfortable_handle_cross_section then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6) / 6 *(100).

relation check_face(Name,Score)
if fits_face(Name,Score)
and face_output(Name,Score).

action face (Score);
        do restart
        and enter_cellular_phone_face(Name,Score)
        and check_face(Name,Score) .

action face_output(Name,Score);
if Score = 100 then
pass_result_face(Name,Score) else
fail_result_face(Name,Score)
end if.
```

```
/*action face_outputfail(Name,Score);
comparison(<, Score, 100) and
fail_result_face(Name,Score).*/

action face_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* FITS IN POCKET CODE */

/* ATTRIBUTE MODEL */

```
relation fits_in_pocket(Name,Score)

if Name is an instance of cellular_phone
and the Score1 is
if the cellular_phone_length of Name is less than 181 then 1 else 0
and the Score2 is
if the cellular_phone_width of Name is less than 81 then 1 else 0
and the Score3 is
if the cellular_phone_thickness of Name is less than 46 then 1 else 0
and the Score4 is
if the cellular_phone_shape of Name is some instance of fits_in_pocket_shape then 1 else 0
and the Score5 is
if the cellular_phone_cross_section of Name is some instance of fits_in_pocket_cross_section
then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5) / 5 *(100).

relation check_fits_in_pocket(Name,Score)
if fits_in_pocket(Name,Score)
        and pocket_output(Name,Score).
```

```
action pocket (Score);
        do restart
        and enter_cellular_phone_pocket(Name,Score)
        and check_fits_in_pocket(Name,Score) .

action pocket_output(Name,Score);
if Score = 100 then
pass_result_pocket(Name,Score)else
fail_result_pocket(Name,Score)
end if.

/*action pocket_outputfail(Name,Score);
fail_result_pocket(Name,Score).*/

action pocket_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* MOBILE PHONE ATTRIBUTE MODEL GRAPHICAL INTERFACE DIALOG CODE (EXAMPLE) */

```
enter_cellular_phone_comfortable(Name,Score) :-

create_cellular_phone_dialog_comfortable([Name,CPL,CPW,CPT,CPS,CPCS,CPM,CPHT])
,
       convert_to_number_phone_comfortable([CPL,CPW,CPT],
              [CPL1,CPW1,CPT1]),
       new_instance(Name,cellular_phone),
       new_slot(cellular_phone_length,Name,CPL1),
       new_slot(cellular_phone_width,Name,CPW1),
       new_slot(cellular_phone_thickness,Name,CPT1),
       new_slot(cellular_phone_shape,Name,CPS),
```

```
        new_slot(cellular_phone_cross_section,Name,CPCS),
        new_slot(cellular_phone_material,Name,CPM),
        new_slot(cellular_phone_handle_texture,Name,CPHT).

create_cellular_phone_dialog_comfortable([Name,CPL,CPW,CPT,CPS,CPCS,CPM,CPHT])
:-
        dialog('Comfortable to hold Evaluation',40,5,430,330,
                [button(400,250,25,60,'OK'),
          button(400,170,20,60,'Cancel'),
        text(10,10,16,140,'Cellular Phone Name:'),
        edit(10,160,16,145,'',Name),
        text(50,10,16,220,'Cellular Phone Length (mm):'),
        edit(70,160,16,145,'',CPL),
        text(100,10,16,200,'Cellular Phone Width (mm):'),
        edit(120,160,16,145,'',CPW),
        text(150,10,16,210,'Cellular Phone Thickness (mm):'),
        edit(170,160,16,145,'',CPT),
        text(200,10,160,170,'Cellular Phone Shape:'),
        edit(220,160,16,145,'',CPS),
        text(250,10,16,210,'Cellular Phone Cross Section:'),
        edit(270,160,16,145,'',CPCS),
        text(300,10,16,170,'Cellular Phone Material:'),
        edit(320,160,16,145,'',CPM),
        text(350,10,16,200,'Cellular Phone Texture/Finish:'),
        edit(370,160,16,145,'',CPHT)
],
        Btn).

convert_to_number_phone_comfortable([],[]).
convert_to_number_phone_comfortable([CP|L],[CP1|L1]) :-
        name(CP,W),
        name(CP1,W),
```

```
convert_to_number_phone_comfortable(L,L1).

pass_result_phone_comfortable(Name,Score) :-
        phone_mydialog('WOULD BE COMFORTABLE TO HOLD',Name,Score).

fail_result_phone_comfortable(Name,Score) :-
    phone_mydialog('WOULD NOT BE COMFORTABLE TO HOLD',Name,Score).
```

/* MOBILE PHONE EXPLANATION FACILITY */

Explain Evaluation 'WOULD NOT FIT IN MOST POCKETS' /* Phone concept would not fit in most pockets!

(1) The overall phone length should range between 130-210 mm. (Oikawa et al, 1984) (Matsui, 1982).

(2) The phone width should be between 30-65 mm. (Woodson et al, 1992) (Pheasant, 1986).

(3) The phone thickness should not exceed 35 mm. (Woodson et al, 1992).

(4) The preferred phone shape is rectangular with rounded corners or a similar variation, eg. straight (rounded corners), contoured (varying width), etc. (Woodson et al, 1992).

(5) Avoid square cross-sections and edges (Woodson, 1992). Circular cross-sections are the most comfortable to grip (Pheasant, 1986).

Explain Evaluation 'WOULD FIT MOST POCKET SIZES' /* Phone concept would fit most sizes of pocket because:

(1) The overall phone length lies between 130-210 mm. (Oikawa et al, 1984) (Matsui, 1982).

(2) The width of the phone is between 30-65 mm. (Woodson et al, 1992) (Pheasant, 1986).

(3) The phone thickness does not exceed 35 mm. (Woodson et al, 1992).

(4) The phone shape is either rectangular with rounded corners or a similar preferable variation, eg. straight (rounded corners), contoured (varying width), etc. (Woodson et al, 1992).

(5) The phone concept avoids square cross-sections and edges (Woodson, 1992).

Explain Evaluation 'WOULD NOT LOOK ATTRACTIVE' /* Phone concept would not look attractive!

(1) The phone length (overall) should be between 130-210 mm. (Woodson et al, 1992).

(2) The phone width should range between 30-65 mm. (Pheasant, 1986).

(3) The phone thickness should not exceed 35 mm. (Woodson et al, 1992).

(4) British Telecom (1990) suggest the phone colour(s) should be either: brilliant white, polar white, light grey, mid grey, dark grey, charcoal grey, or black.

(5) British Telecom (1990) suggest the button colour(s) should be either: brilliant white, polar white, light grey, mid grey. Or alternatively: red, green, blue, yellow, pink, silver. No more than three colours should be used together.

(6) From a biomechanical point of view, it makes no difference whether one selects a round, square, or rectangular push button. Other acceptable button shapes include: elliptical, oval (Woodson et al, 1992).

(7) The phone shape should be either straight, rectangular or contoured (Woodson et al, 1992).

(8) The phone cross-section should avoid square cross-sections and edges (Pheasant, 1986).

Explain Evaluation 'WOULD LOOK ATTRACTIVE' /* Phone concept would look attractive because:

(1) The phone length (overall) is between 130-210 mm. (Woodson et al, 1992).

(2) The phone width ranges between 30-65 mm. (Pheasant, 1986).

(3) The phone thickness does not exceed 35 mm. (Woodson et al, 1992).

(4) The phone colour(s) is either: brilliant white, polar white, light grey, mid grey, dark grey, charcoal grey, or black. (British Telecom, 1990).

(5) The button colour(s) are either: brilliant white, polar white, light grey, mid grey. Or alternatively: red, green, blue, yellow, pink, silver. (British Telecom, 1990).

(6) The shape of the buttons are either: round, square, rectangular, elliptical, or oval (Woodson et al, 1992).

(7) The phone shape is either straight, rectangular or contoured (Woodson et al, 1992).

(8) The phone cross-section does not have square cross-sections or edges (Pheasant, 1986).

Explain Evaluation 'WOULD NOT BE EASY TO DIAL' /* Phone concept would not be easy to dial!

(1) From a biomechanical point of view, it makes no difference whether one selects a round, square, or rectangular push button. Other acceptable button shapes include: elliptical, oval (Woodson et al, 1992).

(2) Ideally the length of the buttons should be between 12-17 mm, however, the absolute minimum is 6 mm. (Woodson et al, 1992), (Pheasant, 1986).
(3) Ideally the button width should range between 12-17 mm, however, the absolute minimum is 6 mm. (Woodson et al, 1992), (Pheasant, 1986).
(4) Research has shown that there is no significant performance difference between the numeric layout of the conventional calculator versus that of the conventional telephone. (Woodson et al, 1992).
(5) The spacing between buttons (edge to edge) should be between 6-20 mm. (Pheasant 1986).
(6) The material of the buttons should be either: ABS (acrylonitrile-butadiene-styrene), Polypropylene blends, Polycarbonate blends, or similar polymers. (Richardson, 1989).
(7) The height of characters should be no less than 4 mm. (Pheasant, 1986).

Explain Evaluation 'WOULD BE EASY TO DIAL' /* Phone concept would be easy to dial because:
(1) The shape of the buttons are either: round, square, rectangular, oval, or elliptical. (Woodson et al, 1992).
(2) The length of the buttons range between 6-17 mm. (Woodson et al, 1992).
(3) The button width ranges between 6-17 mm. (Pheasant, 1986).
(4) The button layout is either: (a) numeric, or (b) conventional telephone. (Woodson et al, 1992).
(5) The spacing between buttons (edge to edge) is between 6-20 mm. (Pheasant 1986).
(6) The material of the buttons is either: ABS (acrylonitrile-butadiene-styrene), Polypropylene blends, Polycarbonate blends, or similar polymers. (Richardson, 1989).
(7) The height of characters is not less than 4 mm. (Pheasant, 1986).

Explain Evaluation 'WOULD NOT BE TOO HEAVY' /* Phone concept would not be too heavy because:
(1) The phone material is either: ABS (acrylonitrile-butadiene-styrene), Polypropylene blends, Polycarbonate blends, or similar polymers. (Richardson, 1989).
(2) The material of the buttons is either: ABS (acrylonitrile-butadiene-styrene), Polypropylene blends, Polycarbonate blends, or similar polymers. (Richardson, 1989).
(3) The phone length (overall) lies between 130-210 mm. (Woodson et al, 1992).

(4) The phone width is between 30-65 mm. (Pheasant, 1986).

(5) The phone thickness does not exceed 35 mm. (Woodson et al, 1992).

(6) The phone cross-section does not have square cross-sections or edges (Pheasant, 1986).

Explain Evaluation 'WOULD BE TOO HEAVY' /* Phone concept would be too heavy!

(1) The phone material should be made from either: ABS (acrylonitrile-butadiene-styrene), Polypropylene blends, Polycarbonate blends, or similar polymers. (Richardson, 1989).

(2) The material of the buttons should be either: ABS (acrylonitrile-butadiene-styrene), Polypropylene blends, Polycarbonate blends, or similar polymers. (Richardson, 1989).

(3) The phone length (overall) should be between 130-210 mm. (Woodson et al, 1992).

(4) The phone width should be between 30-65 mm. (Pheasant, 1986).

(5) The phone thickness should not exceed 35 mm. (Woodson et al, 1992).

(6) The phone cross-section should not have square cross-sections or edges (Pheasant, 1986).

Explain Evaluation 'WOULD NOT BE COMFORTABLE TO HOLD' /* Phone concept would not be comfortable to hold!

(1) The phone length (overall) should be between 130-210 mm. (Woodson et al, 1992).

(2) The phone width should be between 30-65 mm. (Pheasant, 1986).

(3) The phone thickness should not exceed 35 mm. (Woodson et al, 1992).

(4) The phone shape should be either straight, rectangular or contoured (Woodson et al, 1992).

(5) The phone cross-section should not have square cross-sections or edges (Pheasant, 1986).

(6) The phone material should be made from either: ABS (acrylonitrile-butadiene-styrene), Polypropylene blends, Polycarbonate blends, or similar polymers. (Richardson, 1989).

(7) Ideally the phone should have a matt finish to prevent glare. (Pheasant, 1986).

Explain Evaluation 'WOULD BE COMFORTABLE TO HOLD' /* Phone concept would be comfortable to hold because:

(1) The phone length (overall) is between 130-210 mm. (Woodson et al, 1992).

(2) The phone width is between 30-65 mm. (Pheasant, 1986).

(3) The phone thickness does not exceed 35 mm. (Woodson et al, 1992).

(4) The phone shape is either straight, rectangular or contoured (Woodson et al, 1992).

(5) The phone cross-section does not have square cross-sections or edges (Pheasant, 1986).

(6) The phone material is made from either: ABS (acrylonitrile-butadiene-styrene), Polypropylene blends, Polycarbonate blends, or similar polymers. (Richardson, 1989).
(7) The phone has a matt, or suitable alternative finish. (Pheasant, 1986).

Explain Evaluation 'WOULD NOT FIT MOST FACE SIZES' /* Phone concept would not fit most face sizes!
(1) The distance between the phone's earpiece and mouthpiece should be between 129-146 mm. (Oikawa et al, 1984), (Matsui et al, 1982).
(2) The phone shape should be either straight, rectangular or contoured (Woodson et al, 1992).
(3) The phone length (overall) should be between 130-210 mm. (Woodson et al, 1992).
(4) The phone width should be between 30-65 mm. (Pheasant, 1986).
(5) The phone thickness should not exceed 35 mm. (Woodson et al, 1992).
(6) The phone cross-section should not have square cross-sections or edges (Pheasant, 1986).

Explain Evaluation 'WOULD FIT MOST FACE SIZES' /* Phone concept would fit most face sizes because:
(1) The distance between the phone's earpiece and mouthpiece lies between 129-146 mm. (Oikawa et al, 1984), (Matsui et al, 1982).
(2) The phone shape is either straight, rectangular or contoured (Woodson et al, 1992).
(3) The phone length (overall) lies between 130-210 mm. (Woodson et al, 1992).
(4) The phone width lies between 30-65 mm. (Pheasant, 1986).
(5) The phone thickness does not exceed 35 mm. (Woodson et al, 1992).
(6) The phone cross-section does not have square cross-sections or edges (Pheasant, 1986).

Explain Evaluation 'WOULD NOT BE OPERABLE WITH ONE HAND' /* Phone concept would not be operable with one hand!
(1) The phone width should be between 30-65 mm. (Pheasant, 1986).
(2) The phone cross-section should not have square cross-sections or edges (Pheasant, 1986).
(3) The phone shape should be either straight, rectangular or contoured (Woodson et al, 1992).
(4) The phone thickness should not exceed 35 mm. (Woodson et al, 1992).
(5) From a biomechanical point of view, it makes no difference whether one selects a round, square, or rectangular push button. Other acceptable button shapes include: elliptical, oval

(Woodson et al, 1992).

(6) Ideally the length of the buttons should be between 12-17 mm, however, the absolute minimum is 6 mm. (Woodson et al, 1992), (Pheasant, 1986).

(7) Ideally the button width should range between 12-17 mm, however, the absolute minimum is 6 mm. (Woodson et al, 1992), (Pheasant, 1986).

Explain Evaluation 'WOULD BE OPERABLE WITH ONE HAND' /* Phone concept would be operable with one hand because:

(1) The phone width lies between 30-65 mm. (Pheasant, 1986).

(2) The phone cross-section does not have square cross-sections or edges (Pheasant, 1986).

(3) The phone shape is either straight, rectangular or contoured (Woodson et al, 1992).

(4) The phone thickness does not exceed 35 mm. (Woodson et al, 1992).

(5) The shape of the buttons are either: round, square, rectangular, elliptical, or oval. (Woodson et al, 1992).

(6) The length of the buttons range between 6-17 mm. (Woodson et al, 1992).

(7) The button width ranges between 6-17 mm. (Pheasant, 1986).

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OIKAWA, H., MATSUI, H. and SHINOHARA, S., ‘Design Limits for Telephone Handset”, Review of the Electrical Communication Labs., 1984, Vol. 32, No. 2, pp 239-244

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BRITISH TELECOM TELEPHONE GUIDE, “Colours and Textures”, Issue 1: 31/3/1990, pp 14-15

WOODSON, W.E., TILLMAN, B. and TILLMAN, P., Human Factors Design Handbook (Second Edition), New York: McGraw-Hill Inc., 1992

PHEASANT, S., BODYSPACE: Anthropometry, Ergonomics and Design, London: Taylor & Francis, 1986

RICHARDSON, T.L., Industrial Plastics: Theory and Application, New York: Delmar Publishers Inc., 1989 */

(3) DISPOSABLE & SYSTEM SHAVERS

/* SHAVER SELECT ATTRIBUTE CODE */

```
'Shaver'('looks attractive'):- shaver_attractive(S1).
'Shaver'('gives a close shave') :- shave(S2).
'Shaver'('comfortable to hold'):- shaver_comfortable(S3).
'Shaver'('does not irritate skin') :- irritate_skin(S4).
'Shaver'('easy to clean') :- clean(S5).
'Shaver'('removes hair in difficult areas') :- hair(S6).
'Shaver'('does not cut or nick face'):- cut_or_nick(S7).
'Shaver'('is hygienic'):- hygienic(S8).
'Shaver'('total evaluation'):- shaver_total.
```

/* SHAVER EVALUATION - GRAPHICAL INTERFACE DIALOG CODE */

```
shaver_mydialog(Message,Name,Score) :-!,
        beep(1),
        screen(D,W),
    T is D - 140,
        L is W - 520,
        dialog(Message,T,L,120,360,
        [button(16,280,25,60,'OK'),
        button(52,280,20,60,'Cancel'),
        button(88,280,20,50,'Explain'),
        text(20,10,16,150, 'SHAVER CONCEPT: '),
        text(20,160,16,100,Name),
        text(50,10,16,260, Message),
        text(80,10,16,60, 'SCORE: '),
        text(80,80,16,60, writeq(Score))],
        Btn,
        shaver_explain(Message)).

shaver_explain(D, 3, Message) :-!,
```

```
        help(cadet_shaver_file, 'Explain Evaluation', Message),
                fail.
        shaver_explain(_,_,_).

shaver_total_dialog(Name,Score) :-!,
        beep(1),
        screen(D,W),
    T is D - 140,
        L is W - 520,
        dialog('Total Evaluation Result',T,L,120,360,
    [button(16,280,25,60,'OK'),
        button(52,280,20,60,'Cancel'),
        text(20,10,16,150, 'SHAVER CONCEPT: '),
        text(20,160,16,100, writeq(Name)),
        text(80,10,16,160, 'TOTAL SCORE: '),
        text(80,120,16,100, writeq(Score))],
        Btn).
```

/* SHAVER TOTAL EVALUATION CODE */

```
action shaver_total_output(Name,Score);
if Score = 100 then
pass_result_shaver_total(Name,Score) else
fail_result_shaver_total(Name,Score)
end if.

action pass_result_shaver_total(Name,Score);
    shaver_total_dialog(Name,Score).

action fail_result_shaver_total(Name,Score);
        shaver_total_dialog(Name,Score).
```

/* CODE FOR EVALUATING EVERY ATTRIBUTE IN TURN */

```
action shaver_total;
do restart
and shaver_attractive(S1)
and shave(S2)
and shaver_comfortable(S3)
and irritate_skin(S4)
and clean(S5)
and hair(S6)
and cut_or_nick(S7)
and hygienic(S8)
and shaver_total_output(Name,(S1 + S2 + S3 + S4 + S5 + S6 + S7 + S8) / 800 *(100)).
```

/* DOES NOT CUT OR NICK FACE CODE */

/* ATTRIBUTE MODEL */

```
relation does_not_cut_or_nick(Name,Score)

if Name is an instance of shaver
and the Score1 is
if the shaver_blade_material of Name is some instance of metal_that_will_cut_hair then 1 else 0
and the Score2 is
if the number_of_blades of Name is greater than or equal to 1.0 and the number_of_blades of
Name is less than or equal to 2.0 then 1 else 0
 and the Score3 is
if the shaver_blade_length of Name is greater than or equal to 33 and the shaver_blade_length
of Name is less than or equal to 39 then 1 else 0
and the Score4 is
if the shaver_head_cross_section of Name is some instance of cross_section_safe_for_razor
then 1 else 0
and the Score5 is
if the distance_between_blades of Name is greater than or equal to 1.0 and the
distance_between_blades of Name is less than or equal to 2.0 then 1 else 0
and the Score6 is
```

```
if the shaver_head_shape of Name is some instance of shape_safe_for_razor_head then 1 else 0

and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6) / 6 *(100).

relation check_cut_or_nick(Name,Score)
if does_not_cut_or_nick(Name,Score)
 and cut_or_nick_output(Name,Score).

action cut_or_nick (Score);
        do restart
        and enter_shaver_cut_or_nick(Name,Score)
        and check_cut_or_nick(Name,Score) .

action cut_or_nick_output(Name,Score);
if Score = 100 then
 pass_result_cut_or_nick(Name,Score) else
 fail_result_cut_or_nick(Name,Score)
end if.

/*action cut_or_nick_outputfail(Name,Score);
comparison(<, Score, 100) and
 fail_result_cut_or_nick(Name,Score).*/

action cut_or_nick_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* DOES NOT IRRITATE SKIN CODE */

/* ATTRIBUTE MODEL */

```
relation does_not_irritate_skin(Name,Score)
```

```
if Name is an instance of shaver
and the Score1 is
if the shaver_head_material of Name is some instance of hygienic_material then 1 else 0
and the Score2 is
if the shaver_blade_material of Name is some instance of metal_that_will_cut_hair then 1 else 0
and the Score3 is
if the number_of_blades of Name is greater than or equal to 1.0 and the number_of_blades of
Name is less than or equal to 2.0 then 1 else 0
and the Score4 is
if the shaver_blade_length of Name is greater than or equal to 33 and the shaver_blade_length
of Name is less than or equal to 39 then 1 else 0
and the Score5 is
if the distance_between_blades of Name is greater than or equal to 1.0 and the
distance_between_blades of Name is less than or equal to 2.0 then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5) / 5 *(100).

relation check_irritate_skin(Name,Score)
if does_not_irritate_skin(Name,Score)
and skin_output(Name,Score).

action irritate_skin (Score);
        do restart
        and enter_shaver_skin(Name,Score)
        and check_irritate_skin(Name,Score) .

action skin_output(Name,Score);
if Score = 100 then
pass_result_skin(Name,Score) else
fail_result_skin(Name,Score)
end if.

/*action skin_outputfail(Name,Score);
```

```
comparison(<, Score, 100) and
fail_result_skin(Name,Score).*/

action skin_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* EASY TO CLEAN CODE */

/* ATTRIBUTE MODEL */

```
relation easy_to_clean(Name,Score)

if Name is an instance of shaver
and the Score1 is
if the shaver_head_material of Name is some instance of easy_clean_material then 1 else 0
and the Score2 is
if the shaver_texture of Name is some instance of easy_clean_texture then 1 else 0
and the Score3 is
if the shaver_blade_material of Name is some instance of metal_that_will_cut_hair then 1 else 0
and the Score4 is
if the number_of_blades of Name is greater than or equal to 1.0 and the number_of_blades of
Name is less than or equal to 2.0 then 1 else 0
and the Score5 is
if the shaver_blade_length of Name is greater than or equal to 33 and the shaver_blade_length
of Name is less than or equal to 39 then 1 else 0
and the Score6 is
if the distance_between_blades of Name is greater than or equal to 1.0 and the
distance_between_blades of Name is less than or equal to 2.0 then 1 else 0
and the Score7 is
if the shaver_head_length of Name is greater than or equal to 37 and the shaver_head_length of
Name is less than or equal to 43 then 1 else 0
and the Score8 is
```

```
if the shaver_head_width of Name is greater than or equal to 4 and the shaver_head_width of
Name is less than or equal to 10 then 1 else 0
and the Score9 is
if the shaver_head_shape of Name is some instance of easy_clean_shape then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6 + Score7 + Score8 +
Score9) / 9 *(100).

relation check_clean(Name,Score)
if easy_to_clean(Name,Score)
        and clean_output(Name,Score).

action clean (Score);
        do restart
        and enter_shaver_easy_to_clean(Name,Score)
        and check_clean(Name,Score) .

action clean_output(Name,Score);
if Score = 100 then
pass_result_clean(Name,Score)else
fail_result_clean(Name,Score)
end if.

/*action clean_outputfail(Name,Score);
fail_result_clean(Name,Score).*/

action clean_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* GIVES A CLOSE SHAVE CODE */

/* ATTRIBUTE MODEL */

```
relation close_shave(Name,Score)

if Name is an instance of shaver
and the Score1 is
if the shaver_blade_material of Name is some instance of metal_that_will_cut_hair then 1 else 0
and the Score2 is
if the number_of_blades of Name is greater than or equal to 1.0 and the number_of_blades of
Name is less than or equal to 2.0 then 1 else 0
and the Score3 is
if the shaver_blade_length of Name is greater than or equal to 33 and the shaver_blade_length
of Name is less than or equal to 39 then 1 else 0
and the Score4 is
if the angle_between_head_and_handle of Name is greater than or equal to 40 and the
angle_between_head_and_handle of Name is less than or equal to 50 then 1 else 0
and the Score5 is
if the shaver_head_cross_section of Name is some instance of cross_section_safe_for_razor
then 1 else 0
and the Score6 is
if the distance_between_blades of Name is greater than or equal to 1.0 and the
distance_between_blades of Name is less than or equal to 2.0 then 1 else 0
and the Score7 is
if the shaver_head_shape of Name is some instance of shape_safe_for_razor_head then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6 + Score7) / 7 *(100).

relation check_close_shave(Name,Score)
if close_shave(Name,Score)
        and shave_output(Name,Score).

action shave(Score);
        do restart
        and enter_shaver_close(Name,Score)
        and check_close_shave(Name,Score) .
```

```
action shave_output(Name,Score);
if Score = 100 then
pass_result_shave(Name,Score) else
fail_result_shave(Name,Score)
end if.

/*action shave_outputfail(Name,Score);
fail_result_shave(Name,Score).*/

action shave_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* IS HYGIENIC CODE */

/* ATTRIBUTE MODEL */

```
relation is_hygienic(Name,Score)

if Name is an instance of shaver
and the Score1 is
if the shaver_handle_material of Name is some instance of  hygienic_material then 1 else 0
and the Score2 is
if the shaver_head_material of Name is some instance of hygienic_material then 1 else 0
and the Score3 is
if the shaver_texture of Name is some instance of hygienic_texture then 1 else 0
and the Score4 is
if the shaver_blade_material of Name is some instance of metal_that_will_cut_hair then 1 else 0
and the Score5 is
if the distance_between_blades of Name is greater than or equal to 1.0 and the
distance_between_blades of Name is less than or equal to 2.0 then 1 else 0
and the Score6 is
```

```
if the shaver_blade_length of Name is greater than or equal to 33 and the shaver_blade_length
of Name is less than or equal to 39 then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6) / 6 *(100).

relation check_hygienic(Name,Score)
if is_hygienic(Name,Score)
 and hygienic_output(Name,Score).

action hygienic (Score);
        do restart
        and enter_shaver_hygienic(Name,Score)
        and check_hygienic(Name,Score) .

action hygienic_output(Name,Score);
if Score = 100 then
 pass_result_hygienic(Name,Score) else
 fail_result_hygienic(Name,Score)
end if.

/*action hygienic_outputfail(Name,Score);
comparison(<, Score, 100) and
 fail_result_hygienic(Name,Score).*/

action hygienic_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* REMOVES DIFFICULT HAIR CODE */

/* ATTRIBUTE MODEL */

```
relation removes_difficult_hair(Name,Score)
```

if Name is an instance of shaver

and the Score1 is

if the shaver_head_length of Name is greater than or equal to 37 and the shaver_head_length of Name is less than or equal to 43 then 1 else 0

and the Score2 is

if the shaver_head_width of Name is greater than or equal to 4 and the shaver_head_width of Name is less than or equal to 10 then 1 else 0

and the Score3 is

if the shaver_head_thickness of Name is greater than or equal to 4 and the shaver_head_thickness of Name is less than or equal to 10 then 1 else 0

and the Score4 is

if the number_of_blades of Name is greater than or equal to 1.0 and the number_of_blades of Name is less than or equal to 2.0 then 1 else 0

and the Score5 is

if the shaver_blade_length of Name is greater than or equal to 33 and the shaver_blade_length of Name is less than or equal to 39 then 1 else 0

and the Score6 is

if the shaver_head_shape of Name is some instance of shape_safe_for_razor_head then 1 else 0

and the Score7 is

if the angle_between_head_and_handle of Name is greater than or equal to 40 and the angle_between_head_and_handle of Name is less than or equal to 50 then 1 else 0

and the Score8 is

if the shaver_head_cross_section of Name is some instance of cross_section_safe_for_razor then 1 else 0

and the Score9 is

if the distance_between_blades of Name is greater than or equal to 1.0 and the distance_between_blades of Name is less than or equal to 2.0 then 1 else 0

and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6 + Score7 + Score8 + Score9) / 9 *(100).

relation check_removes_difficult_hair(Name,Score)

if removes_difficult_hair(Name,Score)

```
        and hair_output(Name,Score).

action hair (Score);
        do restart
        and enter_shaver_hair(Name,Score)
        and check_removes_difficult_hair(Name,Score) .

action hair_output(Name,Score);
if Score = 100 then
pass_result_hair(Name,Score) else
fail_result_hair(Name,Score)
end if.

/*action hair_outputfail(Name,Score);
fail_result_hair(Name,Score).*/

action hair_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* SHAVER COMFORTABLE TO HOLD CODE */

/* ATTRIBUTE MODEL */

```
relation shaver_comfortable_to_hold(Name,Score)

if Name is an instance of shaver
and the Score1 is
if the shaver_overall_length of Name is greater than or equal to 100 and the
shaver_overall_length of Name is less than or equal to 130 then 1 else 0
and the Score2 is
if the shaver_handle_length of Name is greater than or equal to 75 and the
shaver_handle_length of Name is less than or equal to 101 then 1 else 0
```

and the Score3 is
if the shaver_handle_width of Name is greater than or equal to 7 and the shaver_handle_width of Name is less than or equal to 12 then 1 else 0
and the Score4 is
if the shaver_handle_thickness of Name is greater than or equal to 7 and the shaver_handle_thickness of Name is less than or equal to 12 then 1 else 0
and the Score5 is
if the shaver_handle_shape of Name is some instance of comfortable_handle_shape then 1 else 0
and the Score6 is
if the shaver_handle_cross_section of Name is some instance of comfortable_handle_cross_section then 1 else 0
and the Score7 is
if the shaver_texture of Name is some instance of comfortable_handle_texture then 1 else 0
and the Score8 is
if the shaver_handle_material of Name is some instance of not_heavy_material then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6 + Score7 + Score8) / 8 *(100).

relation check_shaver_comfort(Name,Score)
if shaver_comfortable_to_hold(Name,Score)
and shaver_comfortable_output(Name,Score).

action shaver_comfortable (Score);
do restart
and enter_shaver_comfortable(Name,Score)
and check_shaver_comfort(Name,Score) .

action shaver_comfortable_output(Name,Score);
if Score = 100 then
pass_result_shaver_comfortable(Name,Score) else
fail_result_shaver_comfortable(Name,Score)

```
end if.


action shaver_comfortable_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* SHAVER LOOKS ATTRACTIVE CODE */

/* ATTRIBUTE MODEL */

```
relation looks_shaver_attractive(Name,Score)

if Name is an instance of shaver
and the Score1 is
if the shaver_handle_material of Name is some instance of attractive_material then 1 else 0
and the Score2 is
if the shaver_head_material of Name is some instance of attractive_material then 1 else 0
and the Score3 is
if the shaver_handle_colour of Name is some instance of attractive_shaver_colour then 1 else 0
and the Score4 is
if the shaver_head_colour of Name is some instance of attractive_shaver_colour then 1 else 0
and the Score5 is
if the shaver_texture of Name is some instance of comfortable_handle_texture then 1 else 0
and the Score6 is
if the shaver_handle_shape of Name is some instance of attractive_shape then 1 else 0
and the Score7 is
if the shaver_head_cross_section of Name is some instance of attractive_shape then 1 else 0
and the Score8 is
if the shaver_handle_cross_section of Name is some instance of attractive_shape then 1 else 0
and the Score9 is
if the shaver_head_shape of Name is some instance of attractive_shape then 1 else 0
and Score is (Score1 + Score2 + Score3 + Score4 + Score5 + Score6 + Score7 + Score8 +
```

```
Score9) / 9 *(100).

relation check_looks_shaver_attractive(Name,Score)
if looks_shaver_attractive(Name,Score)
        and shaver_attractive_output(Name,Score).

action shaver_attractive (Score);
        do restart
        and enter_shaver_attractive(Name,Score)
        and check_looks_shaver_attractive(Name,Score) .

action shaver_attractive_output(Name,Score);
if Score = 100 then
pass_result_shaver_attractive(Name,Score) else
fail_result_shaver_attractive(Name,Score)
end if.

action shaver_attractive_write_value(Label, Value);
        do write(Label)
        and write(Value)
        and nl .
```

/* SHAVER ATTRIBUTE MODEL GRAPHICAL INTERFACE DIALOG CODE (EXAMPLE) */

```
enter_shaver_attractive(Name,Score) :-

create_shaver_dialog_attractive([Name,SHAM,SHEM,SHAC,SHEC,ST,SHAS,HECS,HAC
S,SHES]),
        new_instance(Name,shaver),
        new_slot(shaver_handle_material,Name,SHAM),
        new_slot(shaver_head_material,Name,SHEM),
new_slot(shaver_handle_colour,Name,SHAC),
```

```
	new_slot(shaver_head_colour,Name,SHEC),
	new_slot(shaver_texture,Name,ST),
	new_slot(shaver_handle_shape,Name,SHAS),
	new_slot(shaver_head_cross_section,Name,HECS),
	new_slot(shaver_handle_cross_section,Name,HACS),
	new_slot(shaver_head_shape,Name,SHES).

create_shaver_dialog_attractive([Name,SHAM,SHEM,SHAC,SHEC,ST,SHAS,HECS,HAC
S,SHES]) :-
	dialog('Looks attractive Evaluation',40,5,420,380,
		[button(350,300,25,60,'OK'),
	  button(380,300,20,60,'Cancel'),
	text(5,10,16,140,'Shaver Name:'),
	edit(5,140,16,140,'',Name),
	text(35,10,16,220,'Shaver Handle Material:'),
	edit(55,140,16,140,'',SHAM),
	text(75,10,16,220,'Shaver Head Material:'),
	edit(95,140,16,140,'',SHEM),
	text(115,10,16,220,'Shaver Handle Colour (foremost):'),
	edit(135,140,16,140,'',SHAC),
	text(155,10,16,220,'Shaver Head Colour (foremost):'),
	edit(175,140,16,140,'',SHEC),
	text(195,10,160,220,'Shaver Handle Texture:'),
	edit(215,140,16,140,'',ST),
	text(235,10,16,220,'Shaver Handle Shape:'),
	edit(255,140,16,140,'',SHAS),
	text(275,10,16,220,'Shaver Head Cross-Section:'),
	edit(295,140,16,140,'',HECS),
	text(315,10,16,220,'Shaver Handle Cross-Section:'),
	edit(335,140,16,140,'',HACS),
	text(355,10,16,220,'Shaver Head Shape:'),
	edit(375,140,16,140,'',SHES)
```

```
],
      Btn).

pass_result_shaver_attractive(Name,Score) :-
      shaver_mydialog('WOULD LOOK ATTRACTIVE',Name,Score).

fail_result_shaver_attractive(Name,Score) :-
            shaver_mydialog('WOULD NOT LOOK ATTRACTIVE',Name,Score).
```

/* SHAVER EXPLANATION FACILITY */

Explain Evaluation 'WOULD NOT LOOK ATTRACTIVE' /* Shaver concept would not look attractive!

(1) The shaver handle is generally made from thermoplastics such as: polystyrene or polypropylene or ABS, or metals, such as: steel, brass, zinc diecast (Warrick, 1994). Other suitable materials include Polypropylene blends, and Polystyrene blends (Terry, 1991).

(2) Generally thermoplastics such as: polystyrene or polypropylene, or metals, such as: steel, brass, zinc diecast are suitable materials for the shaver head (Richardson, 1989).

(3) Colours which portray an image of cleanliness, freshness, and healthiness etc. are suitable colours for the shaver handle. These colours include blue, green, white, grey, yellow (Kobayashi, 1990).

(4) Colours which portray an image of cleanliness, freshness, and healthiness etc. are suitable colours for the shaver head. These colours include blue, green, white, grey, yellow (Kobayashi, 1990).

(5) Suitable textures are those whose surface quality is neither too smooth as to be slippery nor too rough as to be abrasive (Pheasant, 1986).

(6) Generally the handle shape should be based on the standard 'T', which is a long straight handle with the cartridge at one end of the handle (Warrick, 1994).

(7) The head cross-section should generally be based on a rectangular shape (Warrick, 1994).

(8) The cross-sectional profile of the handle should be based on two common shapes, the circle and the rectangle. Variations or combinations of these two basic shapes may also be used (Warrick, 1994). Handles of circular cross-sections are the most comfortable to grip (Woodson et al, 1992).

(9) The shaver head shape should be based on a rectangular shape (Warrick, 1994).

Explain Evaluation 'WOULD LOOK ATTRACTIVE' /* Shaver concept would look attractive because:

(1) The shaver handle is made from a thermoplastic such as: polystyrene or polypropylene or ABS, or a metal, such as: steel, brass, zinc diecast (Warrick, 1994) (Terry, 1991).

(2) The shaver head is made from a thermoplastic such as: polystyrene, ABS, polypropylene or like-blends, or a metal, such as: steel, brass, zinc diecast (Richardson, 1989).

(3) The shaver handle colour portrays an image of cleanliness, freshness, or healthiness etc. Colours including blue, green, white, grey, yellow (Kobayashi, 1990).

(4) The shaver head colour portrays an image of cleanliness, freshness, or healthiness etc. Colours including blue, green, white, grey, yellow (Kobayashi, 1990).

(5) The shaver texture has a surface quality which is neither too smooth as to be slippery nor too rough as to be abrasive (Pheasant, 1986).

(6) The handle shape is based on the standard 'T', which is a long straight handle with the cartridge at one end of the handle (Warrick, 1994).

(7) The head cross-section is based on a rectangular shape (Warrick, 1994).

(8) The cross-sectional profile of the handle is based on either of the two common shapes, the circle and the rectangle. Variations or combinations of these two basic shapes may also be used (Warrick, 1994). Handles of circular cross-sections are the most comfortable to grip (Woodson et al, 1992).

(9) The shaver head shape is based on a rectangular shape (Warrick, 1994).

Explain Evaluation 'WOULD NOT GIVE A CLOSE SHAVE' /* Shaver concept would not give a close shave!

(1) Steel, stainless steel and platinum blades, with a chromium content of 12-14% and a carbon content of 0.6-0.7%, are generally the most appropriate metals used (Alexander, 1981).

(2) Single bladed devices are still used and preferred by some over the twin bladed device, however general preference is for two blades (Warrick, 1994).

(3) Most blades are approximately 35.5 mm. long (Warrick, 1994).

(4) General range of angle between head and handle for both types of razors: 40° to 50° (Terry, 1991) (Warrick, 1994).

(5) The head cross-section should generally be based on a rectangular shape (Warrick, 1994).
(6) A space of 1.5 mm. between the first and second blade improves the closeness of shave (Terry, 1991).
(7) The shaver head shape should be based on a rectangular shape (Warrick, 1994).

Explain Evaluation 'WOULD GIVE A CLOSE SHAVE' /* Shaver concept would give a close shave because:
(1) The blades are made from either steel, stainless steel or platinum blades, with a chromium content of 12-14% and a carbon content of 0.6-0.7% (Alexander, 1981).
(2) The shaver is either single bladed or has two blades (Warrick, 1994).
(3) The shaver blade length is 35.5 mm. long (+/- 5mm) (Warrick, 1994).
(4) The angle between head and handle lies between 40° and 50° (Terry, 1991) (Warrick, 1994).
(5) The head cross-section is based on a rectangular shape (Warrick, 1994).
(6) There is a space of 1.5 mm. between the first and second blade of the shaver (Terry, 1991).
(7) The shaver head shape is based on a rectangular shape (Warrick, 1994).

Explain Evaluation 'WOULD NOT BE COMFORTABLE TO HOLD' /* Shaver concept would not be comfortable to hold!
(1) Razors are broken down into two different markets: Disposables and Systems. Disposable Razor Length Range - 100 to 115 mm. in twin blade devices. System Razor Length Range - 118 to 130 mm. (Warrick, 1994).
(2) Handle length refers to the area designed for general holding of the razor, this may or may not have finger grips. Disposable Razor Length Range - 77 to 94 mm. in twin blade devices. System Razor Length Range - 75 to 100 mm. (Warrick, 1994)
(3) This range refers to both the Disposable and System Razors, i.e. 7 - 12 mm. (Warrick, 1994).
(4) Generally the same range as handle width (i.e. 7 - 12 mm.), (Warrick, 1994).
(5) Generally the handle shape should be based on the standard 'T', which is a long straight handle with the cartridge at one end of the handle (Warrick, 1994).
(6) The cross-sectional profile of the handle should be based on two common shapes, the circle and the rectangle. Variations or combinations of these two basic shapes may also be used

(Warrick, 1994). Handles of circular cross-sections are the most comfortable to grip (Woodson et al, 1992).

(7) Suitable textures are those whose surface quality is neither too smooth as to be slippery nor too rough as to be abrasive (Pheasant, 1986).

(8) The shaver handle is generally made from thermoplastics such as: polystyrene or polypropylene or ABS, or metals, such as: steel, brass, zinc diecast (Warrick, 1994). Other suitable materials include Polypropylene blends, and Polystyrene blends (Terry, 1991).

Explain Evaluation 'WOULD BE COMFORTABLE TO HOLD' /* Shaver concept would be comfortable to hold because:

(1) The overall length of the shaver is between 100 and 130 mm. (Warrick, 1994).

(2) The handle length ranges from 75 to 100 mm. (Warrick, 1994)

(3) The handle width is between 7 - 12 mm. (Warrick, 1994).

(4) The handle thickness is between 7 - 12 mm. (Warrick, 1994).

(5) The handle shape is based on the standard 'T', which is a long straight handle with the cartridge at one end of the handle (Warrick, 1994).

(6) The cross-sectional profile of the handle is based on either one of the two common shapes, the circle and the rectangle. Variations or combinations of these two basic shapes may also be used (Warrick, 1994). Handles of circular cross-sections are the most comfortable to grip (Woodson et al, 1992).

(7) The texture of the shaver handle is neither too smooth as to be slippery nor too rough as to be abrasive (Pheasant, 1986).

(8) The shaver handle is made from a thermoplastic such as: polystyrene or polypropylene or ABS, or a metal, such as: steel, brass, zinc diecast (Warrick, 1994) (Terry, 1991).

Explain Evaluation 'WOULD NOT IRRITATE SKIN' /* Shaver concept would not irritate skin because:

(1) The shaver head is made from a thermoplastic such as: polystyrene, ABS, polypropylene or like-blends, or a metal, such as: steel, brass, zinc diecast (Richardson, 1989)

(2) The blades are made from either steel, stainless steel or platinum blades, with a chromium content of 12-14% and a carbon content of 0.6-0.7% (Alexander, 1981).

(3) The shaver is either single bladed or has two blades (Warrick, 1994).

(4) The shaver blade length is 35.5 mm. long (+/- 5mm) (Warrick, 1994).

(5) There is a space of 1.5 mm. between the first and second blade of the shaver (Terry, 1991).

Explain Evaluation 'WOULD IRRITATE SKIN' /* Shaver concept would irritate skin!

(1) The shaver head is generally made from a thermoplastic such as: polystyrene, ABS, polypropylene or like-blends, or a metal, such as: steel, brass, zinc diecast (Richardson, 1989)

(2) The shaver blades are usually made from either steel, stainless steel or platinum blades, with a chromium content of 12-14% and a carbon content of 0.6-0.7% (Alexander, 1981).

(3) The shaver should be either single or double bladed (Warrick, 1994).

(4) The shaver blade length should be 35.5 mm. long (give or take 5mm) (Warrick, 1994).

(5) There should be a space of 1.5 mm.-2 mm. between the first and second blade of the shaver (Terry, 1991).

Explain Evaluation 'WOULD NOT BE EASY TO CLEAN' /* Shaver concept would not be easy to clean!

(1) The shaver head is generally made from a thermoplastic such as: polystyrene, ABS, polypropylene or like-blends, or a metal, such as: steel, brass, zinc diecast (Richardson, 1989).

(2) Suitable textures are those whose surface quality is neither too smooth as to be slippery nor too rough as to be abrasive (Pheasant, 1986).

(3) The shaver blades are usually made from either steel, stainless steel or platinum blades, with a chromium content of 12-14% and a carbon content of 0.6-0.7% (Alexander, 1981).

(4) The shaver should be either single or double bladed (Warrick, 1994).

(5) The shaver blade length should be 35.5 mm. long (give or take 5mm) (Warrick, 1994).

(6) There should be a space of 1.5 mm.-2 mm. between the first and second blade of the shaver (Terry, 1991).

(7) The nominal value is 39.5 mm. for both Disposable and System Razors (give or take 5mm) (Warrick, 1994).

(8) Fixed blade cartridges are generally 5 mm. wide. Dynamic blade systems (sprung mounted blades) are usually approx. 8.5 mm. wide (Warrick, 1994).

(9) The shaver head shape should be based on a rectangular shape (Warrick, 1994).

Explain Evaluation 'WOULD BE EASY TO CLEAN' /* Shaver concept would be easy to clean because:

(1) The shaver head is made from a thermoplastic such as: polystyrene, ABS, polypropylene or like-blends, or a metal, such as: steel, brass, zinc diecast (Richardson, 1989).

(2) The shaver texture has a surface quality which is neither too smooth as to be slippery nor too rough as to be abrasive (Pheasant, 1986).

(3) The shaver blades are made from either steel, stainless steel or platinum blades, with a chromium content of 12-14% and a carbon content of 0.6-0.7% (Alexander, 1981).

(4) The shaver is either a single or double bladed device (Warrick, 1994).

(5) The shaver blade length is 35.5 mm. long (give or take 5mm) (Warrick, 1994).

(6) There is a space of 1.5 mm.-2 mm. between the first and second blade of the shaver (Terry, 1991).

(7) The shaver head length is 39.5 mm. (give or take 5mm.) (Warrick, 1994).

(8) The shaver head width is between 5 mm. wide. and 10.0 mm. wide (Warrick, 1994).

(9) The shaver head shape is based on a rectangular shape (Warrick, 1994).

Explain Evaluation 'WOULD NOT REMOVE HAIR IN DIFFICULT AREAS' /* Shaver concept would not remove hair in difficult areas!

(1) The nominal head length value is 39.5 mm. for both Disposable and System Razors (give or take 5mm) (Warrick, 1994).

(2) Fixed blade cartridges are generally 5 mm. wide. Dynamic blade systems (sprung mounted blades) are usually approx. 8.5 mm. wide (Warrick, 1994).

(3) Generally between 4 to 10 mm., but ultimately depends on the blade dynamics (Warrick, 1994).

(4) The shaver should be either single or double bladed (Warrick, 1994).

(5) The shaver blade length should be 35.5 mm. long (give or take 5mm) (Warrick, 1994).

(6) The shaver head shape should be based on a rectangular shape (Warrick, 1994).

(7) Generally the range of angle between head and handle for both types of razors should be between 40° to 50° (Terry, 1991) (Warrick, 1994).

(8) The head cross-section should generally be based on a rectangular shape (Warrick, 1994).

(9) There should be a space of 1.5 mm.-2 mm. between the first and second blade of the shaver (Terry, 1991).

Explain Evaluation 'WOULD REMOVE HAIR IN DIFFICULT AREAS' /* Shaver concept would remove hair in difficult areas because:

(1) The head length value is 39.5 mm. (give or take 5mm) (Warrick, 1994).

(2) The head width lies between 5 mm. wide. and 8.5 mm. wide (Warrick, 1994).

(3) The head thickness is between 4 to 10 mm. (Warrick, 1994).

(4) The shaver is either a single or double bladed system (Warrick, 1994).

(5) The shaver blade length is 35.5 mm. long (give or take 5mm) (Warrick, 1994).

(6) The shaver head shape is based on a rectangular shape (Warrick, 1994).

(7) The angle between head and handle is between 40° to 50° (Terry, 1991) (Warrick, 1994).

(8) The head cross-section is based on a rectangular shape (Warrick, 1994).

(9) There is a space of 1.5 mm.-2 mm. between the first and second blade of the shaver (Terry, 1991).

Explain Evaluation 'WOULD NOT CUT OR NICK FACE' /* Shaver concept would not cut or nick face because:

(1) The shaver blades are made from either steel, stainless steel or platinum blades, with a chromium content of 12-14% and a carbon content of 0.6-0.7% (Alexander, 1981).

(2) The shaver is either a single or double bladed device (Warrick, 1994).

(3) The shaver blade length is 35.5 mm. long (give or take 5mm) (Warrick, 1994).

(4) The head cross-section is based on a rectangular shape (Warrick, 1994).

(5) There is a space of 1.5 mm. to 2 mm. between the first and second blade of the shaver (Terry, 1991).

(6) The shaver head shape is based on a rectangular shape (Warrick, 1994).

Explain Evaluation 'WOULD CUT OR NICK FACE' /* Shaver concept would cut or nick face!

(1) The shaver blades are usually made from either steel, stainless steel or platinum blades, with a chromium content of 12-14% and a carbon content of 0.6-0.7% (Alexander, 1981).

(2) The shaver should be either single or double bladed (Warrick, 1994).

(3) The shaver blade length should be 35.5 mm. long (give or take 5mm) (Warrick, 1994).

(4) The head cross-section should be based on a rectangular shape (Warrick, 1994).

(5) There should be a space of 1.5 mm. - 2 mm. between the first and second blade of the

shaver (Terry, 1991).

(6) The shaver head shape should be based on a rectangular shape (Warrick, 1994).

Explain Evaluation 'WOULD NOT BE HYGIENIC' /* Shaver concept would not be hygienic!

(1) The shaver handle is generally made from thermoplastics such as: polystyrene or polypropylene or ABS, or metals, such as: steel, brass, zinc diecast (Warrick, 1994). Other suitable materials include Polypropylene blends, and Polystyrene blends (Terry, 1991).

(2) Generally thermoplastics such as: polystyrene or polypropylene, or metals, such as: steel, brass, zinc diecast are suitable materials for the shaver head (Richardson, 1989).

(3) Suitable textures are those whose surface quality is neither too smooth as to be slippery nor too rough as to be abrasive (Pheasant, 1986).

(4) The shaver blades are usually made from either steel, stainless steel or platinum blades, with a chromium content of 12-14% and a carbon content of 0.6-0.7% (Alexander, 1981).

(5) There should be a space of 1.5 mm. - 2 mm. between the first and second blade of the shaver (Terry, 1991).

(6) The shaver blade length should be 35.5 mm. long (give or take 5mm) (Warrick, 1994).

Explain Evaluation 'WOULD BE HYGIENIC' /* Shaver concept would be hygienic because:

(1) The shaver handle is made from a thermoplastic such as: polystyrene or polypropylene or ABS, or a metal, such as: steel, brass, zinc diecast (Warrick, 1994). Other suitable materials include Polypropylene blends, and Polystyrene blends (Terry, 1991).

(2) The shaver head material is made from a thermoplastic such as: polystyrene or polypropylene, or a metal, such as: steel, brass, zinc diecast are suitable materials for the shaver head (Richardson, 1989).

(3) The shaver texture has a surface quality which is neither too smooth as to be slippery nor too rough as to be abrasive (Pheasant, 1986).

(4) The shaver blades are made from either steel, stainless steel or platinum blades, with a chromium content of 12-14% and a carbon content of 0.6-0.7% (Alexander, 1981).

(5) There is a space of 1.5 mm. - 2 mm. between the first and second blade of the shaver (Terry, 1991).

(6) The shaver blade length is 35.5 mm. long (give or take 5mm) (Warrick, 1994).

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COLOUR DATABASE (INCOMPLETE)

/* COLOUR DATA taken from KOBAYASHI, S., Colour Image Scale, London: Kodansha International, 1990 */

frame white is a colour;
default image is {romantic or clear or crystalline or festive or simple or youthful or sporty or fresh or sharp}.

frame silver_grey is a colour;
default image is {chic or refined or quiet or simple_quiet_and_elegant or sober or youthful or distinguished or rational or modern or metallic}.

frame light_grey is a colour;
default image is {simple_and_appealing or simple_quiet_and_elegant or intellectual or provincial or modest or solemn or masculine or formal or sublime}.

frame medium_grey is a colour;
default image is {simple_and_appealing or simple_quiet_and_elegant or intellectual or provincial or modest or solemn or masculine or formal or sublime}.

frame charcoal_grey is a colour;
default image is {subtle_and_mysterious or intellectual or formal or old_fashioned or sturdy or sublime or robust or heavy_and_deep or authoritative}.

frame black is a colour;
default image is {bold or stylish or modern or fiery or intense or sharp or striking or strong_and_robust or metallic}.

frame carmine is a colour;
default image is {bright or festive or lively or hot or vigorous or bold or forceful or dynamic or dynamic_and_active}.

frame rose is a colour;
default image is {sweet or cheerful or childlike or joyful or bright or merry or festive or colourful or brilliant}.

frame baby_pink is a colour;
default image is {agreeable_to_the_touch or amiable or innocent or smooth or gentle or supple or sweet_and_dreamy or soft or charming}.

frame pink_beige is a colour;
default image is {agreeable_to_the_touch or supple or soft or smooth or amiable or tender or gentle_and_elegant or mild or genteel}.

frame rose_grey is a colour;
default image is {gentle_and_elegant or calm or sedate or nostalgic or japanese or elegant or mellow or sleek or emotional}.

frame red is a colour;
default image is {extravagant or mellow or ethnic or rich or luxurious or elaborate or robust or dynamic_and_active or untamed} .

frame brick_red is a colour;
default image is {extravagant or mellow or ethnic or rich or luxurious or elaborate or robust or dynamic_and_active or untamed}.

frame maroon is a colour;
default image is {dynamic_and_active or placid or quiet_and_sophisticated or wild or old_fashioned or dignified or untamed or serious or strong_and_robust}.

frame orange is a colour;
default image is {dazzling or delicious or casual or flamboyant or abundant or enjoyable or forceful or tropical or lively}.

frame persimmon is a colour;
default image is {aromatic or bright or enjoyable or delicious or abundant or rich or luxurious or dynamic_and_active or untamed}.

frame beige is a colour;
default image is {intimate or amiable or wholesome or pleasant or natural or generous or calm or gentle_and_elegant or domestic}.

frame camel is a colour;
default image is {calm or simple_quiet_and_elegant or provincial or aromatic or rustic or diligent or old_fashioned or classic or traditional}.

frame brown is a colour;
default image is {delicious or aromatic or pastoral or rustic or practical or traditional or untamed or grand or sturdy}.

frame yellow is a colour;
default image is {vivid or flamboyant or sporty or showy or dazzling or lively or bold or dynamic or intense}.

frame gold is a colour;
default image is {hot or ethnic or extravagant or rich or mature or decorative or substantial or luxurious or gorgeous}.

frame sulphur is a colour;
default image is {cheerful or healthy or citrus or cute or childlike or youthful or merry or open or young}.

frame ivory is a colour;
default image is {gentle or free or wholesome or friendly or dreamy or plain or generous or open or peaceful}.

frame mustard is a colour;
default image is {intimate or wholesome or simple_and_appealing or restful or calm or natural or pastoral or provincial or interesting}.

frame khaki is a colour;
default image is {extravagant or decorative or pastoral or elaborate or ethnic or rustic or gorgeous or wild or bitter}.

frame olive is a colour;
default image is {tasteful or placid or bitter or sturdy or quiet_and_sophisticated or traditional or untamed or old_fashioned or conservative}.

frame yellow_green is a colour;
default image is {enjoyable or healthy or fresh or festive or open or clean_and_fresh or flamboyant or amusing or striking}.

frame grass_green is a colour;
default image is {lighthearted or wholesome or calm or natural or interesting or quiet or untamed or ethnic or artistic}.

frame canary is a colour;
default image is {sweet_sour or youthful or free or cute or friendly or fresh or bright or citrus or steady}.

frame mist_green is a colour;
default image is {soft or tranquil or plain or restful or wholesome or natural or domestic or pastoral or interesting}.

frame ivy_green is a colour;
default image is {wild or pastoral or subtle_and_mysterious or ethnic or tasteful or quiet_and_sophisticated or untamed or traditional or conservative}.

frame green is a colour;
default image is {vigorous or vivid or steady or lively or flamboyant or showy or provocative or active or dynamic}.

frame emerald is a colour;
default image is {lighthearted or open or fresh or enjoyable or bright or youthful or merry or showy or provocative}.

frame opaline_green is a colour;
default image is {free or fresh_and_young or pure_and_simple or open or fresh or refreshing or cute or steady or progressive}.

frame ash_grey is a colour;
default image is {supple or tranquil or pure_and_simple or natural or simple_and_appealing or plain or domestic or peaceful or crystalline}.

frame jade_green is a colour;
default image is {abundant or natural or intellectual or adult or tranquil or quiet or complex or interesting or deep}.

frame viridian is a colour;
default image is {tropical or natural or tranquil or wild or decorative or progressive or ethnic or practical or sound}.

frame bottle_green is a colour;
default image is {abundant or adult or quiet or rich or untamed or dignified or robust or classic or practical}.

frame jewel_green is a colour;
default image is {sporty or active or agile or tropical or grand or smart or provocative or mysterious or sharp}.

frame turquoise is a colour;
default image is {pretty or youthful or refreshing or enjoyable or young or clean_and_fresh or tropical or colourful or progressive}.

frame horizon_blue is a colour;
default image is {supple or pure or neat or soft or dreamy or clean or gentle or steady or crystalline}.

frame eggshell_blue is a colour;
default image is {pretty or peaceful or neat or tender or friendly or simple or lighthearted or stylish or pure}.

frame cambridge_blue is a colour;
default image is {ethnic or exact or smart or decorative or mysterious or modern or elaborate or complex or magnificent}.

frame blue is a colour;
default image is {showy or sporty or young or vivid or provocative or speedy or active or bold or sharp}.

frame cerulean_blue is a colour;
default image is {showy or sporty or young or vivid or provocative or speedy or active or bold or sharp}.

frame light_blue is a colour;
default image is {young or fresh_and_young or simple or casual or noble or smart or sporty or masculine or modern}.

frame sky_blue is a colour;
default image is {open or fresh or refreshing or enjoyable or youthful or crystalline or striking or agile or speedy}.

frame aqua_blue is a colour;
default image is {peaceful or clear or crystalline or cute or simple or clean or childlike or clean_and_fresh or smart}.

frame pale_blue is a colour;
default image is {charming or romantic or clear or dreamy or crystalline or pure or pure_and_simple or fresh_and_young or refreshing}.

frame aquamarine is a colour;
default image is {peaceful or interesting or pure_and_simple or noble_and_elegant or intellectual or urbane or stylish or smart or precise}.

frame ultramarine is a colour;
default image is {lively or clean_and_fresh or nimble or vigorous or fleet or progressive or striking or intense or sharp}.

frame sapphire is a colour;
default image is {youthful or neat or pure or young or urbane or refreshing or steady or masculine or intellectual}.

frame mineral_blue is a colour;
default image is {lively or smart or agile or vigorous or composed or rational or sublime or masculine or earnest}.

frame purple is a colour;
default image is {dazzling or glossy or amusing or showy or fascinating or mysterious or decorative or brilliant or provocative}.

frame violet is a colour;
default image is {alluring or glossy or noble_and_elegant or brilliant or mysterious or eminent or elaborate or aristocratic or precious}.

frame lilac is a colour;
default image is {tender or sweet_and_dreamy or pure_and_simple or feminine or emotional or pure_and_elegant or fascinating or brilliant or sleek}.

frame pale_lilac is a colour;
default image is {soft or romantic or tender or sweet_and_dreamy or cultured or dreamy or feminine or delicate or subtle}.

frame pansy is a colour;
default image is {colourful or brilliant or eminent or luxurious or mellow or extravagant or gorgeous or alluring or precious}.

frame prune is a colour;
default image is {mellow or tasteful or modest or elaborate or classic or sublime or decorative or traditional or majestic}.

frame magenta is a colour;
default image is {dazzling or vivid or flamboyant or tropical or showy or colourful or dynamic or fiery or provocative}.

frame cherry_rose is a colour;
default image is {agreeable_to_the_touch or supple or romantic or sunny or innocent or charming or pleasant or gentle_and_elegant or emotional}.

frame orchid is a colour;
default image is {pleasant or tender or feminine or nostalgic or sedate or graceful or glossy or alluring or western}.

frame orchid_grey is a colour;
default image is {tender or sleek or elegant or mild or emotional or subtle or alluring or graceful or chic}.

frame wine is a colour;

default image is {mature or extravagant or gorgeous or mellow or ethnic or decorative or alluring or luxurious or elaborate}.

frame red_grape is a colour;

default image is {substantial or mellow or tasteful or elaborate or classic or majestic or mature or old_fashioned or strong_and_robust}.

frame taupe_brown is a colour;

default image is {luxurious or rustic or intrepid or mature or sturdy or majestic or heavy_and_deep or serious or solemn}.

PLASTICS DATABASE (INCOMPLETE)

/* PLASTICS DATA taken from:

(i) MURPHY, J. (Ed.), New Horizons in Plastics- A handbook for design engineering, London: Weka Publishing Group, February 1991 and

(ii) BASF CAMPUS® Plastics Database Version 2.0, 1991 */

```
frame abs is a thermoplastic;
    default density is 1.07 and
    default water_absorption is 0.35 and
    default tensile_strength is 62 and
    default impact_strength is 50 and
    default  ball_indentation_hardness is 135 and
    default melting_temperature is 250 and
    default toxicity_level is 0.0.

frame abs_15%gf is a thermoplastic;
    default density is 1.19 and
    default water_absorption is 0.3 and
    default tensile_strength is 56 and
    default impact_strength is 19 and
    default  ball_indentation_hardness is 160 and
    default melting_temperature is 250 and
    default toxicity_level is 0.0.

frame polyamide is a thermoplastic;
    default density is 1.13 and
    default water_absorption is 3.4 and
    default tensile_strength is 80 and
    default impact_strength is 50 and
    default ball_indentation_hardness is 150 and
    default melting_temperature is 220 and
    default toxicity_level is 0.0.
```

```
frame polyamide_66 is a thermoplastic;
        default density is 1.13 and
        default water_absorption is 3.1 and
        default tensile_strength is 80 and
        default impact_strength is 50 and
        default ball_indentation_hardness is 160 and
        default melting_temperature is 255 and
        default toxicity_level is 0.0.

frame polyamide_612 is a thermoplastic;
        default density is 1.06 and
        default water_absorption is 0.4 and
        default tensile_strength is 61 and
        default impact_strength is 50 and
        default ball_indentation_hardness is 114 and
        default melting_temperature is 216 and
        default toxicity_level is 0.0.

frame polyamide_12 is a thermoplastic;
        default density is 1.02 and
        default water_absorption is 1.5 and
        default tensile_strength is 55 and
        default impact_strength is 50 and
        default ball_indentation_hardness is 98 and
        default melting_temperature is 220 and
        default toxicity_level is 0.0.

frame polycarbonate is a thermoplastic;
        default density is 1.2 and
        default water_absorption is 0.15 and
        default tensile_strength is 60 and
        default impact_strength is 60 and
```

```
    default ball_indentation_hardness is 110 and
    default melting_temperature is 220 and
    default toxicity_level is 0.0.

frame polybutylene_teraphthalate, is a thermoplastic;
    default density is 1.3 and
    default water_absorption is 0.22 and
    default tensile_strength is 57 and
    default impact_strength is 55 and
    default ball_indentation_hardness is 125 and
    default melting_temperature is 225 and
    default toxicity_level is 0.0.

frame polypropylene is a thermoplastic;
    default density is 0.905 and
    default water_absorption is 0.01 and
    default tensile_strength is 35 and
    default impact_strength is 65 and
    default ball_indentation_hardness is 70 and
    default melting_temperature is 166 and
    default toxicity_level is 0.0.

frame pbtp is a thermoplastic;
    default density is 1.3 and
    default water_absorption is 0.22 and
    default tensile_strength is 57 and
    default impact_strength is 55 and
    default ball_indentation_hardness is 125 and
    default melting_temperature is 225 and
    default toxicity_level is 0.0.
```

```
frame polyamide_pa_6 is a thermoplastic;
        default density is 1.13 and
        default water_absorption is 2.6 and
        default tensile_strength is 80 and
        default impact_strength is 65 and
        default  ball_indentation_hardness is 150 and
        default melting_temperature is 220 and
        default toxicity_level is 0.0.

frame polyamide_pa_4_6 is a thermoplastic;
        default density is 1.18 and
        default water_absorption is 3.0 and
        default tensile_strength is 80 and
        default impact_strength is 75 and
        default  ball_indentation_hardness is 120 and
        default melting_temperature is 290 and
        default toxicity_level is 0.0.

frame polyamide_pa_12 is a thermoplastic;
        default density is 1.02 and
        default water_absorption is 1.5 and
        default tensile_strength is 55 and
        default impact_strength is 65 and
        default  ball_indentation_hardness is 98 and
        default melting_temperature is 290 and
        default toxicity_level is 0.0.

frame polyamide_pa_66_rubber_mod is a thermoplastic;
        default density is 1.04 and
        default water_absorption is 1.5 and
        default tensile_strength is 48 and
        default impact_strength is 75 and
```

```
        default  ball_indentation_hardness is 57 and
        default melting_temperature is 215 and
        default toxicity_level is 0.0.

frame polyamide_pa_11_flex is a thermoplastic;
        default density is 1.04 and
        default water_absorption is 1 and
        default tensile_strength is 67 and
        default impact_strength is 75 and
        default  ball_indentation_hardness is 85 and
        default melting_temperature is 187 and
        default toxicity_level is 0.0.

frame polycarbonate_pc is a thermoplastic;
        default density is 1.2 and
        default water_absorption is 0.15 and
        default tensile_strength is 60 and
        default impact_strength is 80 and
        default  ball_indentation_hardness is 110 and
        default melting_temperature is 220 and
        default toxicity_level is 0.0.

frame polycarbonate_pc_12 is a thermoplastic;
        default density is 1.2 and
        default water_absorption is 0.15 and
        default tensile_strength is 60 and
        default impact_strength is 70 and
        default  ball_indentation_hardness is 110 and
        default melting_temperature is 220 and
        default toxicity_level is 0.0.

frame thermoplastic_polyester_petp is a thermoplastic;
```

default density is 1.37 and
default water_absorption is 0.20 and
default tensile_strength is 81 and
default impact_strength is 70 and
default ball_indentation_hardness is 150 and
default melting_temperature is 255 and
default toxicity_level is 0.0.

frame thermoplastic_polyester_pbtp is a thermoplastic;
default density is 1.30 and
default water_absorption is 0.22 and
default tensile_strength is 57 and
default impact_strength is 60 and
default ball_indentation_hardness is 125 and
default melting_temperature is 255 and
default toxicity_level is 0.0.

frame thermoplastic_polyester_pbt_hi_heat_resistant is a thermoplastic;
default density is 1.25 and
default water_absorption is 0.7 and
default tensile_strength is 55 and
default impact_strength is 60 and
default ball_indentation_hardness is 70 and
default melting_temperature is 225 and
default toxicity_level is 0.0.

frame thermoplastic_polyester_pbt_hi_flame_retardant is a thermoplastic;
default density is 1.35 and
default water_absorption is 0.6 and
default tensile_strength is 55 and
default impact_strength is 60 and
default ball_indentation_hardness is 85 and

default melting_temperature is 225 and
default toxicity_level is 0.0.

frame polyphenylene is a thermoplastic;
default density is 1.06 and
default water_absorption is 0.14 and
default tensile_strength is 50 and
default impact_strength is 60 and
default ball_indentation_hardness is 102 and
default melting_temperature is 220 and
default toxicity_level is 0.0.

frame polyphenylene_ppo is a thermoplastic;
default density is 1.06 and
default water_absorption is 0.14 and
default tensile_strength is 50 and
default impact_strength is 60 and
default ball_indentation_hardness is 102 and
default melting_temperature is 220 and
default toxicity_level is 0.0.

frame polyphenylene_sulphide_pps is a thermoplastic;
default density is 1.3 and
default water_absorption is 0.03 and
default tensile_strength is 67 and
default impact_strength is 50 and
default ball_indentation_hardness is 123 and
default melting_temperature is 277 and
default toxicity_level is 0.0.

frame polyphenylene_ether_ppe_hw is a thermoplastic;
default density is 1.10 and

default water_absorption is 0.14 and
default tensile_strength is 55 and
default impact_strength is 45 and
default ball_indentation_hardness is 116 and
default melting_temperature is 270 and
default toxicity_level is 0.0.

frame polyphenylene_pe_ldpe_eva_nsi is a thermoplastic;
default density is 0.95 and
default water_absorption is 0.15 and
default tensile_strength is 22 and
default impact_strength is 45 and
default ball_indentation_hardness is 22 and
default melting_temperature is 73 and
default toxicity_level is 0.0.

frame polyphenylene_pe_ldpe_eva_hsi is a thermoplastic;
default density is 0.92 and
default water_absorption is 0.05 and
default tensile_strength is 18 and
default impact_strength is 45 and
default ball_indentation_hardness is 39 and
default melting_temperature is 104 and
default toxicity_level is 0.0.

frame polypropylene_homopolymer is a thermoplastic;
default density is 0.905 and
default water_absorption is 0.01 and
default tensile_strength is 35 and
default impact_strength is 25 and
default ball_indentation_hardness is 70 and
default melting_temperature is 166 and

default toxicity_level is 0.0.

frame polypropylene_homopolymer_w is a thermoplastic;
default density is 0.915 and
default water_absorption is 0.01 and
default tensile_strength is 33 and
default impact_strength is 25 and
default ball_indentation_hardness is 64 and
default melting_temperature is 165 and
default toxicity_level is 0.0.

frame polypropylene_homopolymer_bs is a thermoplastic;
default density is 0.935 and
default water_absorption is 0.01 and
default tensile_strength is 38 and
default impact_strength is 25 and
default ball_indentation_hardness is 62 and
default melting_temperature is 168 and
default toxicity_level is 0.0.

frame polypropylene_copolymer is a thermoplastic;
default density is 0.903 and
default water_absorption is 0.01 and
default tensile_strength is 28 and
default impact_strength is 20 and
default ball_indentation_hardness is 57 and
default melting_temperature is 165 and
default toxicity_level is 0.0.

frame pvc_e_pvc is a thermoplastic;
default density is 1.38 and
default water_absorption is 1 and

default tensile_strength is 60 and

default impact_strength is 26 and

default ball_indentation_hardness is 120 and

default melting_temperature is 200 and

default toxicity_level is 0.0.

frame pvc_s_pvc is a thermoplastic;

default density is 1.39 and

default water_absorption is 0.3 and

default tensile_strength is 60 and

default impact_strength is 45 and

default ball_indentation_hardness is 130 and

default melting_temperature is 200 and

default toxicity_level is 0.0.

frame pvc_pvs_chlor is a thermoplastic;

default density is 1.55 and

default water_absorption is 0.2 and

default tensile_strength is 75 and

default impact_strength is 20 and

default ball_indentation_hardness is 150 and

default melting_temperature is 200 and

default toxicity_level is 0.0.

frame polymethylmethacrylate_pmma_typ_1 is a thermoplastic;

default density is 1.19 and

default water_absorption is 0.25 and

default tensile_strength is 62 and

default impact_strength is 11 and

default ball_indentation_hardness is 170 and

default melting_temperature is 200 and

default toxicity_level is 0.0.

frame polymethylmethacrylate_pmma_typ_2 is a thermoplastic;

default density is 1.19 and

default water_absorption is 0.25 and

default tensile_strength is 66 and

default impact_strength is 11 and

default ball_indentation_hardness is 180 and

default melting_temperature is 200 and

default toxicity_level is 0.0.

frame polymethylmethacrylate_pmma_hw is a thermoplastic;

default density is 1.19 and

default water_absorption is 0.35 and

default tensile_strength is 80 and

default impact_strength is 10 and

default ball_indentation_hardness is 200 and

default melting_temperature is 220 and

default toxicity_level is 0.0.

frame polyoxymethylene_pom_copolymer_10%_gk is a thermoplastic;

default density is 1.47 and

default water_absorption is 0.3 and

default tensile_strength is 54 and

default impact_strength is 50 and

default ball_indentation_hardness is 160 and

default melting_temperature is 167 and

default toxicity_level is 0.0.

frame polyoxymethylene_pom_homopolymer_chem_geschm is a thermoplastic;

default density is 1.42 and

default water_absorption is 0.27 and

default tensile_strength is 70 and

```
        default impact_strength is 50 and
        default  ball_indentation_hardness is 174 and
        default melting_temperature is 175 and
        default toxicity_level is 0.0.

frame polystyrene is a thermoplastic;
        default density is 1.05 and
        default water_absorption is 0.01 and
        default tensile_strength is 45 and
        default impact_strength is 11 and
        default  ball_indentation_hardness is 150 and
        default melting_temperature is 200 and
        default toxicity_level is 0.0.

frame polystyrene_ps is a thermoplastic;
        default density is 1.05 and
        default water_absorption is 0.01 and
        default tensile_strength is 45 and
        default impact_strength is 11 and
        default  ball_indentation_hardness is 150 and
        default melting_temperature is 200 and
        default toxicity_level is 0.0.

frame polystyrene_gsch is a thermoplastic;
        default density is 1.05 and
        default water_absorption is 0.2 and
        default tensile_strength is 17 and
        default impact_strength is 11 and
        default  ball_indentation_hardness is 150 and
        default melting_temperature is 220 and
        default toxicity_level is 0.0.
```

METALS DATABASE (INCOMPLETE)

/* METALS DATA taken from:

(i) Ashby, M., Cebon, D., Chong, W.T., Thomas, R., CAMBRIDGE MATERIALS SELECTOR (CMS) Version 1.1, CAMBRIDGE UNIVERSITY ENGINEERING DEPARTMENT © 1990 */

frame cast_iron is a metal;

default density is 7.35 and

default youngs_modulus is 173 and

default toughness is 13 and

default themal_conductivity is 26 and

default resistivity is 103.2.

frame iron_based_superalloy is a metal;

default density is 8.1 and

default youngs_modulus is 203.5 and

default toughness is 50 and

default themal_conductivity is 22 and

default resistivity is 69.9.

frame pressure_vessel_steel is a metal;

default density is 7.85 and

default youngs_modulus is 205 and

default toughness is 125 and

default themal_conductivity is 38 and

default resistivity is 25.8.

frame low_alloy_steel is a metal;

default density is 7.85 and

default youngs_modulus is 203.5 and

default toughness is 100 and

default themal_conductivity is 33.5 and

default resistivity is 16.8.

```
frame medium_carbon_steel is a metal;
        default density is 7.81 and
        default youngs_modulus is 203 and
        default toughness is 75 and
        default themal_conductivity is 39.5 and
        default resistivity is 18.9.

frame low_carbon_steel is a metal;
        default density is 7.9 and
        default youngs_modulus is 203 and
        default toughness is 40 and
        default themal_conductivity is 55 and
        default resistivity is 17.

frame high_carbon_steel is a metal;
        default density is 7.81 and
        default youngs_modulus is 203 and
        default toughness is 50 and
        default themal_conductivity is 42 and
        default resistivity is 21.5.

frame austenitic_stainless_steel is a metal;
        default density is 7.85 and
        default youngs_modulus is 201.5 and
        default toughness is 85 and
        default themal_conductivity is 15 and
        default resistivity is 97.6.

frame stainless_steel_302 is a metal;
        default density is 7.9 and
        default youngs_modulus is 211 and
```

```
        default toughness is 85 and
        default themal_conductivity is 15 and
        default resistivity is 97.6.

frame ferritic_stainless_steel is a metal;
        default density is 7.6 and
        default youngs_modulus is 203 and
        default toughness is 70 and
        default themal_conductivity is 25 and
        default resistivity is 55.3.

frame aluminium_alloy is a metal;
        default density is 2.74 and
        default youngs_modulus is 78.3 and
        default toughness is 28.5 and
        default themal_conductivity is 166 and
        default resistivity is 5.7.

frame aluminium_pure is a metal;
        default density is 2.7 and
        default youngs_modulus is 69 and
        default toughness is 32.5 and
        default themal_conductivity is 235 and
        default resistivity is 1.85.

frame aluminium_alloy_2024 is a metal;
        default density is 2.7 and
        default youngs_modulus is 74 and
        default toughness is 30.5 and
        default themal_conductivity is 165 and
        default resistivity is 4.6.
```

```
frame aluminium_alloy_lm6 is a metal;
        default density is 2.65 and
        default youngs_modulus is 70.6 and
        default toughness is 27.5 and
        default themal_conductivity is 165 and
        default resistivity is 4.6.

frame brass is a metal;
        default density is 8.1 and
        default youngs_modulus is 111.5 and
        default toughness is 60 and
        default themal_conductivity is 117.5 and
        default resistivity is 17.3.

frame bronze is a metal;
        default density is 8 and
        default youngs_modulus is 110 and
        default toughness is 50 and
        default themal_conductivity is 121.5 and
        default resistivity is 14.

frame cobalt_alloy is a metal;
        default density is 8.6 and
        default youngs_modulus is 224 and
        default toughness is 32.5 and
        default themal_conductivity is 19 and
        default resistivity is 66.5.

frame copper_alloy is a metal;
        default density is 8.25 and
        default youngs_modulus is 135 and
        default toughness is 95 and
```

```
        default themal_conductivity is 213.5 and
        default resistivity is 21.5.

frame chromium_pure is a metal;
        default density is 7.19 and
        default youngs_modulus is 289 and
        default toughness is 30 and
        default themal_conductivity is 67 and
        default resistivity is 11.3.

frame lead_alloy is a metal;
        default density is 11 and
        default youngs_modulus is 15.9 and
        default toughness is 40 and
        default themal_conductivity is 31 and
        default resistivity is 17.5.

frame magnesium_alloy is a metal;
        default density is 1.85 and
        default youngs_modulus is 44.5 and
        default toughness is 15 and
        default themal_conductivity is 99.5 and
        default resistivity is 9.9.

frame molybdenum_alloy is a metal;
        default density is 11.9 and
        default youngs_modulus is 342.5 and
        default toughness is 30 and
        default themal_conductivity is 118 and
        default resistivity is 12.7.

frame nickel_alloy is a metal;
```

```
        default density is 8.5 and
        default youngs_modulus is 182 and
        default toughness is 95 and
        default themal_conductivity is 50 and
        default resistivity is 118.7.

frame niobium_alloy is a metal;
        default density is 9.2 and
        default youngs_modulus is 95 and
        default toughness is 30 and
        default themal_conductivity is 43 and
        default resistivity is 11.

frame palladium_pure is a metal;
        default density is 12 and
        default youngs_modulus is 124 and
        default toughness is 40 and
        default themal_conductivity is 71 and
        default resistivity is 6.5.

frame platinum_pure is a metal;
        default density is 21.5 and
        default youngs_modulus is 172 and
        default toughness is 40 and
        default themal_conductivity is 74 and
        default resistivity is 8.9.

frame tin_alloy is a metal;
        default density is 7.65 and
        default youngs_modulus is 47 and
        default toughness is 30 and
        default themal_conductivity is 47.5 and
```

```
    default resistivity is 12.9.

frame tungsten_pure is a metal;
    default density is 19.6 and
    default youngs_modulus is 406 and
    default toughness is 30 and
    default themal_conductivity is 168 and
    default resistivity is 5.5.

frame tungsten_alloy is a metal;
    default density is 16.5 and
    default youngs_modulus is 393 and
    default toughness is 30 and
    default themal_conductivity is 150 and
    default resistivity is 5.5.

frame zinc_alloy is a metal;
    default density is 7 and
    default youngs_modulus is 69 and
    default toughness is 30 and
    default themal_conductivity is 111 and
    default resistivity is 6.

frame zinc_pure is a metal;
    default density is 7.13 and
    default youngs_modulus is 96 and
    default toughness is 30 and
    default themal_conductivity is 113.5 and
    default resistivity is 5.7.
```

/* INSTALL GRAPHIC INTERFACE SELECTION MENUS CODE*/

```
start_program :-
install_menu('Select Product', ['Toothbrush', 'Phone', 'Shaver','Nutcracker']),
install_menu('Toothbrush',['comfortable to hold','long lasting','reaches all teeth','does not irritate gums','removes plaque efficiently','looks attractive','(-','total evaluation'],'Select Product'('Toothbrush')),

install_menu('Phone',['looks attractive','easy to dial','comfortable to hold','fits in pocket','not too heavy','fits face','operable with one hand','(-','total evaluation'],'Select Product'('Phone')),

install_menu('Shaver',['looks attractive','gives a close shave','comfortable to hold','does not irritate skin','easy to clean','removes hair in difficult areas','does not cut or nick face','is hygienic','(-','total evaluation'],'Select Product'('Shaver')),

install_menu('Nutcracker',['looks attractive','easy to operate','comfortable to hold','cracks nuts effectively','keeps nut intact','requires little effort','cracks various nut types','(-','total evaluation'],'Select Product'('Nutcracker')),

install_menu('Lists',['Colours', 'Materials']),

install_menu('Colours',['carmine','rouge_coral','rose','baby_pink','pink_beige','sandalwood','rose_grey','old_rose','brick_red','mahogany','maroon','orange','ETC..................'],
'Lists'('Colours')),

install_menu('Materials',['petp','pps','pp','pbtp','pom','polyamide','polyamide_pa_6','polyamide_pa_66','polyamide_pa_610','polyamide_pa_612','polyamide_pa_4_6','polyamide_pa_11','polyamide_pa_12','polyamide_pa_6_bs','polyamide_pa_6_lf','polyamide_pa_66_sf','polyamide_pa_66_hw','polyamide_pa_66_rubber_mod','polyamide_pa_66_pe','polyamide_pa_11_flex','polyamide_pa_11_hflex','polyamide_pa_12','polyamide_pa_12_hflex','polyamide_pa_12_w','polyamide_pa_12_mos','polycarbonate','ETC...........................'],'Lists'('Materials')).
```

/* **SUB-ATTRIBUTES CODE** */

frame global;

default penalty_score is 0.

/* **LONG LASTING MATERIAL SUB-ATTRIBUTE CODE** */

relation long_lasting_material(Material)

if Material is an instance of thermoplastic

and

the density of Material is greater than 0.9 and

the density of Material is less than 2.0

and

the water_absorption of Material is less than 7.0

and

the tensile_strength of Material is greater than 25

and

the impact_strength of Material is greater than 25

and

the ball_indentation_hardness of Material is greater than 50

and

the melting_temperature of Material is greater than 160.

/* **ATTRACTIVE TOOTHBRUSH COLOUR SUB-ATTRIBUTE CODE** */

relation attractive_toothbrush_colour(Hue)

if Hue is an instance of colour

and

the image of Hue is {active or bright or bold or clean or clear or clean_and_fresh or fresh or fresh_and_young or healthy or pure or refreshing or sporty}.

/* **ATTRACTIVE SHAVER COLOUR SUB-ATTRIBUTE CODE** */

relation attractive_shaver_colour(Hue)

if Hue is an instance of colour

and

the image of Hue is {active or bright or bold or clean or clear or clean_and_fresh or fresh or fresh_and_young or healthy or pure or refreshing or sporty or youthful}.

/* **COMFORTABLE HANDLE SHAPE SUB-ATTRIBUTE CODE** */

group comfortable_handle_shape

contoured, straight, rectangular, oval, semi_oval, elliptical, semi_elliptical, circular, semi_circular.

/* **COMFORTABLE HANDLE CROSS-SECTION SUB-ATTRIBUTE CODE** */

group comfortable_handle_cross_section

rectangular, oval, semi_oval, elliptical, semi_elliptical, circular, semi_circular.

/* **COMFORTABLE HANDLE TEXTURE SUB-ATTRIBUTE CODE** */

group comfortable_handle_texture

smooth, transparent, opaque, matt, matte, rubber, gloss, grained.

/* **SHAPE SAFE FOR MOUTH SUB-ATTRIBUTE CODE** */

group shape_safe_for_mouth

rectangular, elliptical, oval, circular, round, semi_elliptical, semi_oval, semi_circular, semi_round.

/* **CROSS-SECTION SAFE FOR MOUTH SUB-ATTRIBUTE CODE** */

group cross_section_safe_for_mouth

rectangular, elliptical, semi_elliptical, oval, circular, semi_circular, round, semi_round.

/* **CROSS-SECTION SAFE FOR RAZOR SUB-ATTRIBUTE CODE** */

group cross_section_safe_for_razor

rectangular, elliptical, semi_elliptical, oval, circular, semi_circular, round, semi_round.

/* **METAL TO CUT HAIR SUB-ATTRIBUTE CODE** */

relation metal_that_will_cut_hair(Material)

if Material is an instance of metal

and

the density of Material is greater than 0.9 and

the density of Material is less than 2.0

and

the melting_temperature of Material is greater than 160

and

the toxicity_level of Material is 0.0.

/* **HYGIENIC MATERIAL SUB-ATTRIBUTE CODE** */

relation hygienic_material(Material)

if Material is an instance of thermoplastic

and

the density of Material is greater than 0.9 and

the density of Material is less than 2.0

and

the water_absorption of Material is less than 7.0

and

the tensile_strength of Material is greater than 25

and

the ball_indentation_hardness of Material is greater than 50

and

the melting_temperature of Material is greater than 160

and

the toxicity_level of Material is 0.0.

/* **EASY TO CLEAN MATERIAL SUB-ATTRIBUTE CODE** */

relation easy_clean_material(Material)

if Material is an instance of thermoplastic

and

the water_absorption of Material is less than 7.0

and

the ball_indentation_hardness of Material is greater than 50

and

the melting_temperature of Material is greater than 160.

/* EASY TO CLEAN SHAPE SUB-ATTRIBUTE CODE */

group easy_clean_shape

rectangular, oval, elliptical, diamond, tapered, square, circular, contoured, straight, semi_elliptical, semi_circular, square, round, semi_round, semi_oval.

/* ATTRACTIVE MATERIAL SUB-ATTRIBUTE CODE */

relation attractive_material(Material)

if Material is an instance of thermoplastic

and

the density of Material is greater than 0.9 and

the density of Material is less than 2.0

and

the water_absorption of Material is less than 7.0

and

the tensile_strength of Material is greater than 25

and

the impact_strength of Material is greater than 25

and

the ball_indentation_hardness of Material is greater than 50

and

the melting_temperature of Material is greater than 160.

/* **SAFE MATERIAL FOR MOUTH SUB-ATTRIBUTE CODE** */

relation safe_material_for_mouth(Material)

if Material is an instance of thermoplastic

and

the density of Material is greater than 0.9 and

the density of Material is less than 2.0

and

the water_absorption of Material is less than 7.0

and

the tensile_strength of Material is greater than 25

and

the impact_strength of Material is greater than 25

and

the ball_indentation_hardness of Material is greater than 50

and

the melting_temperature of Material is greater than 160

and

the toxicity_level of Material is 0.0.

/* **EASY DIAL BUTTON SHAPE SUB-ATTRIBUTE CODE** */

group easy_dial_button_shape

rectangular, elliptical, semi_elliptical, oval, semi_oval, circular, semi_circular, round, semi_round, square.

/* **EASY DIAL BUTTON MATERIAL SUB-ATTRIBUTE CODE** */

relation easy_dial_button_material(Material)

if Material is an instance of thermoplastic

and

the density of Material is greater than 0.9 and

the density of Material is less than 2.0

and

the water_absorption of Material is less than 7.0

and

the tensile_strength of Material is greater than 25

and

the impact_strength of Material is greater than 25

and

the ball_indentation_hardness of Material is greater than 50

and

the melting_temperature of Material is greater than 160.

/* FITS IN POCKET SHAPE SUB-ATTRIBUTE CODE */

group fits_in_pocket_shape

straight, contoured, rectangular, elliptical, semi_elliptical, oval, circular, semi_circular, square, semi_oval, round, semi_round.

/* ATTRACTIVE PHONE COLOUR SUB-ATTRIBUTE CODE */

relation attractive_phone_colour(Hue)

if Hue is an instance of colour

and

the image of Hue is {authoritative or classic or clean or clear or conservative or formal or intellectual or masculine or mature or metallic or modern or professional or serious or sharp or sleek or smart}.

/* ATTRACTIVE SHAPE SUB-ATTRIBUTE CODE */

group attractive_shape

rectangular, oval, elliptical, diamond, tapered, square, circular, contoured, straight, irregular, semi_elliptical, semi_circular, square, round, semi_round, semi_oval, octagonal.

9.2.0 Appendix II - Explanations of CADET System Toothbrush Test

(1) Gibbs: Mentadent-P Ultra Professional

Pass:

'looks attractive' - **(100%)** 'does not irritate gums' - **(100%)** 'lasts long' - **(100%)**

Fail:

'reaches all teeth' - **(80%)** 'comfortable to hold' - **(85%)** 'removes plaque efficiently' - **(83%)**

Combined Total: (91%)

Rating: 4th of 9

Explanation:

The Gibbs Mentadent-P Ultra Professional toothbrush failed to meet acceptable attribute levels of 'reaches all teeth' and 'removes plaque efficiently' as the filaments of the toothbrush measured 8 millimetres in length, too short as suggested by Tsujita et al (1988), Rawls et al (1989) and Delaunay (1982) and the +17 degree angle between toothbrush head and handle exceeding the +15 degree upper limit proposed by Walsh and Lamb (1993). The handle width and handle thickness of the toothbrush also failed to meet the required levels of the attribute 'comfortable to hold' according to Walsh and Lamb (1993).

(2) Aquafresh Flex

Pass:

'looks attractive' - **(100%)** 'lasts long' - **(100%)**

Fail:

'reaches all teeth' - **(40%)** 'comfortable to hold' - **(71%)** 'does not irritate gums' - **(42%)** 'removes plaque efficiently' - **(83%)**

Combined Total: (73%)

Rating: 9th of 9

Explanation:

The Aquafresh Flex toothbrush failed to satisfy the required toothbrush characteristic levels related with the attributes 'reaches all teeth', 'comfortable to hold', 'does not irritate gums' and 'removes plaque efficiently'. The length of the Flex toothbrush is too long at 191 millimetres (Chong and Beech 1983). The head of the toothbrush is too long at 35 millimetres and too wide at 13 millimetres (Silverstone and Featherstone 1988, Golding 1982) and the dimensions of the tapered head would result in harming the gums (Walsh and Lamb 1993).

(3) **Wisdom Reflex**

Pass:

'looks attractive' - **(100%)** 'reaches all teeth' - **(100%)** 'comfortable to hold' - **(100%)** 'does not irritate gums' - **(100%)** 'lasts long' - **(100%)**

Fail:

'removes plaque efficiently' - **(83%)**

Combined Total: (97%)

Rating: 1st of 9

Explanation:

Davies et al (1988), reports that toothbrushes with contoured handles were found to be significantly more efficient at plaque removal than straight-handled toothbrushes, for example the straight-handled Wisdom Reflex toothbrush.

(4) **Jordan 'Le-Brush'**

Pass:

'looks attractive' - **(100%)** 'reaches all teeth' - **(100%)** 'does not irritate gums' - **(100%)**

Fail:

'comfortable to hold' - **(57%)** 'lasts long' - **(66%)** 'removes plaque efficiently' - **(66%)**

Combined Total: (81%)

Rating: 7th of 9

Explanation:

The Jordan 'Le-Brush' toothbrush handle dimensions were unsuitable, specifically the 6 millimetre handle width and 15 millimetre handle thickness, according to Walsh and Lamb (1993). The 26 filaments in each tuft (packing density) is too few and would not ensure that the brush 'lasted long' (Delaunay 1982). Furthermore, the straight-handle of the Jordan toothbrush would not 'remove plaque efficiently' (Davies et al 1988).

(5) Oral-B Right Angle (35 Compact) 'A-35'

Pass:

'looks attractive' - **(100%)** 'reaches all teeth' - **(100%)** 'comfortable to hold' - **(100%)** 'does no irritate gums' - **(100%)** 'removes plaque efficiently' - **(100%)**

Fail:

'lasts long' - **(66%)**

Combined Total: (94%)

Rating: 2nd= of 9

Explanation:

The Oral-B Right Angle toothbrush would not last long as it only has 24 bristles in each tuft. Delaunay (1982), states that the average toothbrush should have approximately 40 bristles in every tuft.

(6) Search 3.5

Pass:

'reaches all teeth' - **(100%)** 'does not irritate gums' - **(100%)** 'removes plaque efficiently' - **(100%)**

Fail:

''looks attractive' - **(85%)** 'comfortable to hold' - **(71%)** 'lasts long' - **(83%)**

Combined Total: (90%)

Rating: 5th of 9

Explanation:

The Search 3.5 toothbrush failed to 'look attractive' as the shade of grey pigment employed in the colouring of the toothbrush projected images of being "dry" and "sedate", according to Kobayashi (1990), images unsuitable for a toothbrush. Whereas a toothbrush should ideally project images of "health", "freshness" and "cleanliness", usually represented by colours such as sulphur-yellow, lettuce-green and aqua-blue. The varied handle width of 9 to 15 millimetres and 8 millimetre handle thickness of the Search 3.5 toothbrush is also erroneous, reports Walsh and Lamb (1993). The packing density of each tuft, 26 bristles, is too few and would result in the overall wear of the toothbrush not 'lasting long' (Silverstone and Featherstone 1988).

(7) **Addis Dual-Texture**

Pass:

None

Fail:

'looks attractive' - **(85%)** 'reaches all teeth' - **(80%)** 'comfortable to hold' - **(85%)**

'does not irritate gums' - **(57%)** 'lasts long' - **(66%)** 'removes plaque efficiently' - **(83%)**

Combined Total: (76%)

Rating: 8th of 9

Explanation:

The size of the Addis Dual Texture toothbrush head, 35 millimetres long by 13 millimetres wide, exceeds the acceptable boundaries (Golding 1982). This results in the Addis toothbrush failing to reach the required levels to satisfy the attributes, 'reaches all teeth' and 'does not irritate gums'. The handle width of the Addis toothbrush is inadequate at 7 millimetres (Walsh and Lamb 1993), and is therefore not 'comfortable to hold'. The 22 filaments in each tuft falls short of the amount of between 31 to 47 prescribed by Silverstone and Featherstone (1988) and means that the Addis toothbrush would not 'last long'. Similar to the Search 3.5 toothbrush aforementioned, the Addis Dual Texture toothbrush tested was coloured using a grey-shade pigment and was found to be unsuitable to achieve the status of 'looking attractive'. The filaments of the Addis toothbrush are Polyester, differing from most toothbrushes on the U.K. market. Although Polyester may be a suitable material, tests suggest that materials such as Nylon 6-12 and "Zytel" improve the efficiency of plaque removal (Walsh and Lamb 1992/ 93).

(8) **Colgate Diamond Head**

Pass:

'looks attractive' - **(100%)** 'lasts long' - **(100%)** 'comfortable to hold' - **(100%)**

Fail:

'reaches all teeth' - **(80%)** 'does not irritate gums' - **(71%)**

'removes plaque efficiently' - **(83%)**

Combined Total: (89%)

Rating: 6th of 9

Explanation:

It is generally agreed that a small toothbrush head is more effective overall for cleaning purposes than a large toothbrush head (Golding 1982). The large diamond head of the Colgate toothbrush fails to comply with the limitations specified by the attributes, 'removes plaque efficiently', 'does not irritate gums' and 'reaches all teeth'. The 7 millimetre handle width of the Colgate toothbrush is not wide enough to feel 'comfortable to hold' (Walsh and Lamb 1993).

(9) **Reach Anti-Plaque**

Pass:

'looks attractive' - **(100%)** 'comfortable to hold' - **(100%)** 'does not irritate gums' - **(100%)** 'lasts long' - **(100%)**

Fail:

'reaches all teeth' - **(80%)** 'removes plaque efficiently' - **(83%)**

Combined Total: (94%)

Rating: 2nd= of 9

Explanation:

The -7 degree angle of the Reach toothbrush exceeds the boundaries specified by Walsh and Lamb (1993). Therefore, the Reach toothbrush does not meet the levels required to 'reach all teeth' nor 'remove plaque efficiently'.

9.3.0 Appendix III - Script of Interview with Dr. T.F. WALSH and Mr. D.J. LAMB, Sheffield University Dental School, March 19th. 1993

This is the transcript of an interview between Dr. Trevor F. Walsh, Principal Lecturer of Clinical Dentistry at the School of Clinical Dentistry, University of Sheffield, Mr. David J. Lamb, Senior Lecturer of Clinical Dentistry at the School of Clinical Dentistry, University of Sheffield, and Paul A. Rodgers, research scholar at the University of Westminster. The time taken for the interview was approximately 1 hour.

Transcript of Conversation

(P.R.) What are the recommended values for the following list of toothbrush characteristics ?

(P.R.) (1) **HANDLE LENGTH ?**
(T.F.W. & D.J.L.) There is good evidence that a long handle 140 to 150 millimetres performs significantly better than a short handle of say approximately 100 millimetres.

(P.R.) (2) **OVERALL LENGTH ?**
(T.F.W. & D.J.L.) The overall length of toothbrushes should range between 150 and 190 millimetres.

(P.R.) (3) **HEAD LENGTH ?**
(T.F.W. & D.J.L.) The length of the brush head should be approximately 20 millimetres long and certainly no greater than 30 millimetres long.

(P.R.) (4) **BRISTLE LENGTH ?**
(T.F.W. & D.J.L.) The head of a modern toothbrush should have bristles about 10 or 11 millimetres long.

(P.R.) (5) **BRISTLE DIAMETER ?**
(T.F.W. & D.J.L.) Usually ranges between 0.17 and 0.3 millimetres.

(P.R.) (6) **HANDLE WIDTH ?**

(T.F.W. & D.J.L.) A brush with a varied handle width; small width at bottom and top(say 9 millimetres) and a larger handle width in the middle(say no greater than 13 millimetres is preferred.

(P.R.) (7) **HEAD WIDTH ?**

(T.F.W. & D.J.L.) The brush head width should be between 10 and 12 millimetres.

(P.R.) (8) **HANDLE THICKNESS ?**

(T.F.W. & D.J.L.) A toothbrush handle with varying thickness is preferred to uniform thickness. MINIMUM: 5 millimetres, MAXIMUM: 7 millimetres. If uniform optimum thickness is 6 millimetres.

(P.R.) (9) **HEAD THICKNESS ?**

(T.F.W. & D.J.L.) The optimum size for head thickness is 5 millimetres.

(P.R.) (10) **NUMBER OF BRISTLES IN ONE TUFT (PACKING DENSITY) ?**

(T.F.W. & D.J.L.) The number of bristles in one tuft should be between 30 to 50.

(P.R.) (11) **NUMBER OF TUFTS IN HEAD ?**

(T.F.W. & D.J.L.) Minimum number of tufts in head should not be less than 18 and no greater than 50.

(P.R.) (12) **BRISTLE MATERIAL ?**

(T.F.W. & D.J.L.) Most bristles nowadays are made from either a grade of Nylon, "Zytel" or Polyamide. However, some bristles can be natural; this natural bristle is primarily from China (from the wild boar of Tchung King province).

(P.R.) (13) **TOOTHBRUSH(HANDLE & HEAD) MATERIAL ?**

(T.F.W. & D.J.L.) The most usual present day plastics used for toothbrush handles are cellulose acetate, styrene acrylo-nitrile (SAN), or cellulose propionate. Cellulose nitrate (celluloid) is no longer used because of its high flammability. Some very inexpensive brushes use polystyrene for the handles; this material has the disadvantage that it is liable to break if pressure is applied to the handle. By comparison cellulose propionate produces a handle which is almost impossible to break. Synthetic resins such as polypropylene, styrene acrylo-nitrile SAN, and polyamide are currently the most popular.

(P.R.) (14) **HEAD SHAPE ?**

(T.F.W. & D.J.L.) It is generally agreed that a small toothbrush head is more effective for cleaning the teeth than a large head. The small head is able to fit into the curved arch of the teeth much more easily and thus to obtain greater contact with the rear of the teeth and be able to reach into places in the mouth which would be inaccessible to a large head. The preferred head shape is rectangular with rounded corners, **not** diamond or tapered.

(P.R.) (15) **HANDLE SHAPE ?**

(T.F.W. & D.J.L.) Toothbrushes with contoured handles are found to be significantly more efficient at plaque removal than straight handled brushes.

(P.R.) (16) **BRISTLE-END SHAPE (CROSS-SECTION) ?**

(T.F.W. & D.J.L.) One important factor in toothbrush design that appears to have a consensus of agreement is that the bristles should be end-rounded to minimise gingival trauma.

(P.R.) (17) **SHAPE OF HANDLE CROSS-SECTION ?**

(T.F.W. & D.J.L.) The handle should not have hard projections or sharp corners, although there is no objection to a rectangular end to the stock as opposed to a rounded or curved end.

(P.R.) (18) **SHAPE OF HEAD CROSS-SECTION ?**

(T.F.W. & D.J.L.) The head cross-section should be rectangular with rounded corners.

(P.R.) (19) **TUFT ARRANGEMENT ?**

(T.F.W. & D.J.L.) A rectangular arrangement is preferred against diamond or tapered arrangements.

(P.R.) (20) **TUFT TRIM ?**

(T.F.W. & D.J.L.) It is universally thought that the tuft trim should be flat, in preference to concave or convex trims.

(P.R.) (21) **NUMBER OF ROWS ?**

(T.F.W. & D.J.L.) 3, 4 or 5 rows are by far the most popular.

(P.R.) (22) **NUMBER OF COLUMNS ?**

(T.F.W. & D.J.L.) The more columns, the more effective the cleaning, however there is a maximum limit of approximately 8 or 9 columns.

(P.R.) (23) **TOOTHBRUSH COLOURS ?**

(T.F.W. & D.J.L.) The most popular colours are bright primary colours which include yellow, green, blue, clear. Unpopular colours include red, white, brown, black.

(P.R.) (24) **BRISTLE COLOURS ?**

(T.F.W. & D.J.L.) The most popular colours are white, clear, green and blue.

(P.R.) (25) **TEXTURE/ FINISH OF TOOTHBRUSH ?**

(T.F.W. & D.J.L.) The toothbrush should be smooth all over, and a transparent finish is preferable.

(P.R.) (26) **ANGLE BETWEEN TOOTHBRUSH HEAD AND TOOTHBRUSH HANDLE ?**

(T.F.W. & D.J.L.) There is no evidence which conclusively shows that a cranked or bent handle is better than a straight one except in the case of certain toothbrushes which are manufactured for disabled persons, or cases where dental malformation has resulted in special requirements. In any case the angle between handle and head should not exceed 15 degrees.

P.R. = Paul Rodgers

T.F.W. = Dr. Trevor F. Walsh

D.J.L. = Mr. David J. Lamb

9.4.0 Appendix IV - Interview with Paul Warrick IEng MIMechIE New System Dept., Gillette Inc. Research and Development Laboratories, August 1, 1994

This is the transcript of an interview between Mr. Paul Warrick, Senior Design Engineer at the Research and Development Laboratories of Gillette Inc. (UK), and Paul A. Rodgers, research scholar at the University of Westminster. The time taken for the interview was approximately 45 minutes.

Transcript of Conversation

(P.R.) What are the recommended values for the following list of Shaver characteristics ?

(P.R.) (1) **(OVERALL) SHAVER LENGTH ?**

(P.W.) Razors are broken down into two different markets: Disposables and Systems which are then divided into male and female shavers. This answer and the ones to follow deal with the male shaving market in general.

Disposable Razor Length Range	100 to 115 mm. in twin blade devices.
System Razor Length Range	118 to 130 mm.

(P.R.) (2) **SHAVER HANDLE LENGTH ?**

(P.W.) Handle length refers to the area designed for general holding of the razor, this may or may not have finger grips.

Disposable Razor Length Range	77 to 94 mm. in twin blade devices.
System Razor Length Range	75 to 100 mm.

(P.R.) (3) **SHAVER HANDLE WIDTH ?**

(P.W.) This range refers to both the Disposable and System Razors, i.e. 7 - 12 mm.

(P.R.) (4) **SHAVER HANDLE THICKNESS ?**

(P.W.) Usually the same range as question (3), but not always the same figure.

(P.R.) (5) **SHAVER HANDLE SHAPE ?**

(P.W.) In general the shape is the standard 'T', which is a long straight handle and the cartridge at one end of the handle.

(P.R.) (6) **SHAVER HANDLE CROSS-SECTION ?**

(P.W.) The cross-sectional profile is based on two common shapes, the circle and the rectangle. Variations or combinations of these two basic shapes may also be used.

(P.R.) (7) **SHAVER HEAD CROSS-SECTION ?**

(P.W.) Generally rectangular.

(P.R.) (8) **SHAVER HANDLE MATERIAL ?**

(P.W.) Disposables: Generally thermoplastics such as: styrene or polypropylene.

Systems: Usually a combination of thermoplastics and metals, such as: steel, brass, zinc die-cast.

(P.R.) (9) **SHAVER HEAD MATERIAL ?**

(P.W.) Combinations are used for both Disposable and System Razors, as stated in question (8).

(P.R.) (10) **SHAVER BLADE MATERIAL ?**

(P.W.) Usually steel. 13% Chromium and 0.6 to 0.7% Carbon in content.

(P.R.) (11) **SHAVER HANDLE TEXTURE/ FINISH ?**

(P.W.) This is mainly a cost related issue. A smooth flat finish is cheaper to produce (tooling) and is less likely to cause production problems. However, texture is more desirable and is important for grip.

(P.R.) (12) **SHAVER HANDLE COLOUR(S) ?**

(P.W.) General colours used for Disposables are: black, blue, green, orange and red.

Colours for Systems are usually more conservative: black, red, metal finish.

(P.R.) (13) **SHAVER HEAD COLOUR(S) ?**

(P.W.) If the cartridge platform is part of the handle then the colours are the same as question (12), otherwise colours used are: black, grey, blue or white.

(P.R.) (14) **ANGLE BETWEEN SHAVER HEAD AND SHAVER HANDLE ?**

(P.W.) General range for both types of razors: 40° to 50°.

(P.R.) (15) **SHAVER HEAD LENGTH ?**

(P.W.) The nominal value is 39.5 mm. for both Disposable and System Razors.

(P.R.) (16) **SHAVER HEAD WIDTH ?**

(P.W.) Fixed blade cartridges are generally 5 mm. wide. Dynamic blade systems (sprung mounted blades) are usually approx. 8.5 mm. wide.

(P.R.) (17) **SHAVER HEAD THICKNESS ?**

(P.W.) Generally between 4 to 10 mm., but ultimately depends on the blade dynamics.

(P.R.) (18) **SHAVER BLADE LENGTH AREA ?**

(P.W.) Most blades are 35.5 mm. long.

(P.R.) (19) **NUMBER OF BLADES ?**

(P.W.) Single bladed devices are still used and preferred by some over the twin bladed device, however general preference is for two blades.

(P.R.) (20) **DISTANCE BETWEEN BLADES ?**

(P.W.) Most manufacturers use a spacer to separate the two blades in twin blade devices, this is normally a 0.5 mm. spacer and the distance between the primary blade edge and the secondary is in the region of 1.5 mm.

P.R. = Paul Rodgers

P.W. = Paul Warrick (New system Dept., Gillette Inc.)

9.5.0 Appendix V - Toothbrush Characteristics

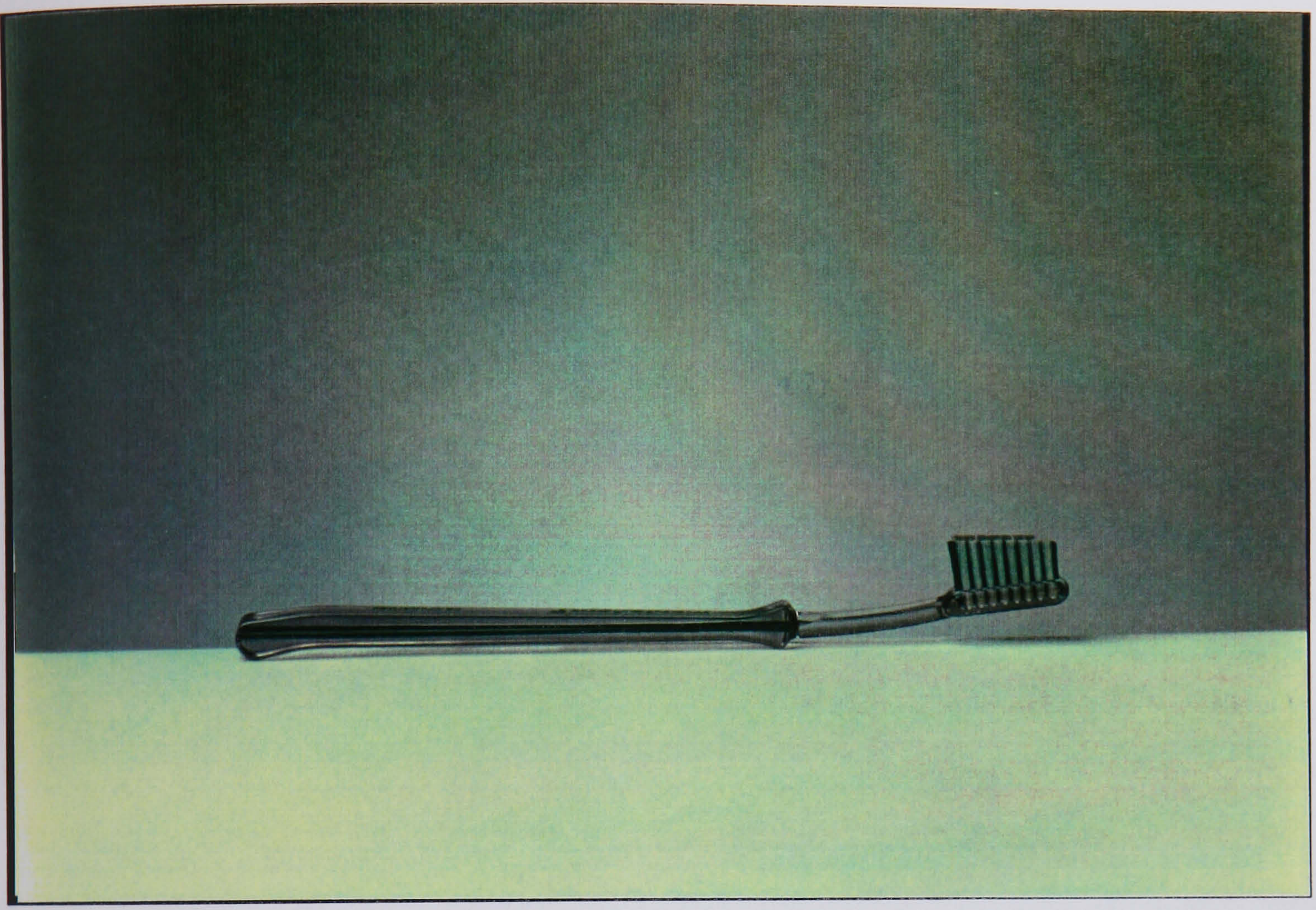

Plate 9.5.0a: Gibbs Mentadent-P Ultra Professional

HANDLE LENGTH: ***120 mm.***

OVERALL LENGTH: ***185 mm.***

HEAD LENGTH: ***30 mm.***

FILAMENT LENGTH: ***8 mm. - 11 mm.***

FILAMENT DIAMETER: ***0.2 mm.***

HANDLE WIDTH: ***8mm. - 13 mm.***

HEAD WIDTH: ***12 mm.***

HANDLE THICKNESS: ***5 mm. - 8 mm.***

HEAD THICKNESS: ***5 mm.***

NUMBER OF FILAMENTS IN ONE TUFT(PACKING DENSITY): ***46***

NUMBER OF TUFTS IN HEAD: ***34***

FILAMENT MATERIAL: ***Nylon***

TOOTHBRUSH MATERIAL: ***Polyamide***

HEAD SHAPE: ***Rectangular***

HANDLE SHAPE: ***Contoured***

SHAPE OF HANDLE CROSS-SECTION: ***Rectangular***

SHAPE OF HEAD CROSS-SECTION: ***Rectangular***

TUFT ARRANGEMENT: ***Rectangular***

TOOTHBRUSH COLOUR(S): ***Clear***

FILAMENT COLOUR(S): ***Clear - Green***

TEXTURE/ FINISH OF TOOTHBRUSH: ***Smooth - Clear - Transparent***

ANGLE BETWEEN HEAD AND HANDLE: ***+ 17 Degrees***

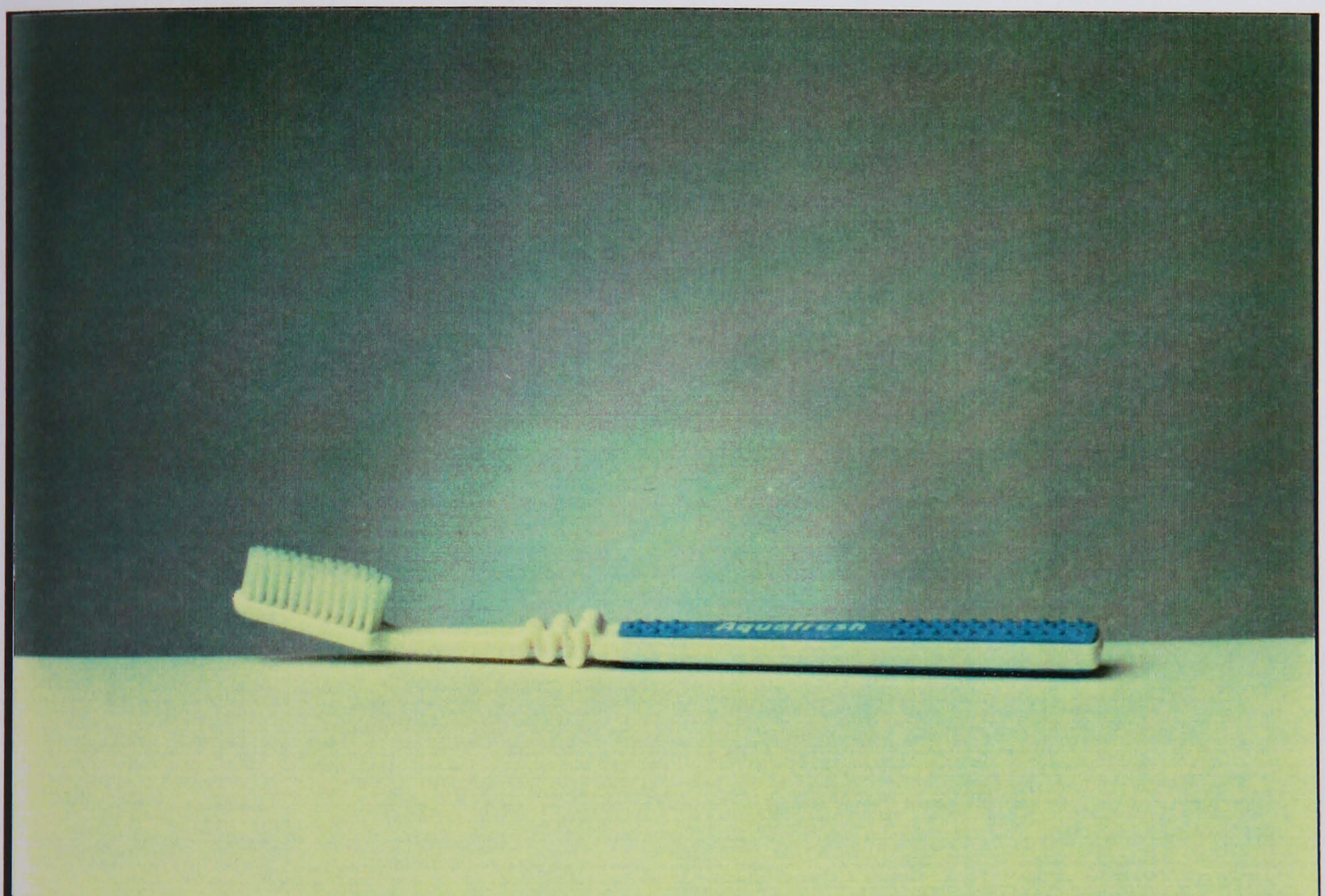

Plate 9.5.0b: Aquafresh Flex

HANDLE LENGTH: ***110 mm.***

OVERALL LENGTH: ***191 mm.***

HEAD LENGTH: ***35 mm.***

FILAMENT LENGTH: ***11 mm.***

FILAMENT DIAMETER: ***0.21 mm.***

HANDLE WIDTH: ***10 mm. - 13 mm.***

HEAD WIDTH: ***8 mm. - 13 mm.***

HANDLE THICKNESS: **9 mm. - 10 mm.**

HEAD THICKNESS: **5 mm.**

NUMBER OF FILAMENTS IN ONE TUFT(PACKING DENSITY): **34**

NUMBER OF TUFTS IN HEAD: **43**

FILAMENT MATERIAL: **Nylon 6 - 12**

TOOTHBRUSH MATERIAL: **Polypropylene - Rubber**

HEAD SHAPE: **Tapered**

HANDLE SHAPE: **Contoured**

SHAPE OF HANDLE CROSS-SECTION: **Rectangular**

SHAPE OF HEAD CROSS-SECTION: **Rectangular**

TUFT ARRANGEMENT: **Tapered**

TOOTHBRUSH COLOUR(S): **Blue - White**

FILAMENT COLOUR(S): **White**

TEXTURE/ FINISH OF TOOTHBRUSH: **Opaque - Smooth - Rubber-grip**

ANGLE BETWEEN HEAD AND HANDLE: **+ 13 Degrees (varies)**

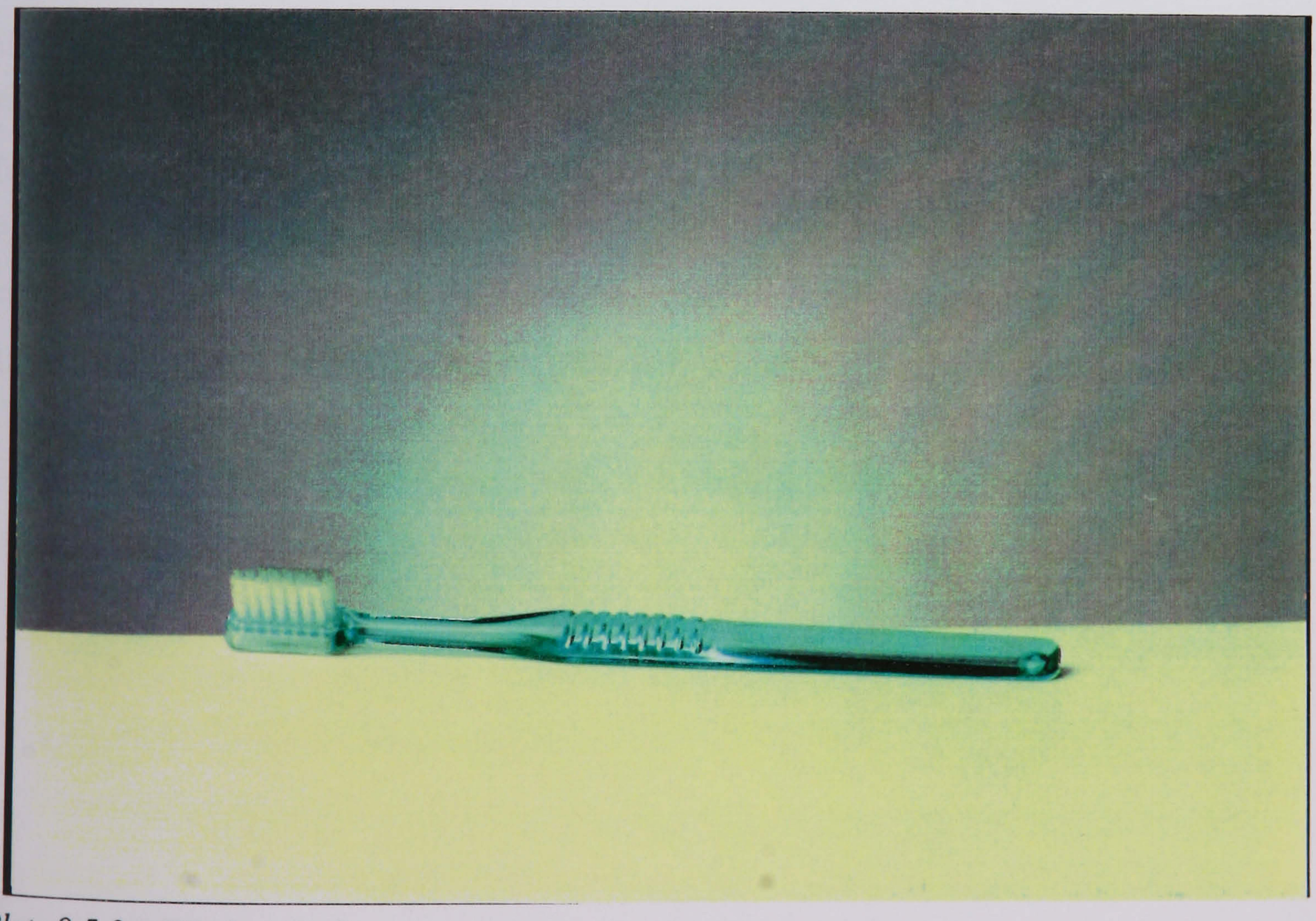

Plate 9.5.0c: Wisdom Reflex

HANDLE LENGTH: ***110 mm.***

OVERALL LENGTH: ***185 mm.***

HEAD LENGTH: ***28 mm.***

FILAMENT LENGTH: ***10 mm. (varies)***

FILAMENT DIAMETER: ***0.16 mm. - 0.23 mm.***

HANDLE WIDTH: ***12 mm.***

HEAD WIDTH: ***11 mm.***

HANDLE THICKNESS: ***5 mm. - 7 mm.***

HEAD THICKNESS: ***5 mm.***

NUMBER OF FILAMENTS IN ONE TUFT(PACKING DENSITY): ***46***

NUMBER OF TUFTS IN HEAD: ***30***

FILAMENT MATERIAL: ***Nylon 6 - 12***

TOOTHBRUSH MATERIAL: ***Polycarbonate***

HEAD SHAPE: ***Rectangular***

HANDLE SHAPE: ***Straight***

SHAPE OF HANDLE CROSS-SECTION: ***Oval***

SHAPE OF HEAD CROSS-SECTION: ***Rectangular***

TUFT ARRANGEMENT: ***Rectangular***

TOOTHBRUSH COLOUR(S): ***Green***

FILAMENT COLOUR(S): ***Clear***

TEXTURE/ FINISH OF TOOTHBRUSH: ***Smooth - Transparent***

ANGLE BETWEEN HEAD AND HANDLE: ***0 Degrees***

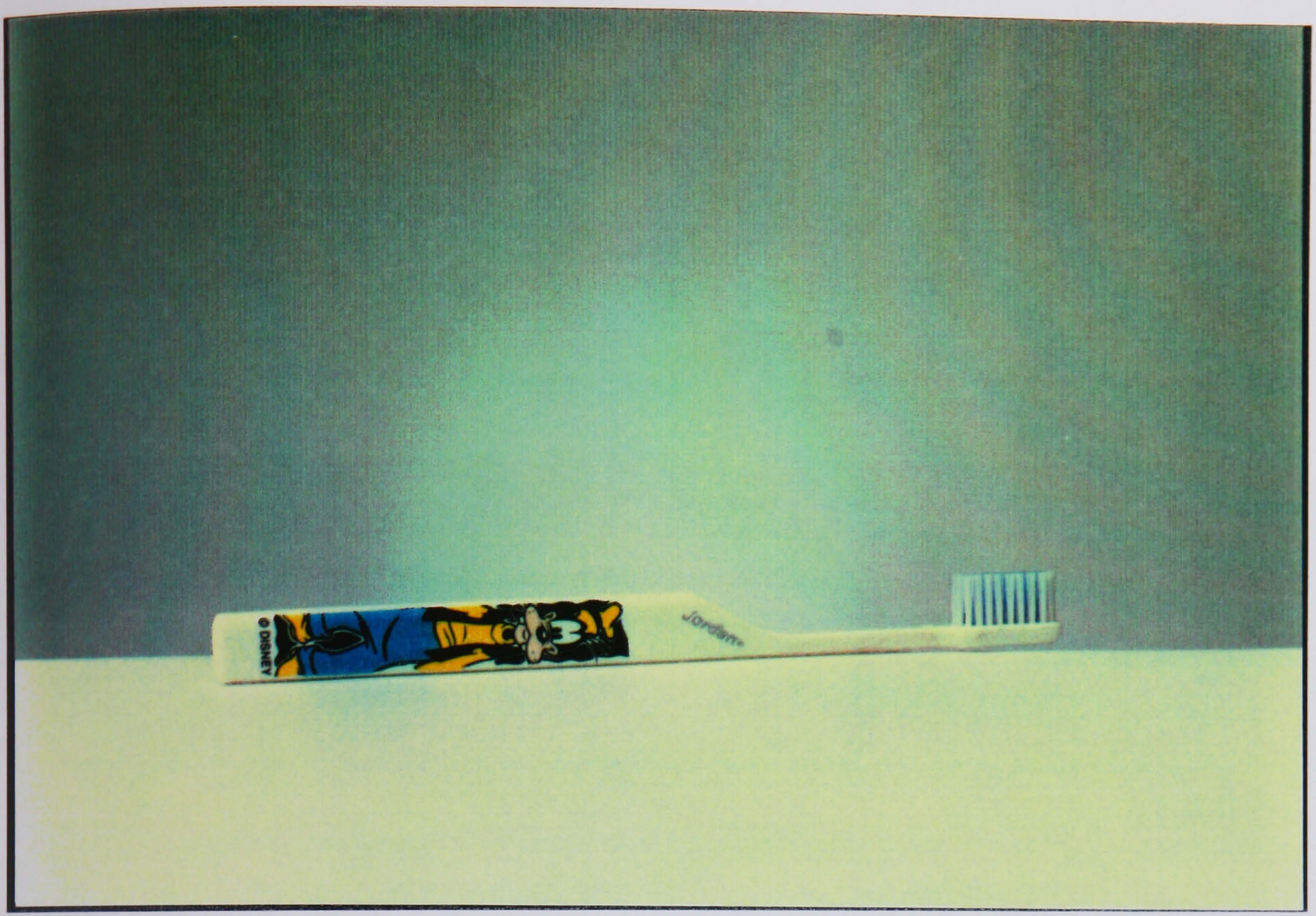

Plate 9.5.0d: Jordan 'Le-Brush'

HANDLE LENGTH: ***115 mm.***

OVERALL LENGTH: ***190 mm.***

HEAD LENGTH: ***27 mm.***

FILAMENT LENGTH: ***11 mm.***

FILAMENT DIAMETER: ***0.21 mm.***

HANDLE WIDTH: ***6 mm.***

HEAD WIDTH: ***11 mm.***

HANDLE THICKNESS: ***15 mm.***

HEAD THICKNESS: ***5 mm.***

NUMBER OF FILAMENTS IN ONE TUFT(PACKING DENSITY): ***26***

NUMBER OF TUFTS IN HEAD: ***36***

FILAMENT MATERIAL: ***Polyamide***

TOOTHBRUSH MATERIAL: ***SAN***

HEAD SHAPE: ***Rectangular***

HANDLE SHAPE: ***Straight***

SHAPE OF HANDLE CROSS-SECTION: ***Oval***

SHAPE OF HEAD CROSS-SECTION: **Semi-Oval**

TUFT ARRANGEMENT: **Rectangular**

TOOTHBRUSH COLOUR(S): **White (predominately) with graphics**

FILAMENT COLOUR(S): **Blue - White**

TEXTURE/ FINISH OF TOOTHBRUSH: **Smooth - Opaque**

ANGLE BETWEEN HEAD AND HANDLE: **0 Degrees**

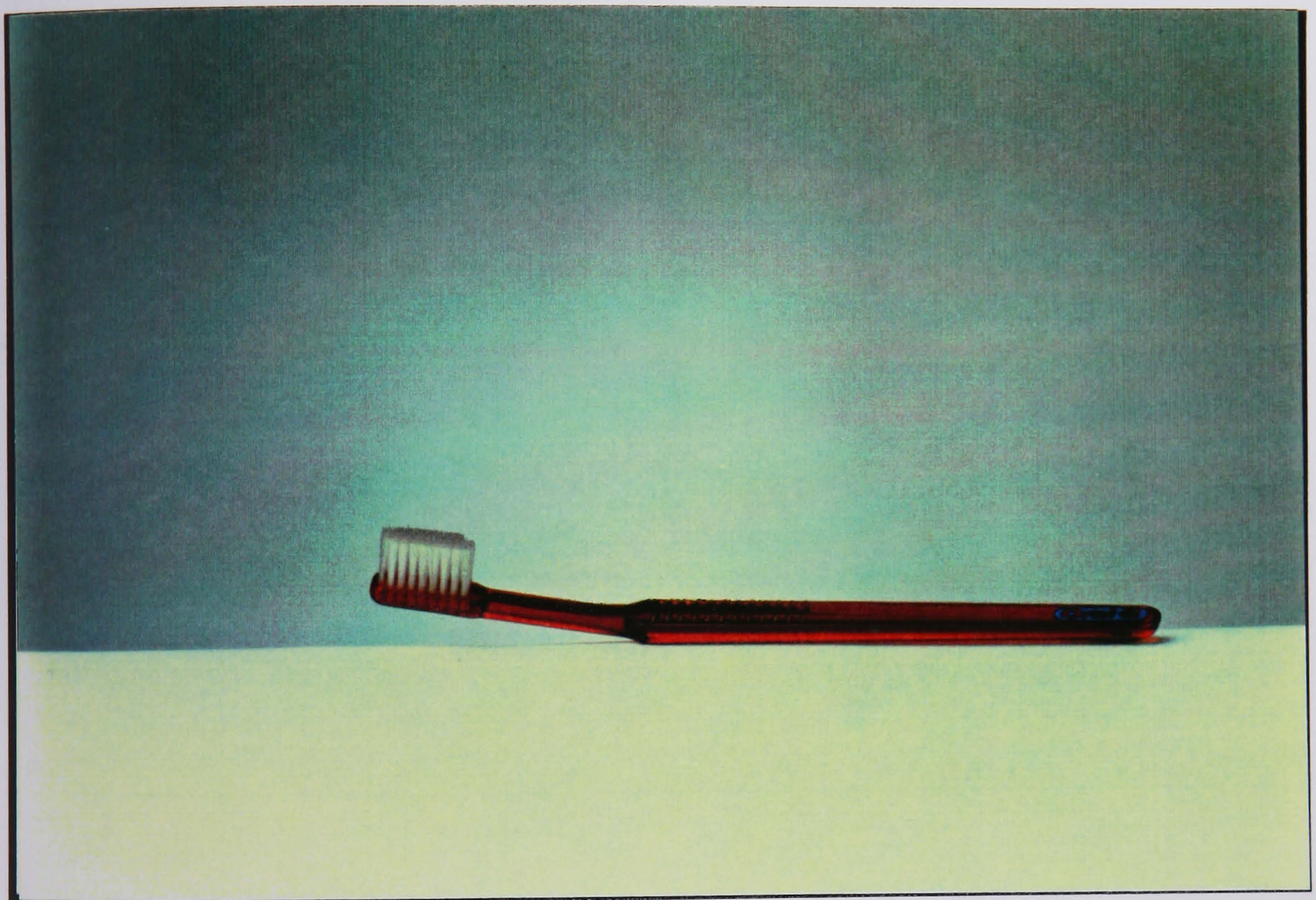

Plate 9.5.0e: Oral-B Right Angle 'A-35'

HANDLE LENGTH: **120 mm.**

OVERALL LENGTH: **177 mm.**

HEAD LENGTH: **25 mm.**

FILAMENT LENGTH: **11 mm.**

FILAMENT DIAMETER: **0.24 mm.**

HANDLE WIDTH: **10 mm. - 13 mm.**

HEAD WIDTH: **10 mm.**

HANDLE THICKNESS: **5 mm. - 6 mm.**

HEAD THICKNESS: **5 mm.**

NUMBER OF FILAMENTS IN ONE TUFT(PACKING DENSITY): **24**

NUMBER OF TUFTS IN HEAD: **35**

FILAMENT MATERIAL: **Nylon 6 - 12**

TOOTHBRUSH MATERIAL: **Cellulose Propionate**

HEAD SHAPE: **Rectangular**

HANDLE SHAPE: **Contoured**

SHAPE OF HANDLE CROSS-SECTION: **Semi-Oval**

SHAPE OF HEAD CROSS-SECTION: **Rectangular**

TUFT ARRANGEMENT: **Rectangular**

TOOTHBRUSH COLOUR(S): **Red**

FILAMENT COLOUR(S): **Clear**

TEXTURE/ FINISH OF TOOTHBRUSH: **Smooth - Transparent**

ANGLE BETWEEN HEAD AND HANDLE: **+ 9 Degrees**

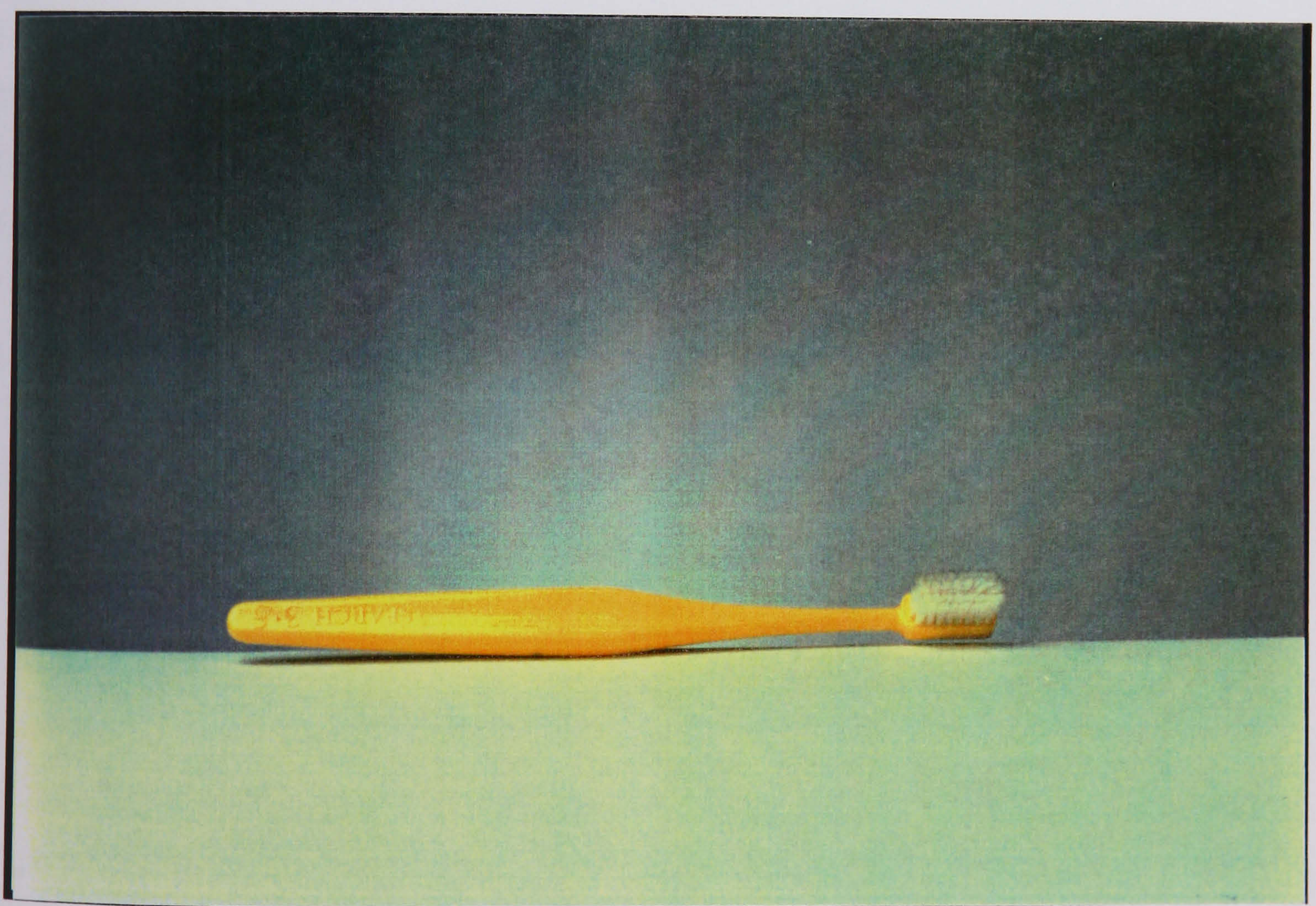

Plate 9.5.0f: Search 3.5

HANDLE LENGTH: **100 mm.**

OVERALL LENGTH: **172 mm.**

HEAD LENGTH: ***22 mm.***

FILAMENT LENGTH: ***10 mm.***

FILAMENT DIAMETER: ***0.2 mm.***

HANDLE WIDTH: ***9 mm. - 15 mm.***

HEAD WIDTH: ***9 mm.***

HANDLE THICKNESS: ***5 mm. - 8 mm.***

HEAD THICKNESS: ***5 mm.***

NUMBER OF FILAMENTS IN ONE TUFT(PACKING DENSITY): ***26***

NUMBER OF TUFTS IN HEAD: ***34***

FILAMENT MATERIAL: ***Polyester***

TOOTHBRUSH MATERIAL: ***Polypropylene***

HEAD SHAPE: ***Rectangular***

HANDLE SHAPE: ***Contoured***

SHAPE OF HANDLE CROSS-SECTION: ***Oval***

SHAPE OF HEAD CROSS-SECTION: ***Rectangular***

TUFT ARRANGEMENT: ***Rectangular***

TOOTHBRUSH COLOUR(S): ***Grey***

FILAMENT COLOUR(S): ***White***

TEXTURE/ FINISH OF TOOTHBRUSH: ***Smooth - Opaque***

ANGLE BETWEEN HEAD AND HANDLE: ***0 Degrees***

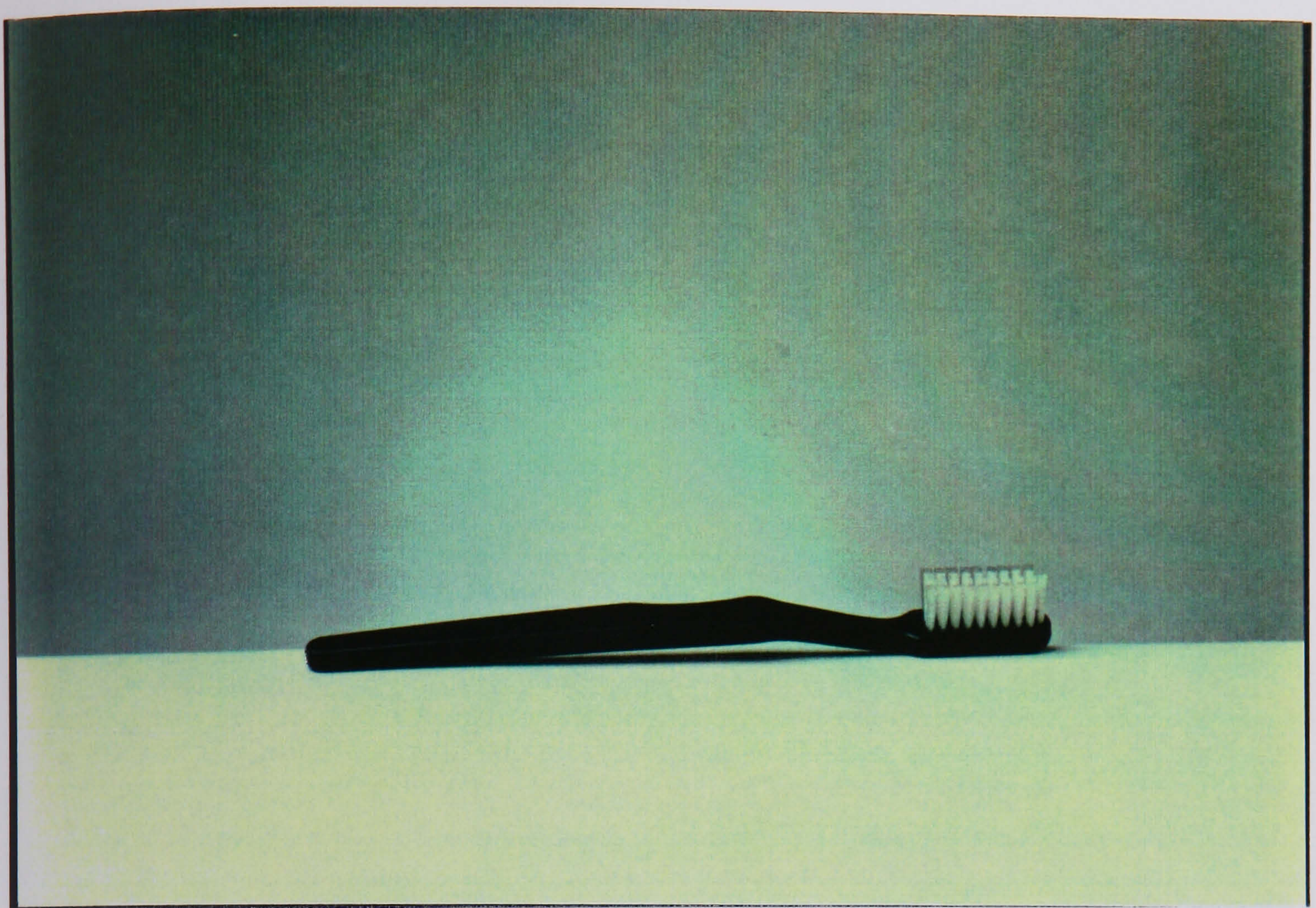

Plate 9.5.0g: Addis Dual-Texture

HANDLE LENGTH: **100 mm.**

OVERALL LENGTH: **165 mm.**

HEAD LENGTH: **35 mm.**

FILAMENT LENGTH: **12 mm.**

FILAMENT DIAMETER: **0.26 mm.**

HANDLE WIDTH: **7 mm. - 13 mm.**

HEAD WIDTH: **13 mm.**

HANDLE THICKNESS: **6 mm.**

HEAD THICKNESS: **6 mm.**

NUMBER OF FILAMENTS IN ONE TUFT(PACKING DENSITY): **22**

NUMBER OF TUFTS IN HEAD: **38**

FILAMENT MATERIAL: **Polyester**

TOOTHBRUSH MATERIAL: **Polypropylene**

HEAD SHAPE: **Rectangular**

HANDLE SHAPE: **Contoured**

SHAPE OF HANDLE CROSS-SECTION: **Rectangular**

SHAPE OF HEAD CROSS-SECTION: **Rectangular**

TUFT ARRANGEMENT: **Rectangular**

TOOTHBRUSH COLOUR(S): **Charcoal Grey**

FILAMENT COLOUR(S): **Clear - White**

TEXTURE/ FINISH OF TOOTHBRUSH: **Smooth - Opaque**

ANGLE BETWEEN HEAD AND HANDLE: **- 4 Degrees**

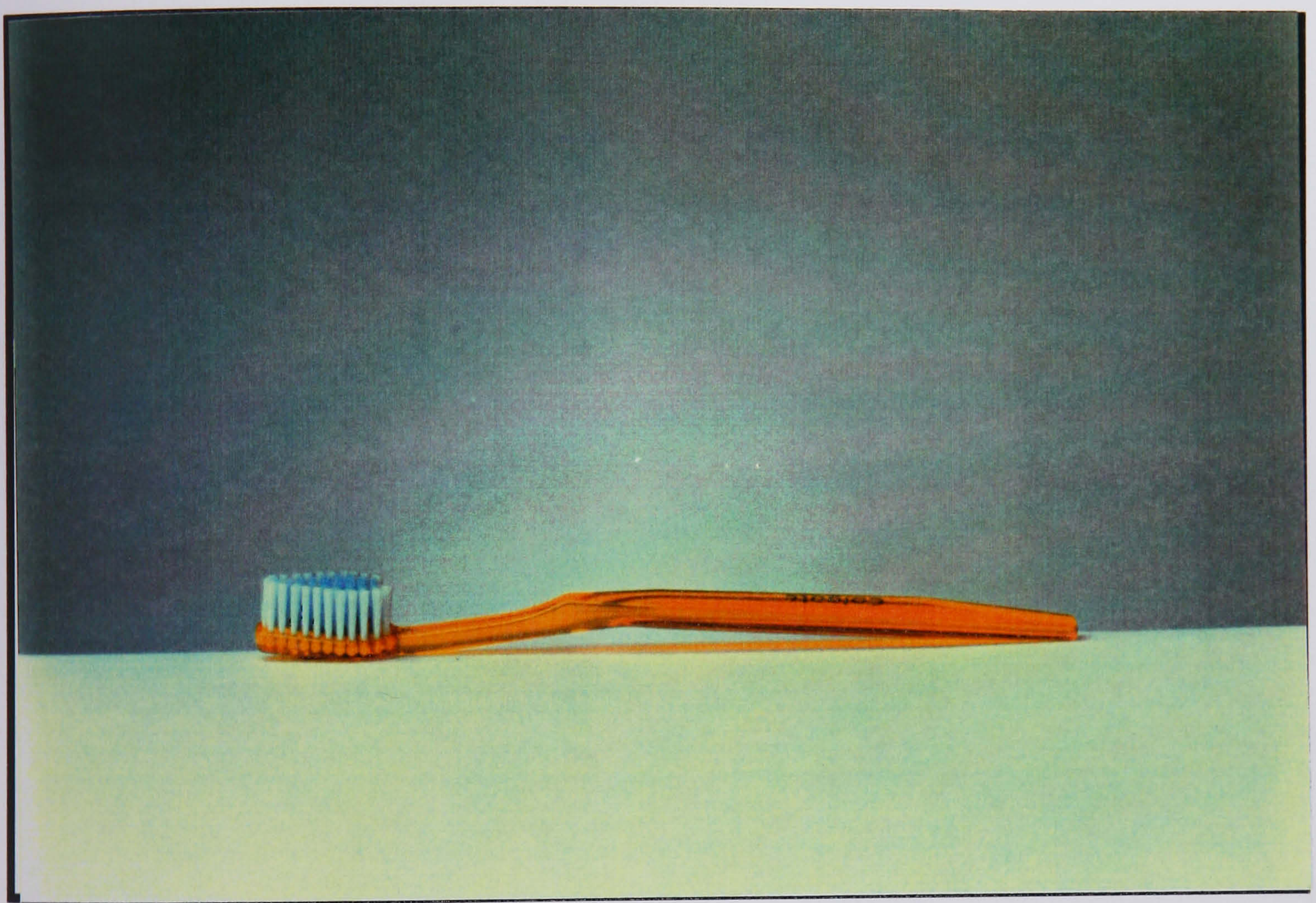

Plate 9.5.0h: Colgate Diamond Head

HANDLE LENGTH: **115 mm.**

OVERALL LENGTH: **182 mm.**

HEAD LENGTH: **30 mm.**

FILAMENT LENGTH: **11 mm.**

FILAMENT DIAMETER: **0.21 mm.**

HANDLE WIDTH: **7 mm. - 11 mm.**

HEAD WIDTH: **7 mm. - 15 mm.**

HANDLE THICKNESS: **5 mm. - 7 mm.**

HEAD THICKNESS: **5 mm.**

NUMBER OF FILAMENTS IN ONE TUFT(PACKING DENSITY): **38**

NUMBER OF TUFTS IN HEAD: **45**

FILAMENT MATERIAL: **'ZYTEL' (Nylon)**

TOOTHBRUSH MATERIAL: **ABS (Acetyl-Butyl-Stearate)**

HEAD SHAPE: **Diamond**

HANDLE SHAPE: **Contoured**

SHAPE OF HANDLE CROSS-SECTION: **Rectangular**

SHAPE OF HEAD CROSS-SECTION: **Rectangular**

TUFT ARRANGEMENT: **Diamond**

TOOTHBRUSH COLOUR(S): **Yellow**

FILAMENT COLOUR(S): **Blue - White**

TEXTURE/ FINISH OF TOOTHBRUSH: **Smooth - Transparent**

ANGLE BETWEEN HEAD AND HANDLE: **0 Degrees**

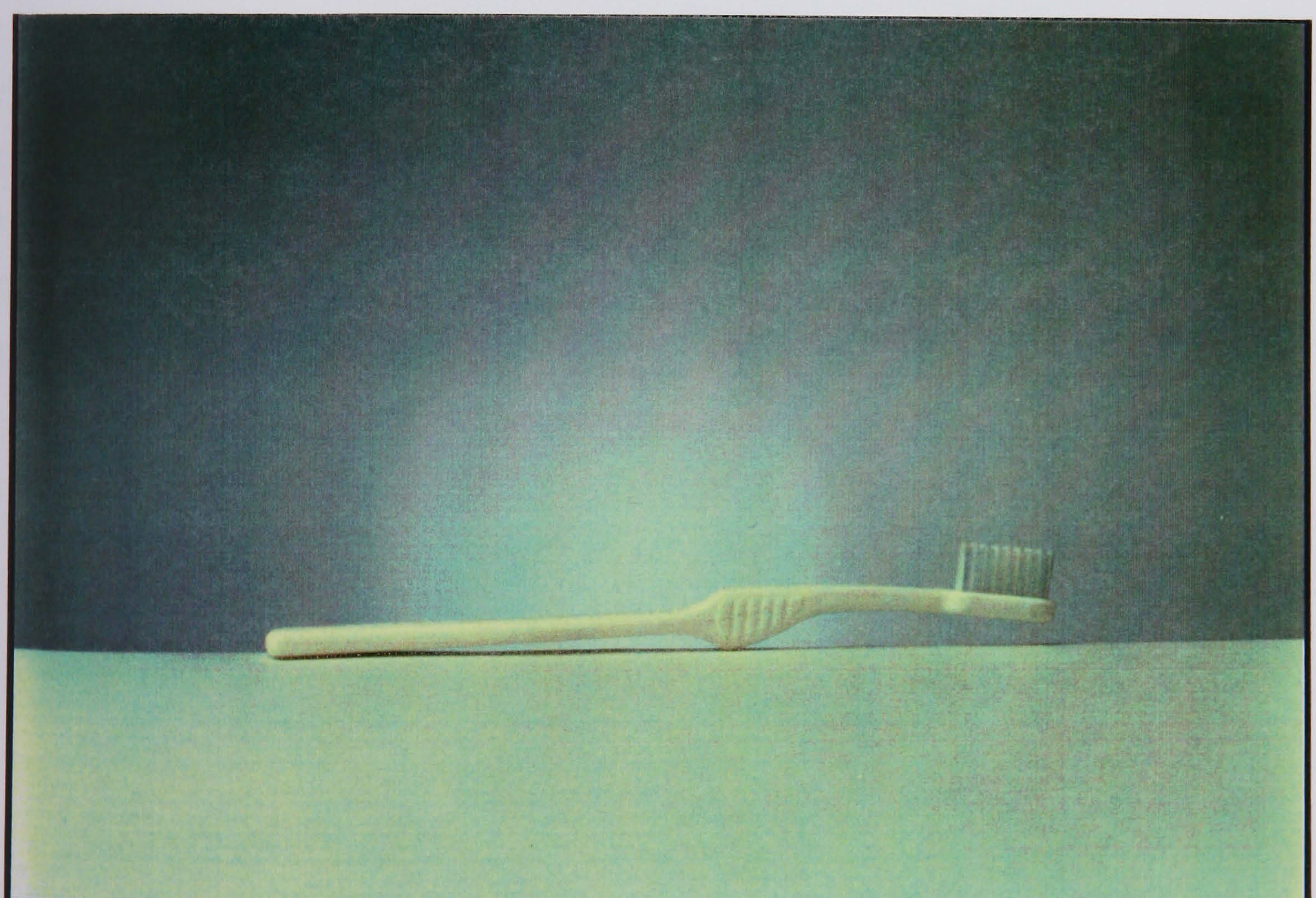

Plate 9.5.0j: Johnson & Johnson Anti-Plaque Reach

HANDLE LENGTH: **100 mm.**

OVERALL LENGTH: **175 mm.**

HEAD LENGTH: ***25 mm.***

FILAMENT LENGTH: ***10 mm. - 11 mm.***

FILAMENT DIAMETER: ***0.21 mm.***

HANDLE WIDTH: ***11 mm. - 13 mm.***

HEAD WIDTH: ***11 mm.***

HANDLE THICKNESS: ***5 mm. - 6 mm.***

HEAD THICKNESS: ***5 mm.***

NUMBER OF FILAMENTS IN ONE TUFT(PACKING DENSITY): ***44***

NUMBER OF TUFTS IN HEAD: ***34***

FILAMENT MATERIAL: ***PBT (Polybutylene-Terthalate)***

TOOTHBRUSH MATERIAL: ***SAN***

HEAD SHAPE: ***Rectangular***

HANDLE SHAPE: ***Contoured***

SHAPE OF HANDLE CROSS-SECTION: ***Rectangular***

SHAPE OF HEAD CROSS-SECTION: ***Rectangular***

TUFT ARRANGEMENT: ***Rectangular***

TOOTHBRUSH COLOUR(S): ***White***

FILAMENT COLOUR(S): ***White - Clear***

TEXTURE/ FINISH OF TOOTHBRUSH: ***Smooth - Opaque***

ANGLE BETWEEN HEAD AND HANDLE: ***- 7 Degrees***

9.6.0 Appendix VI - Mobile Telephone Characteristics

Plate 9.6.0a: Sony CM-H333

PHONE LENGTH: ***150 mm.***

PHONE WIDTH: ***38 mm.***

PHONE THICKNESS: ***40 mm.***

PHONE COLOUR(S): ***Charcoal Grey***

BUTTON COLOUR(S): ***Charcoal Grey***

PHONE SHAPE: ***Straight***

BUTTON SHAPE: ***Oval***

PHONE CROSS-SECTION: **Semi-Oval**

BUTTON LENGTH: **6 mm.**

BUTTON WIDTH: **9 mm.**

BUTTON CONFIGURATION: **Standard**

BUTTON SPACING (edge to edge): **2 mm.**

BUTTON MATERIAL: **Synthetic Rubber**

BUTTON DIGIT SIZE: **4 mm.**

PHONE MATERIAL: **ABS (Acetyl-Butyl-Stearate)**

PHONE TEXTURE/FINISH: **Gloss**

DISTANCE BETWEEN EAR-PIECE AND MOUTHPIECE: **131 mm.**

Plate 9.6.0b: Ericsson Hotline GH197

PHONE LENGTH: ***145 mm.***

PHONE WIDTH: ***59 mm.***

PHONE THICKNESS: ***26 mm.***

PHONE COLOUR(S): ***Black***

BUTTON COLOUR(S): ***White***

PHONE SHAPE: ***Contoured***

BUTTON SHAPE: ***Square***

PHONE CROSS-SECTION: ***Rectangular***

BUTTON LENGTH: ***7 mm.***

BUTTON WIDTH: ***7 mm.***

BUTTON CONFIGURATION: ***Standard***

BUTTON SPACING (edge to edge): ***4 mm.***

BUTTON MATERIAL: ***Synthetic Rubber***

BUTTON DIGIT SIZE: ***3 mm.***

PHONE MATERIAL: ***ABS (Acetyl-Butyl-Stearate)***

PHONE TEXTURE/FINISH: ***Matte***

DISTANCE BETWEEN EAR-PIECE AND MOUTHPIECE: ***120 mm.***

Plate 9.6.0c: NEC P-4

PHONE LENGTH: ***153 mm.***

PHONE WIDTH: ***56 mm.***

PHONE THICKNESS: ***21 mm.***

PHONE COLOUR(S): ***Black***

BUTTON COLOUR(S): ***Black***

PHONE SHAPE: ***Straight***

BUTTON SHAPE: ***Rectangular***

PHONE CROSS-SECTION: ***Octagonal***

BUTTON LENGTH: ***8 mm.***

BUTTON WIDTH: ***10 mm.***

BUTTON CONFIGURATION: ***Standard***

BUTTON SPACING (edge to edge): ***3 mm.***

BUTTON MATERIAL: ***ABS (Acetyl-Butyl-Stearate)***

BUTTON DIGIT SIZE: ***5 mm.***

PHONE MATERIAL: ***ABS (Acetyl-Butyl-Stearate)***

PHONE TEXTURE/FINISH: ***Matte***

DISTANCE BETWEEN EAR-PIECE AND MOUTHPIECE: ***127 mm.***

Plate 9.6.0d: NEC P-100

PHONE LENGTH: ***162 mm.***

PHONE WIDTH: ***54 mm.***

PHONE THICKNESS: ***27 mm.***

PHONE COLOUR(S): ***Charcoal Grey***

BUTTON COLOUR(S): ***White***

PHONE SHAPE: ***Contoured***

BUTTON SHAPE: ***Circular***

PHONE CROSS-SECTION: ***Rectangular***

BUTTON LENGTH: ***8 mm.***

BUTTON WIDTH: ***8 mm.***

BUTTON CONFIGURATION: ***Standard***

BUTTON SPACING (edge to edge): ***6 mm.***

BUTTON MATERIAL: ***ABS (Acetyl-Butyl-Stearate)***

BUTTON DIGIT SIZE: ***5 mm.***

PHONE MATERIAL: ***ABS (Acetyl-Butyl-Stearate)***

PHONE TEXTURE/FINISH: ***Matte***

DISTANCE BETWEEN EAR-PIECE AND MOUTHPIECE: ***132 mm.***

Plate 9.6.0e: Mitsubishi MT-5

PHONE LENGTH: ***155 mm.***

PHONE WIDTH: ***55 mm.***

PHONE THICKNESS: ***23 mm.***

PHONE COLOUR(S): ***Charcoal Grey***

BUTTON COLOUR(S): ***White***

PHONE SHAPE: ***Straight***

BUTTON SHAPE: ***Oval***

PHONE CROSS-SECTION: ***Rectangular***

BUTTON LENGTH: ***5 mm.***

BUTTON WIDTH: ***11 mm.***

BUTTON CONFIGURATION: ***Standard***

BUTTON SPACING (edge to edge): ***4 mm.***

BUTTON MATERIAL: ***ABS (Acetyl-Butyl-Stearate)***

BUTTON DIGIT SIZE: ***3 mm.***

PHONE MATERIAL: ***ABS (Acetyl-Butyl-Stearate)***

PHONE TEXTURE/FINISH: ***Matte***

DISTANCE BETWEEN EAR-PIECE AND MOUTHPIECE: ***130 mm.***

9.7.0 Appendix VII - System & Disposable Shaver Characteristics

Plate 9.7.0a: Gillette Contour System

SHAVER HANDLE MATERIAL: ***Polypropylene***

SHAVER HEAD MATERIAL: ***Polypropylene***

SHAVER HANDLE COLOUR(S): ***Black***

SHAVER HEAD COLOUR(S): ***Black***

SHAVER TEXTURE: ***Opaque***

SHAVER HANDLE SHAPE: ***Straight***

SHAVER BLADE MATERIAL: ***Chromium Steel***

NUMBER OF BLADES: ***2***

SHAVER BLADE LENGTH: ***36 mm.***

ANGLE BETWEEN SHAVER HEAD & HANDLE: ***55 Degrees***

SHAVER HEAD CROSS-SECTION: ***Elliptical***

OVERALL SHAVER LENGTH: ***125 mm.***

SHAVER HANDLE LENGTH: ***86 mm.***

SHAVER HANDLE WIDTH: ***11 mm.***

SHAVER HANDLE THICKNESS: ***11 mm.***

SHAVER HANDLE CROSS-SECTION: ***Circular***

DISTANCE BETWEEN BLADES: ***1 mm.***

SHAVER HEAD LENGTH: ***39 mm.***

SHAVER HEAD WIDTH: ***10 mm.***

SHAVER HEAD THICKNESS: ***5 mm.***

SHAVER HEAD SHAPE: ***Rectangular***

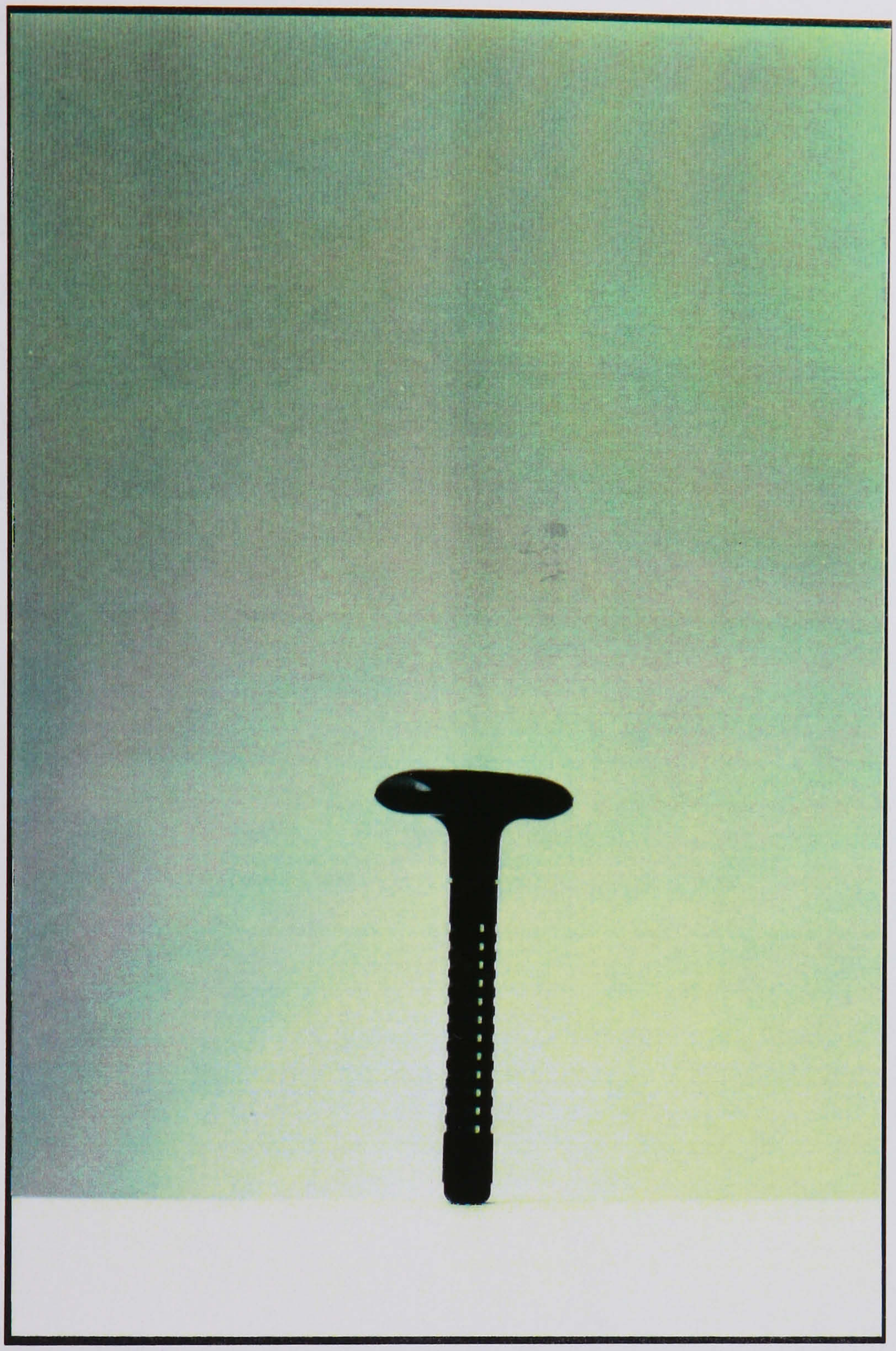

Plate 9.7.0b: Wilkinson Classic System

SHAVER HANDLE MATERIAL: ***Polypropylene***

SHAVER HEAD MATERIAL: ***Polypropylene***

SHAVER HANDLE COLOUR(S): ***Black***

SHAVER HEAD COLOUR(S): ***Black***

SHAVER TEXTURE: ***Opaque***

SHAVER HANDLE SHAPE: ***Straight***

SHAVER BLADE MATERIAL: ***Stainless Steel***

NUMBER OF BLADES: ***1***

SHAVER BLADE LENGTH: ***37 mm.***

ANGLE BETWEEN SHAVER HEAD & HANDLE: ***90 Degrees***

SHAVER HEAD CROSS-SECTION: ***Oval***

OVERALL SHAVER LENGTH: ***105 mm.***

SHAVER HANDLE LENGTH: ***80 mm.***

SHAVER HANDLE WIDTH: ***12 mm.***

SHAVER HANDLE THICKNESS: ***12 mm.***

SHAVER HANDLE CROSS-SECTION: ***Circular***

DISTANCE BETWEEN BLADES: ***0 mm.***

SHAVER HEAD LENGTH: ***48 mm.***

SHAVER HEAD WIDTH: ***24 mm.***

SHAVER HEAD THICKNESS: ***3 mm. - 11 mm.***

SHAVER HEAD SHAPE: ***Rectangular***

Plate 9.7.0c: Gillette Lady Contour System

SHAVER HANDLE MATERIAL: ***Polypropylene***

SHAVER HEAD MATERIAL: ***Polypropylene***

SHAVER HANDLE COLOUR(S): ***Cream***

SHAVER HEAD COLOUR(S): ***Black***

SHAVER TEXTURE: ***Opaque***

SHAVER HANDLE SHAPE: ***Contoured***

SHAVER BLADE MATERIAL: ***Chromium Steel***

NUMBER OF BLADES: ***2***

SHAVER BLADE LENGTH: ***36 mm.***

ANGLE BETWEEN SHAVER HEAD & HANDLE: ***45 Degrees***

SHAVER HEAD CROSS-SECTION: ***Elliptical***

OVERALL SHAVER LENGTH: ***121 mm.***

SHAVER HANDLE LENGTH: ***91 mm.***

SHAVER HANDLE WIDTH: ***10 mm. - 15 mm.***

SHAVER HANDLE THICKNESS: ***6 mm. - 12 mm.***

SHAVER HANDLE CROSS-SECTION: ***Elliptical***

DISTANCE BETWEEN BLADES: ***1 mm.***

SHAVER HEAD LENGTH: ***39 mm.***

SHAVER HEAD WIDTH: ***10 mm.***

SHAVER HEAD THICKNESS: ***5 mm.***

SHAVER HEAD SHAPE: ***Rectangular***

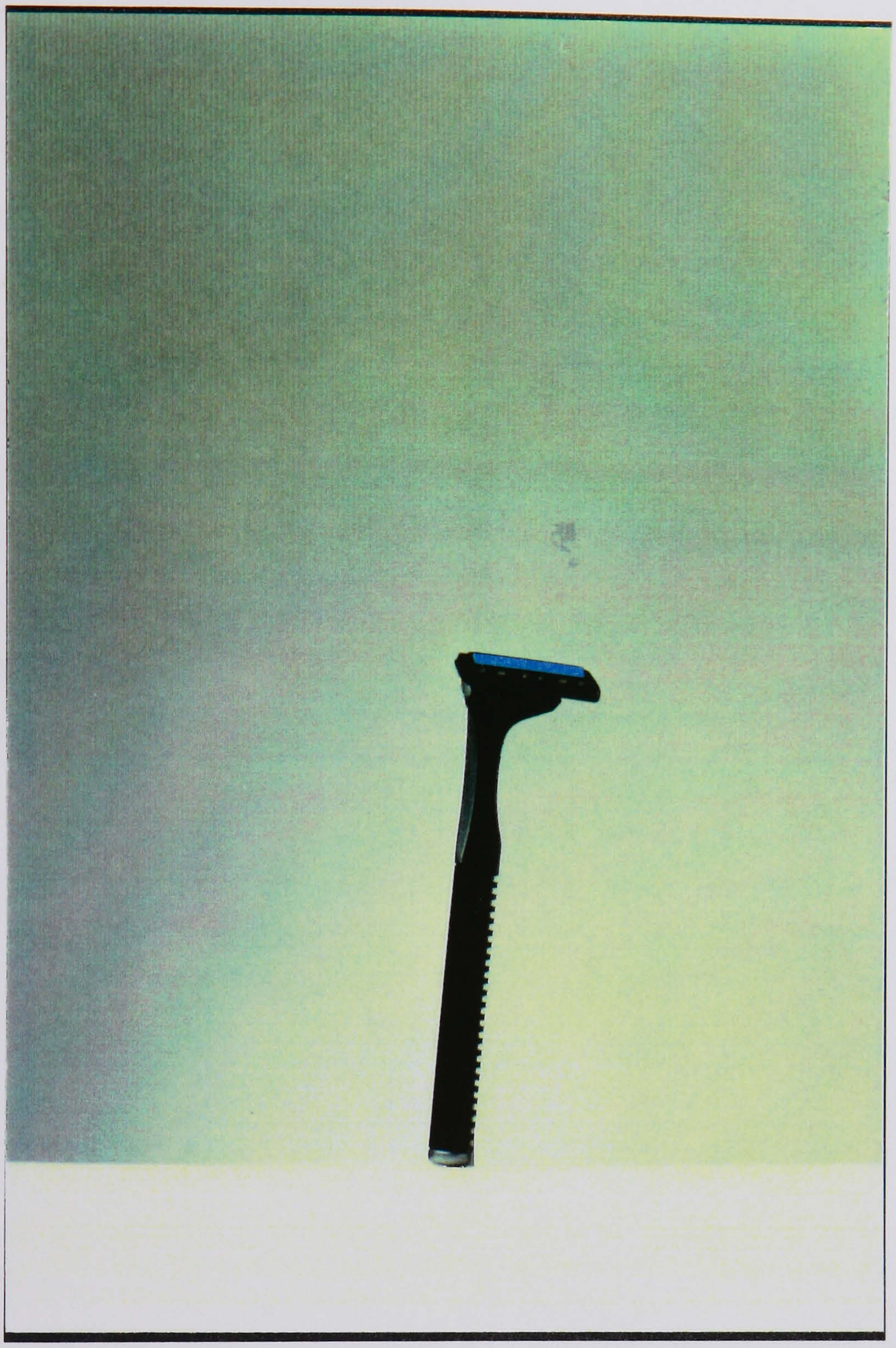

Plate 9.7.0d: Wilkinson Swivel Profile System

SHAVER HANDLE MATERIAL: ***Polystyrene***

SHAVER HEAD MATERIAL: ***Polystyrene***

SHAVER HANDLE COLOUR(S): ***Black***

SHAVER HEAD COLOUR(S): ***Black***

SHAVER TEXTURE: ***Matte***

SHAVER HANDLE SHAPE: ***Straight***

SHAVER BLADE MATERIAL: ***Steel***

NUMBER OF BLADES: ***2***

SHAVER BLADE LENGTH: ***36 mm.***

ANGLE BETWEEN SHAVER HEAD & HANDLE: ***48 Degrees***

SHAVER HEAD CROSS-SECTION: ***Elliptical***

OVERALL SHAVER LENGTH: ***124 mm.***

SHAVER HANDLE LENGTH: ***76 mm.***

SHAVER HANDLE WIDTH: ***10 mm.***

SHAVER HANDLE THICKNESS: ***10 mm.***

SHAVER HANDLE CROSS-SECTION: ***Circular***

DISTANCE BETWEEN BLADES: ***1 mm.***

SHAVER HEAD LENGTH: ***39 mm.***

SHAVER HEAD WIDTH: ***10 mm.***

SHAVER HEAD THICKNESS: ***5 mm.***

SHAVER HEAD SHAPE: ***Rectangular***

Plate 9.7.0e: Gillette Sensor System

SHAVER HANDLE MATERIAL: ***Stainless Steel Alloy***

SHAVER HEAD MATERIAL: ***Polystyrene***

SHAVER HANDLE COLOUR(S): ***Silver Grey***

SHAVER HEAD COLOUR(S): ***Black***

SHAVER TEXTURE: ***Polished***

SHAVER HANDLE SHAPE: ***Straight***

SHAVER BLADE MATERIAL: ***Chromium Steel***

NUMBER OF BLADES: ***2***

SHAVER BLADE LENGTH: ***35 mm.***

ANGLE BETWEEN SHAVER HEAD & HANDLE: ***45 Degrees***

SHAVER HEAD CROSS-SECTION: ***Rectangular***

OVERALL SHAVER LENGTH: ***128 mm.***

SHAVER HANDLE LENGTH: ***85 mm.***

SHAVER HANDLE WIDTH: ***11 mm.***

SHAVER HANDLE THICKNESS: ***11 mm.***

SHAVER HANDLE CROSS-SECTION: ***Circular***

DISTANCE BETWEEN BLADES: ***1 mm.***

SHAVER HEAD LENGTH: ***40 mm.***

SHAVER HEAD WIDTH: ***8 mm.***

SHAVER HEAD THICKNESS: ***4 mm.***

SHAVER HEAD SHAPE: ***Rectangular***

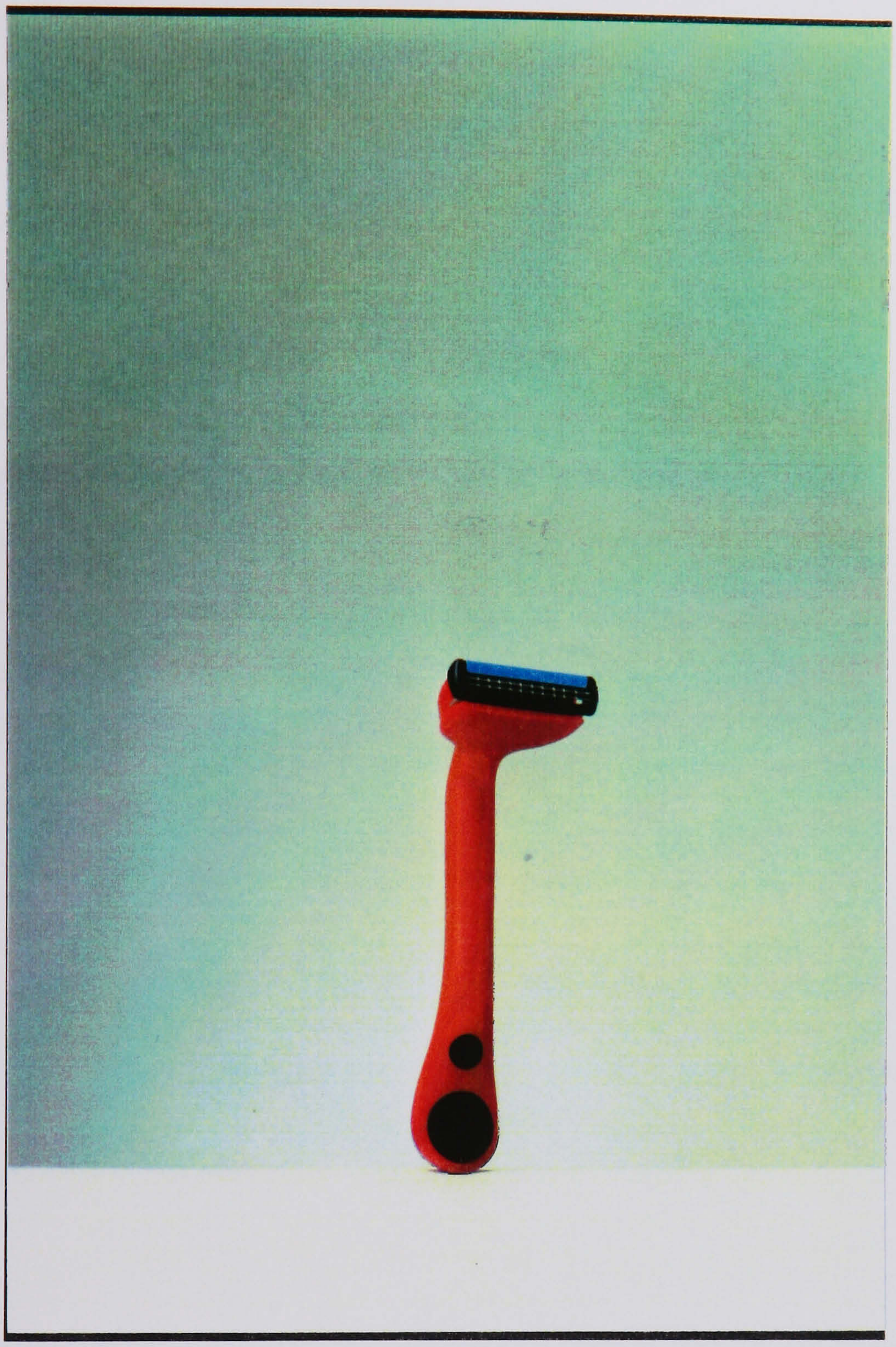

Plate 9.7.0f: Wilkinson Protector System

SHAVER HANDLE MATERIAL: ***Polypropylene***

SHAVER HEAD MATERIAL: ***Polypropylene***

SHAVER HANDLE COLOUR(S): ***Red***

SHAVER HEAD COLOUR(S): ***Black***

SHAVER TEXTURE: ***Gloss***

SHAVER HANDLE SHAPE: ***Contoured***

SHAVER BLADE MATERIAL: ***Chromium Steel***

NUMBER OF BLADES: ***2***

SHAVER BLADE LENGTH: ***35 mm.***

ANGLE BETWEEN SHAVER HEAD & HANDLE: ***50 Degrees***

SHAVER HEAD CROSS-SECTION: ***Rectangular***

OVERALL SHAVER LENGTH: ***125 mm.***

SHAVER HANDLE LENGTH: ***100 mm.***

SHAVER HANDLE WIDTH: ***10 mm. - 22 m.***

SHAVER HANDLE THICKNESS: ***10 mm. - 14 mm.***

SHAVER HANDLE CROSS-SECTION: ***Rectangular***

DISTANCE BETWEEN BLADES: ***1 mm.***

SHAVER HEAD LENGTH: ***40 mm.***

SHAVER HEAD WIDTH: ***9 mm.***

SHAVER HEAD THICKNESS: ***3 mm. - 6 mm.***

SHAVER HEAD SHAPE: ***Rectangular***

Plate 9.7.0g: Gillette Blue Disposable

SHAVER HANDLE MATERIAL: **Polystyrene**

SHAVER HEAD MATERIAL: **Polystyrene**

SHAVER HANDLE COLOUR(S): **Blue**

SHAVER HEAD COLOUR(S): **Blue**

SHAVER TEXTURE: **Opaque**

SHAVER HANDLE SHAPE: **Straight**

SHAVER BLADE MATERIAL: **Stainless Steel Alloy**

NUMBER OF BLADES: **2**

SHAVER BLADE LENGTH: **36 mm.**

ANGLE BETWEEN SHAVER HEAD & HANDLE: **42 Degrees**

SHAVER HEAD CROSS-SECTION: **Oval**

OVERALL SHAVER LENGTH: **100 mm.**

SHAVER HANDLE LENGTH: **83 mm.**

SHAVER HANDLE WIDTH: **10 mm.**

SHAVER HANDLE THICKNESS: **10 mm.**

SHAVER HANDLE CROSS-SECTION: **Square**

DISTANCE BETWEEN BLADES: **1 mm.**

SHAVER HEAD LENGTH: **39 mm.**

SHAVER HEAD WIDTH: **11 mm.**

SHAVER HEAD THICKNESS: **5 mm.**

SHAVER HEAD SHAPE: **Rectangular**

Plate 9.7.0h: Gillette Grey Disposable

SHAVER HANDLE MATERIAL: ***Polystyrene***

SHAVER HEAD MATERIAL: ***Polystyrene***

SHAVER HANDLE COLOUR(S): ***Light Grey***

SHAVER HEAD COLOUR(S): ***Black***

SHAVER TEXTURE: ***Opaque***

SHAVER HANDLE SHAPE: ***Straight***

SHAVER BLADE MATERIAL: ***Stainless Steel Alloy***

NUMBER OF BLADES: ***2***

SHAVER BLADE LENGTH: ***36 mm.***

ANGLE BETWEEN SHAVER HEAD & HANDLE: ***40 Degrees***

SHAVER HEAD CROSS-SECTION: ***Elliptical***

OVERALL SHAVER LENGTH: ***100 mm.***

SHAVER HANDLE LENGTH: ***75 mm.***

SHAVER HANDLE WIDTH: ***10 mm.***

SHAVER HANDLE THICKNESS: ***8 mm.***

SHAVER HANDLE CROSS-SECTION: ***Rectangular***

DISTANCE BETWEEN BLADES: ***1 mm.***

SHAVER HEAD LENGTH: ***39 mm.***

SHAVER HEAD WIDTH: ***10 mm.***

SHAVER HEAD THICKNESS: ***5 mm.***

SHAVER HEAD SHAPE: ***Rectangular***

Plate 9.7.0j: Wilkinson Red Disposable

SHAVER HANDLE MATERIAL: ***Polystyrene***

SHAVER HEAD MATERIAL: ***Polystyrene***

SHAVER HANDLE COLOUR(S): ***Red***

SHAVER HEAD COLOUR(S): ***Red***

SHAVER TEXTURE: ***Opaque***

SHAVER HANDLE SHAPE: ***Contoured***

SHAVER BLADE MATERIAL: ***Chromium Steel***

NUMBER OF BLADES: ***1***

SHAVER BLADE LENGTH: ***37 mm.***

ANGLE BETWEEN SHAVER HEAD & HANDLE: ***40 Degrees***

SHAVER HEAD CROSS-SECTION: ***Triangular***

OVERALL SHAVER LENGTH: ***108 mm.***

SHAVER HANDLE LENGTH: ***90 mm.***

SHAVER HANDLE WIDTH: ***10 mm.***

SHAVER HANDLE THICKNESS: ***10 mm.***

SHAVER HANDLE CROSS-SECTION: ***Semi Elliptical***

DISTANCE BETWEEN BLADES: ***0 mm.***

SHAVER HEAD LENGTH: ***42 mm.***

SHAVER HEAD WIDTH: ***11 mm.***

SHAVER HEAD THICKNESS: ***10 mm.***

SHAVER HEAD SHAPE: ***Rectangular***

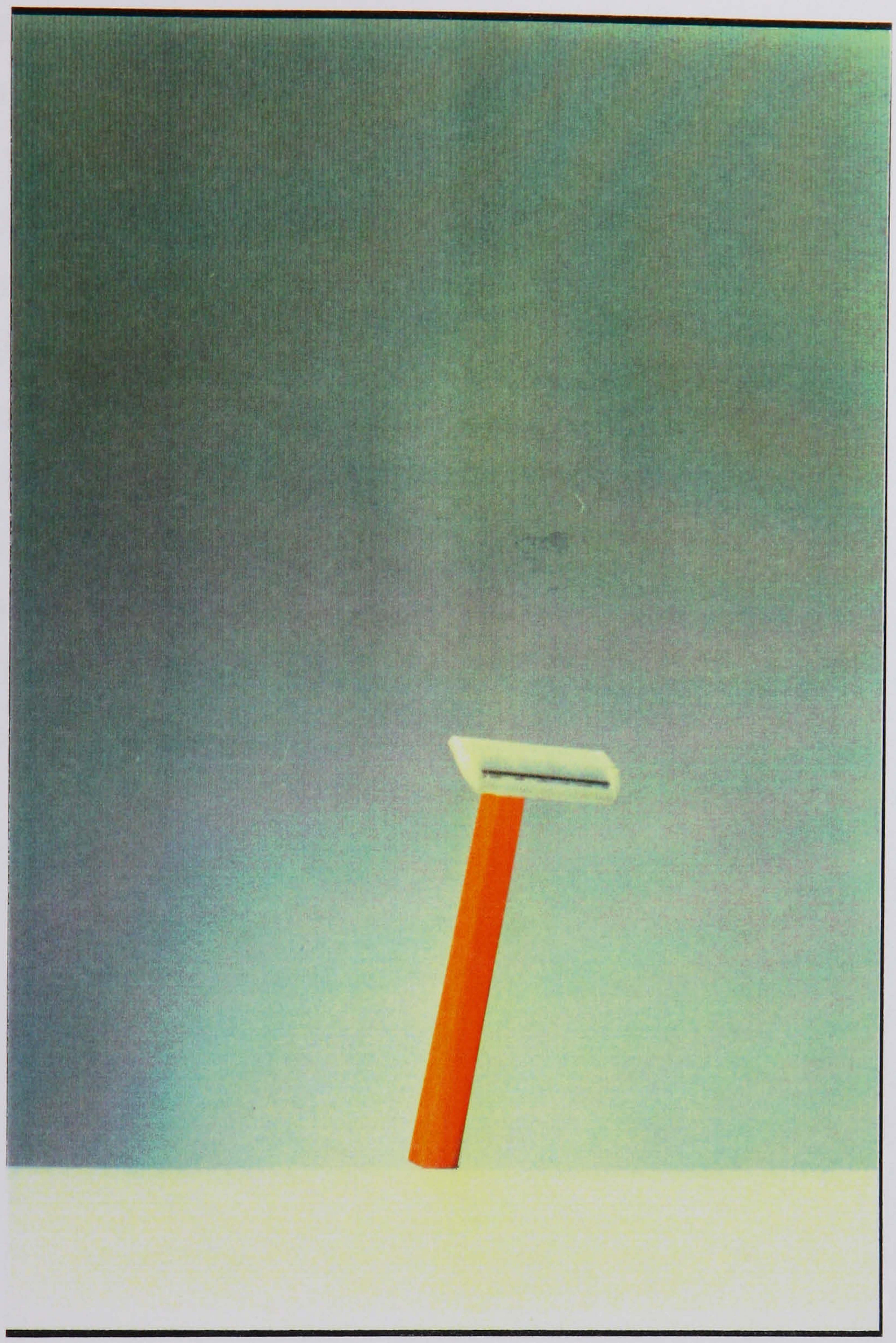

Plate 9.7.0k: Bic Orange Disposable

SHAVER HANDLE MATERIAL: ***Polystyrene***

SHAVER HEAD MATERIAL: ***Polystyrene***

SHAVER HANDLE COLOUR(S): ***Orange***

SHAVER HEAD COLOUR(S): ***White***

SHAVER TEXTURE: ***Opaque***

SHAVER HANDLE SHAPE: ***Straight***

SHAVER BLADE MATERIAL: ***Stainless Steel***

NUMBER OF BLADES: ***1***

SHAVER BLADE LENGTH: ***37 mm.***

ANGLE BETWEEN SHAVER HEAD & HANDLE: ***39 Degrees***

SHAVER HEAD CROSS-SECTION: ***Semi Elliptical***

OVERALL SHAVER LENGTH: ***104 mm.***

SHAVER HANDLE LENGTH: ***90 mm.***

SHAVER HANDLE WIDTH: ***10 mm.***

SHAVER HANDLE THICKNESS: ***9 mm.***

SHAVER HANDLE CROSS-SECTION: ***Octagonal***

DISTANCE BETWEEN BLADES: ***0 mm.***

SHAVER HEAD LENGTH: ***44 mm.***

SHAVER HEAD WIDTH: ***15 mm.***

SHAVER HEAD THICKNESS: ***4 mm.***

SHAVER HEAD SHAPE: ***Rectangular***

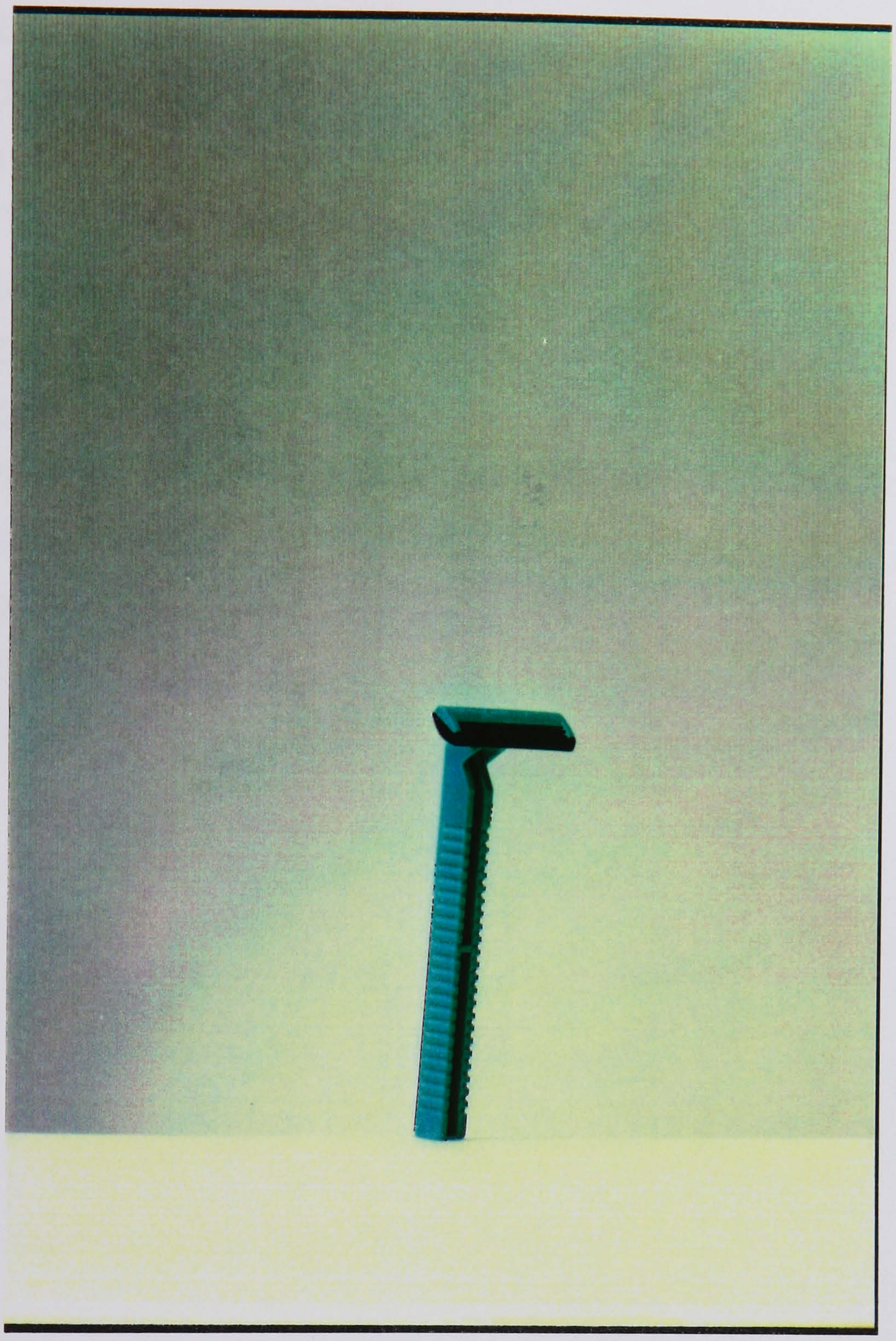

Plate 9.7.0m: Wilkinson Green Disposable

SHAVER HANDLE MATERIAL: ***Polystyrene***

SHAVER HEAD MATERIAL: ***Polystyrene***

SHAVER HANDLE COLOUR(S): ***Green***

SHAVER HEAD COLOUR(S): ***Green***

SHAVER TEXTURE: ***Opaque***

SHAVER HANDLE SHAPE: ***Straight***

SHAVER BLADE MATERIAL: ***Stainless Steel Alloy***

NUMBER OF BLADES: ***2***

SHAVER BLADE LENGTH: ***36 mm.***

ANGLE BETWEEN SHAVER HEAD & HANDLE: ***45 Degrees***

SHAVER HEAD CROSS-SECTION: ***Oval***

OVERALL SHAVER LENGTH: ***103 mm.***

SHAVER HANDLE LENGTH: ***82 mm.***

SHAVER HANDLE WIDTH: ***8 mm.***

SHAVER HANDLE THICKNESS: ***8 mm.***

SHAVER HANDLE CROSS-SECTION: ***Square***

DISTANCE BETWEEN BLADES: ***1.2 mm.***

SHAVER HEAD LENGTH: ***39 mm.***

SHAVER HEAD WIDTH: ***11 mm.***

SHAVER HEAD THICKNESS: ***5 mm.***

SHAVER HEAD SHAPE: ***Rectangular***

9.8.0 Appendix VIII - Explanations of CADET System Mobile Phone Test Results

(1) **Mitsubishi MT-5**

Pass:

'fits_face' - **(100%)** 'fits_in_pocket' - **(100%)** 'not_too_heavy' - **(100%)**
'comfortable_to_hold' - **(100%)** 'looks_attractive' - **(100%)**

Fail:

'operable_with_one_hand' - **(90.9%)** 'easy_to_dial' - **(51.8%)**

Combined Total: (87.7%)

Rating: 3rd of 5

Explanation:

Ideally the length of the buttons should be between 12-17 mm., however, the **absolute minimum** is 6 mm. (Woodson et al, 1992), (Pheasant, 1986), the Mitsubishi MT-5's button length is 5 mm. The spacing between buttons (edge to edge) should be between 6-20 mm. (Pheasant 1986), however the spacing between the buttons of the Mitsubishi MT-5 is only 4 mm. The buttons' digit size of the Mitsubishi MT-5 are too small at 3mm., as the height of characters should be no less than 4 mm. (Pheasant, 1986).

(2) **NEC P-100**

Pass:

'looks_attractive' - **(100%)** 'easy_to_dial' - **(100%)** 'not_too_heavy' - **(100%)**
'comfortable_to_hold' - **(100%)** 'fits_in_pocket' - **(100%)** 'fits_face' - **(100%)**
'operable_with_one_hand' - **(100%)**

Fail:

Combined Total: (100%)

Rating: 1st of 5

Explanation:

The NEC P-100 did not fail any of the attributes tested.

(3) NEC P-4

Pass:

'looks_attractive' - **(100%)**

Fail:

'operable_with_one_hand' - **(77.3%)** 'fits_face' - **(61.9%)** 'fits_in_pocket' - **(78.9%)** 'not_too_heavy' - **(88.8%)** 'comfortable_to_hold' - **(77.3%)** 'easy_to_dial' - **(81.5%)**

Combined Total: (79.6%)

Rating: 5th of 5

Explanation:

The cross-section of the NEC P-4 is not suitable according to Woodson (1992) and Pheasant (1986). Both state: avoid square cross-sections and edges . Circular cross-sections are the most comfortable to grip. The distance between the phone's earpiece and mouthpiece should be between 129-146 mm. (Oikawa et al, 1984), (Matsui et al, 1982), the earpiece to mouthpiece distance of the NEC P-4 is 1 mm. too short. Also the button spacing is too small at 3mm. (Pheasant 1986).

(4) Ericsson Hotline

Pass:

'looks_attractive' - **(100%)** 'operable_with_one_hand' - **(100%)** 'fits_in_pocket' - **(100%)** 'not_too_heavy' - **(100%)** 'comfortable_to_hold' - **(100%)**

Fail:

'fits_face' - **(76.2%)** 'easy_to_dial' - **(70.1%)**

Combined Total: (89.5%)

Rating: 2nd of 5

Explanation:

The spacing between buttons (edge to edge) should be between 6-20 mm. (Pheasant 1986).

The height of characters should be no less than 4 mm. (Pheasant, 1986). The Ericsson Hotline fails because the spacing between buttons on this phone is 4 mm. and the digit height of the button numbers are only 3 mm. Furthermore, the distance between the earpiece and the mouthpiece is too small at 120 mm., as the distance between the phone's earpiece and mouthpiece must be between 129 - 146 mm. (Oikawa et al, 1984), (Matsui et al, 1982).

(5) **SONY CM-H333**

Pass:

'fits_in_pocket' - **(100%)**

Fail:

'operable_with_one_hand' - **(81.8%)** 'fits_face' - **(85.7%)** 'not_too_heavy' - **(83.3%)** 'comfortable_to_hold' - **(86.4%)** easy_to_dial' - **(81.5%)** 'looks_attractive' - **(91.3%)**

Combined Total: (86.3%)

Rating: 4th of 5

Explanation:

The Sony CM-H333 has a thickness of 40 mm., however Woodson, Tillman and Tillman (1992) state that the thickness of a phone should not exceed 35 mm. Furthermore, the spacing between the buttons (edge to edge) of a phone should be between 6 and 20 mm. (Pheasant 1986). In the case of the Sony CM-H333, the spacing edge to edge is only 2 mm.

9.9.0 Appendix IX - Explanations of CADET System Disposable & System Shaver Test Results

DISPOSABLE SHAVERS

(1) Gillette Blue

Pass:

'is_hygienic' - **(100%)** 'doesn't_cut_face' - **(100%)** 'doesn't_irritate_skin' - **(100%)** 'gives_a_close_shave' - **(100%)** 'looks_attractive' - **(100%)**

Fail:

'comfortable_to_hold' - **(82.6%)** 'easy_to_clean' - **(90.9%)** 'removes_difficult_hair' - **(91.6%)**

Combined Total: (96.7%)

Rating: 2nd of 5

Explanation:

The square cross-section of this shaver is not comfortable to hold because the cross-sectional profile of the handle should be based on either one of the two common shapes; the circle and the rectangle. Variations or combinations of these two basic shapes may also be used (Warrick, 1994). Handles of circular cross-sections are the most comfortable to grip (Woodson et al, 1992). The width of this blade is too large as the width of the blade is generally 5 mm. wide to 8.5 mm. wide (Warrick, 1994).

(2) Gillette Grey

Pass:

'gives_a_close_shave' - **(100%)** 'easy_to_clean' - **(100%)** 'doesn't_irritate_skin' - **(100%)** 'comfortable_to_hold' - **(100%)** 'removes_difficult_hair' - **(100%)** 'doesn't_cut_face' - **(100%)** 'is_hygienic' - **(100%)**

Fail:

'looks_attractive' - **(85.7%)**

Combined Total: (99.4%)

Rating: 1st of 5

Explanation:

The application of the light-grey pigment of this shaver is an unsuitable selection for this product (Kobayashi 1990).

(3) **Wilkinson Red**

Pass:

'looks_attractive' - **(100%)** 'comfortable_to_hold' - **(100%)** 'doesn't_irritate_skin' - **(100%)** 'is_hygienic' - **(100%)**

Fail:

'gives_a_close_shave' - **(74.1%)** 'easy_to_clean' - **(77.3%)** 'removes_difficult_hair' - **(66.6%)** 'doesn't_cut_face' - **(70.6%)**

Combined Total: (92.4%)

Rating: 4th of 5

Explanation:

The head cross-section should generally be based on a rectangular shape (Warrick, 1994), not triangular. The width of this blade is too large as the width of the blade is generally 5 mm. wide to 8.5 mm. wide (Warrick, 1994).

(4) **BIC Orange**

Pass:

'doesn't_irritate_skin' - **(100%)** 'doesn't_cut_face' - **(100%)** 'is_hygienic' - **(100%)**

Fail:

'looks_attractive' - **(85.7%)** 'gives_a_close_shave' - **(74.1%)** 'comfortable_to_hold' - **(82.6%)** 'easy_to_clean' - **(68.2%)** 'removes_difficult_hair' - **(54.2%)**

Combined Total: (89.9%)

Rating: 5th of 5

Explanation:

The orange pigment used for this shaver is an unsuitable colour for this product (Kobayashi 1990). Generally the angle range should be between 40° and 50° for both types of razors (Terry, 1991) (Warrick, 1994). The nominal head length value should be between 35 mm. and 40 mm. for both Disposable and System Razors (Warrick, 1994). The width of this blade is too large as the width of the blade is generally 5 mm. wide to 8.5 mm. wide (Warrick, 1994).

(5) Wilkinson Green

Pass:

'looks_attractive' - **(100%)** 'gives_a_close_shave' - **(100%)** 'doesn't_irritate_skin' - **(100%)** 'doesn't_cut_face' - **(100%)** 'is_hygienic' - **(100%)**

Fail:

'comfortable_to_hold' - **(82.6%)** 'easy_to_clean' - **(90.9%)** 'removes_difficult_hair' - **(91.6%)**

Combined Total: (96.7%)

Rating: 2nd of 5

Explanation:

The square cross-section of this shaver is not comfortable to hold because the cross-sectional profile of the handle should be based on either one of the two common shapes; the circle and the rectangle. Variations or combinations of these two basic shapes may also be used (Warrick, 1994). Handles of circular cross-sections are the most comfortable to grip (Woodson et al, 1992). The width of this blade is too large as the width of the blade is generally 5 mm. wide to 8.5 mm. wide (Warrick, 1994).

SYSTEM SHAVERS

(1) Gillette Contour

Pass:

'is_hygienic' - **(100%)** 'doesn't_cut_face' - **(100%)** 'doesn't_irritate_skin' - **(100%)** 'gives_a_close_shave' - **(100%)** 'looks_attractive' - **(100%)** 'comfortable_to_hold' - **(100%)**

Fail:

'gives_a_close_shave' - **(88.8%)** 'removes_difficult_hair' - **(83.3%)**

Combined Total: (95.6%)

Rating: 5th of 6

Explanation:

The angle is too great between head and handle in this shaver. Generally the angle range should be between 40° and 50° for both types of razors (Terry, 1991), (Warrick, 1994).

(2) Wilkinson Classic

Pass:

'looks_attractive' - **(100%)** 'doesn't_irritate_skin' - **(100%)** 'comfortable_to_hold' - **(100%)** 'doesn't_cut_face' - **(100%)** 'is_hygienic' - **(100%)**

Fail:

'easy_to_clean' - **(81.8%)** 'gives_a_close_shave' - **(88.8%)** 'removes_difficult_hair' - **(58.3%)**

Combined Total: (90.9%)

Rating: 6th of 6

Explanation:

The angle is too great between head and handle in this shaver. Generally the angle range should be between 40° and 50° for both types of razors (Terry, 1991), (Warrick, 1994). The head length of this shaver is too large, the usual value is between 35 mm. and 40 mm. for both Disposable and System Razors (Warrick, 1994). The width of this shaver is too great, blade width is generally 5 mm. to 10 mm. wide. (Warrick, 1994). The thickness of the shaver head should generally be between 4 to 10 mm. (Warrick, 1994).

(3) Gillette Lady Contour

Pass:

'gives_a_close_shave' - **(100%)** 'doesn't_irritate_skin' - **(100%)** 'easy_to_clean' -

(100%) 'removes_difficult_hair' - **(100%)** 'doesn't_cut_face' - **(100%)** 'is_hygienic' - **(100%)**

Fail:

'looks_attractive' - **(85.7%)** 'comfortable_to_hold' - **(86.9%)**

Combined Total: (98.3%)

Rating: 4th of 6

Explanation:

The cream colour applied to this shaver is an unsuitable colour selection for this type of product (Kobayashi 1990). The handle thickness range should be between 7 - 12 mm. (Warrick, 1994).

(4) **Wilkinson Swivel**

Pass:

'looks_attractive' - **(100%)** 'gives_a_close_shave' - **(100%)** 'comfortable_to_hold' - **(100%)** 'doesn't_irritate_skin' - **(100%)** 'easy_to_clean' - **(100%)** 'removes_difficult_hair' - **(100%)** 'doesn't_cut_face' - **(100%)** 'is_hygienic' - **(100%)**

Fail:

Combined Total: (100%)

Rating: 1st of 6

Explanation:

The Wilkinson Swivel shaver did not fail any of the attributes tested.

(5) **Gillette Sensor**

Pass:

'looks_attractive' - **(100%)** 'gives_a_close_shave' - **(100%)** 'comfortable_to_hold' - **(100%)** 'doesn't_irritate_skin' - **(100%)** 'easy_to_clean' - **(100%)** 'removes_difficult_hair' - **(100%)** 'doesn't_cut_face' - **(100%)** 'is_hygienic' - **(100%)**

Fail:

Combined Total: (100%)

Rating: 1st of 6

Explanation:

The Gillette Sensor shaver did not fail any of the attributes tested.

(6) **Wilkinson Protector**

Pass:

'looks_attractive' - **(100%)** 'gives_a_close_shave' - **(100%)** 'doesn't_irritate_skin' - **(100%)** 'easy_to_clean' - **(100%)** 'removes_difficult_hair' - **(100%)** 'doesn't_cut_face' - **(100%)** 'is_hygienic' - **(100%)**

Fail:

'comfortable_to_hold' - **(86.9%)**

Combined Total: (98.9%)

Rating: 3rd of 6

Explanation:

The handle thickness of this shaver is too large, the acceptable range is between 7 - 12 mm. (Warrick, 1994).

9.10.0 Appendix X - List of Publications

[1] **RODGERS, P.A., PATTERSON, A.C. & WILSON, D.R.**, "A computer-aided evaluation system for assessing design concepts", *Manufacturing Intelligence*, Summer 1993, No. 15, pp 16-19

[2] **RODGERS, P.A., PATTERSON, A.C. & WILSON, D.R.**, "Concept design assessment from specified user needs", *Proceedings of the International Conference on Managing Integrated Manufacture*, Keele University, 22-24 September 1993, Vol. 2, pp 319-328

[3] **RODGERS, P.A., PATTERSON, A.C. & WILSON, D.R.**, "Product performance assessment based on the definition of user needs", *Proceedings of the International Conference on Data and Knowledge Based Systems in Manufacturing and Engineering*, Chinese University of Hong Kong, Shatin, Hong Kong, 2-4 May 1994

[4] **RODGERS, P.A., PATTERSON, A.C. & WILSON, D.R.**, "Evaluating the relationship between product and user", *IEE Computing and Control Division Colloquium on Customer Driven Quality in Product Design*, Friday 6 May 1994 (Digest No: 1994/086)

[5] **RODGERS, P.A., PATTERSON, A.C. & WILSON, D.R.**, "Product performance assessment", *Proceedings of the International Symposium on Product Development in Engineering Education*, University of Limerick, Ireland, 28-31 October 1994, pp 467-472

[6] **RODGERS, P.A., PATTERSON, A.C. & WILSON, D.R.**, "Integrating End-User Requirements in Product Performance Assessment", *Proceedings of the Brighton Design Forum*, ITRI, University of Brighton, 9 February 1995

[7] **RODGERS, P.A., PATTERSON, A.C. & WILSON, D.R.**, "Product assessment based on Alexander's method", *Proceedings of the 31st International MATADOR Conference*, UMIST, Manchester, UK, 20-21 April 1995, pp 631-638

[8] **RODGERS, P.A., PATTERSON, A.C. & WILSON, D.R.**, "A Formal Method for Assessing Product Performance at the Conceptual Stage of the Design Process", *Proceedings of the IFIP Second Workshop on Formal Design Methods for CAD*, Mexico City, Mexico, 13-16 June 1995, pp 161-188

[9] **RODGERS, P.A., PATTERSON, A.C. & WILSON, D.R.**, "Concept design assessment from specified user needs", *Integrated Manufacturing Systems Journal (Special Conference Edition)*, July 1995, Vol. 6, No. 3, pp 29-35

[10] **RODGERS, P.A., PATTERSON, A.C., WILSON, D.R., BAILEY, A.L.**, "A formal method for assessing product performance", *International Manufacturing Conference - 12 (IMC - 12)*, University College Cork, Ireland, 5-6 September 1995 (to appear)

9.11.0 Appendix XI - Abstract Algebra Definitions

Functions

An abstract algebraic function is a means of associating elements of two sets. The function can be defined by direct enumeration or more usually by some rule which given an element in one set determines the corresponding element in the other set. The first set is called the domain of the function and the second set is called the co-domain. The notation

$$F \mid X \rightarrow Y,$$

denotes a function F with domain X and co-domain Y. In the case when F describes an actual observation the domain X is the physical system under observation.

F(x) denotes the element in set Y associated with the element x in set X.

A function F of two variables x, y is denoted by,

$$F(x, y).$$

A function of two variables can be made a function of one variable by fixing one of the variables. The function of two variables F (above) is made a function of one variable by fixing x and is denoted,

$$F(x,).$$

The composition of two functions F, G is the single function composed when the co-domain of F is the domain of G and is denoted,

$$F \bullet G.$$

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Product Sets

A n-tuple is an ordered list of n individual variables $y_1, y_2, \ldots, y_n$ and is denoted,

$$\mathbf{y} = <y_1, y_2, \ldots, y_n>$$

A product set of n individual sets $Y_1, Y_2, \ldots, Y_n$ contains the n-tuples of combinations of elements in each set and is denoted,

$$\mathbf{Y} = Y_1 \times Y_2 \times \ldots \times Y_n$$