A framework for a novel descriptive product design methodology

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Abstract

Prescriptive design methodologies dictate how designers should carry out their design work while normative methodologies affect the way in which they make decisions. Empirical studies have found that designers rarely apply current prescriptive and normative design methodologies in their work. These methodologies do not support them in designing based on their individual preferences and approaches. Most descriptive design methodologies, such as protocol analysis, are applied for the purpose of investigating and analysing the design process. This paper describes a novel structured descriptive design framework which flexibly supports designers by providing a way to capture and reuse their ideas without affecting their daily activities.

Keywords: product design, design methodology, engineering design

1. Introduction

Design methodologies can be classified into three types, namely normative, descriptive, and prescriptive methodologies [1]. These methodologies focus on providing support and guidance to designers during the design process. Prescriptive [2] and normative [3] design methodologies impose a systematic and rational design approach without consideration for the designer's own preferences. On the other hand, descriptive methodologies allow designers to design according to their preferences but are rarely employed to support designers. Most descriptive design methodologies, such as protocol analysis, have been applied for the purpose of analysis, validation, and investigation of the design process [4].

This is because descriptive design methodologies are often used only to provide a better understanding of prescriptive or normative methodologies and as a means to formulate them. Findings gathered from descriptive methodologies can be diverse and conflicting. A reason for this is the different approaches and preferences of designers [5]. Hence, findings from descriptive methodologies do not always lead to prescriptive or normative methodologies. Furthermore, the most common descriptive design methodology, protocol analysis, is impractical as it requires designers to speak aloud, captures irrelevant information, and produces records that can be misinterpreted [6].

Hence, it is not surprising that design researchers have resorted to experience and logical argument to derive prescriptive and normative methodologies. For example, Pahl and Beitz [2] proposed a design methodology based on the assumption that searching a wider solution space improves a design outcome [7]. Such an assumption may seem legitimate but studies have found otherwise [8]. This is a reason why current prescriptive and normative methodologies are not widely adopted by industry.

This is supported by findings from empirical studies showing that designers rarely apply current prescriptive and normative design methodologies and that these methodologies may not even function in a laboratory environment [8]. Various reasons for the delay in acceptance of these methodologies by industry have been suggested [9]. However, investigation shows that allowing designers to design according to their preferences and approaches is critical [10]. Hence, there is a need to derive a design methodology that describes the actual design process and supports designers in designing based on their individual preferences and approaches.

2. Derivation of a descriptive design methodology that supports designers

Current descriptive methodologies merely provide the characteristics of the existing design processes [7]. The first cycle of the action-research approach [11] adopted to derive and verify the framework of a descriptive methodology that supports designers consists of 4 stages as shown in Fig. 1. In Stage 1, using findings from the literature, the critical factors that affect the common characteristics of a design task and the aims of a designer are identified and the descriptive support facilities that do not affect the designer's preferences and approaches are defined. The output of Stage 1 constitutes the basis for deriving and conceptualising the framework in Stage 2. Stage 3 involves developing and implementing a descriptive design tool based on the framework and Stage 4, reviewing the design framework and tool. Following Stage 4, the development continues into the second cycle. This paper focuses on Stages 1 and 2.

3. Stage 1

3.1 Factors affecting the common characteristics of a design task and the aims of a designer

A product design task has many characteristics. Some are unique and only occur for certain products while some are common. However, it is important to differentiate between design process characteristics and product characteristics. Product characteristics that describe the physical and functional requirements of the final product, for example, "the device should be light in weight", should be captured in the product design specifications.

The common characteristics of a design task and the aims of a designer need to be examined and critical factors which affect them need to be defined. This is to provide the basis for deciding what should form part of the descriptive design framework.

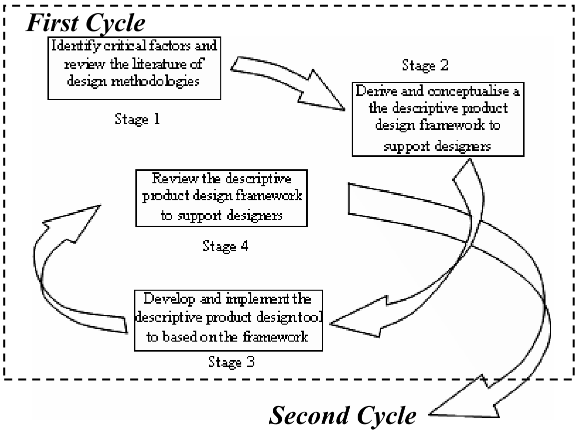

Fig. 1. Action research approach for establishing the descriptive product design framework

Different sources of information can be utilised to identify, examine and define both the common characteristics of a design task and the aims of a designer. The four sources are empirical studies, interviews, design experience and results of analysis from literature reviews [12-14]. This work employed the findings of a well-reported empirical study at Delft [4] and of other empirical studies. In addition, common characteristics (refer to Fig. 2) were also derived from detailed observations of a team carrying design work over a 6-month period.

Using empirical evidence, logical reasoning or axiomatic approaches, researchers have identified what designers aim to achieve. The literature on design, psychology, and cognitive science [15-19] was therefore reviewed to construct a list of the main aims of a designer. It is recognised that the lists of common characteristics of a design task and the aims of a designer are not exhaustive and may not be universally accepted. Nevertheless, they were deemed sufficient for the purpose of deriving the proposed

Critical factors affecting the characteristics/aims \ Common Characteristics of a design task	The task may continue for days and weeks	New information continuously arrives throughout the design process	A designer has limited memory	Visual representation of design problems is important to designers	Design decisions are often made under uncertainty but will be reviewed when new information is available	Product design specifications are identified and documented	All design projects have a time constraint	Designers frequently refer to various resources to construct solutions (e.g. books, datasheets, experts, etc.)	Designers apply logical deduction and mathematical calculation to assist decision making	Current design decisions may affect other past and future design decisions	Past experience or design decisions may be re-applied to solve current design problems	Information and knowledge that lead to a design decision can be implicit	Different designers prefer different approaches	Designers introduce ideas, thoughts, and sub-requirements throughout the design process	There are usually trade-offs in making design decisions.	There is often miscommunication /misunderstanding
Human memory	○	○	○								○					○
Time	○	○	○		○	○	○			○				○		
Information		○			○			○	○	○		○		○	○	○
Source of Information		○						○								
Presentation				○		○										○
Communication				○		○		○				○			○	○
Change					○					○						
Requirement						○									○	
Auxiliary Storage					○											
Knowledge					○			○	○	○	○	○	○	○	○	○
Psychology													○			
Rationale																
Decision Dependency										○						

The aims of a designer	Satisfy pre-defined requirements /constraints /criteria	Make objective unbiased decisions	Make traceable decisions	Explore different design alternatives	Complete a design task as planned	Minimise design iteration	Make decisions based on minimum risk	Make decisions based on minimising utility costs	Make justifiable & defensible decisions	Minimise inter-related (coupled) decisions	**Total**
Decision Dependency										●	2
Rationale			●						●		2
Psychology		●									2
Knowledge	●	●		●	●	●	●	●	●	●	19
Auxiliary Storage			●								2
Requirement	●					●				●	5
Change					●	●					4
Communication	●				●						8
Presentation			●			●					5
Source of Information									●		3
Information	●			●	●	●	●	●	●	●	17
Time				●	●	●	●				12
Human memory											5

Fig. 2. Critical factors affecting the common characteristics of a design task and the aims of a designer

framework.

Critical factors that are directly linked to the common characteristics of a design task and the aims of a designer are as shown in Fig. 2. It is important to note that each critical factor is as important as the others. There are circumstances where there may be additional critical factors linked to either the common characteristics of a design task or the aims of a designer but not shown in Fig. 2. In some situations, the critical factors may be linked differently from what is shown in Fig. 2.

However, the aim of identifying and defining these critical factors is to determine those that strongly influence the common characteristics of a design task and the aims of a designer. As expected, knowledge and information dominate as design is a knowledge- and information-based activity. However, time, internal and external communication, presentation of ideas/thoughts/solutions, functional requirements and human memory also have a significant influence.

With these critical factors identified, the next step is to define the type of support facilities that can be provided to a designer to help improve his design decisions without affecting his preferences and approaches.

3.2 Defining support facilities for designers without affecting their preferences and approaches

Two main types of support facilities have been identified that do not interfere with the designer's preferences, i.e. design-methodology-related and computational-platform-related.

Design-methodology-related support facilities:

i) allow designers to capture their ideas and thoughts;

ii) enable designers to track their ideas and thoughts;

iii) enable designers to decide whether to delay their design decision when information is not available;iv) allow designers to add, edit, or remove their design decisions any time during throughout the design process;

v) indicate the effects of any change in their past design decisions on current and future design decisions;

vi) enable designers to reuse ideas and information recorded during the design process in future design problems with similar requirements.

Computational-platform-related support facilities enable:

i) saving all records of ideas and requirements at any time for later use;

ii) searching for and visualisation of the designer's design decisions at any stage during the design process;

iii) providing a flexible input interface so that the designer can record his ideas through text, sketches, or graphical representation.

The list of support facilities is not exhaustive. One of the important features of a descriptive design methodology is that, if the designer prefers it, a normative or prescriptive tool can be added to improve his design decision. With the definition of support facilities completed, the next stage is to derive and conceptualise the descriptive framework.

4. Stage 2: Deriving and conceptualising the descriptive design methodology

With the critical factors determined and support facilities defined, the next step is to conceptualise a descriptive framework to represent these factors and model the design process. Empirical observations show that design is a process where the product goal is translated into a set of requirements (stated as product design specifications) before the designer decomposes them into more sub-requirements and sub-solutions and then arrives at the final concept solution (Fig. 3). This process could be depicted by a "cause and effect" diagram (also known as a fishbone diagram) with several causal branches (requirements) that lead to the final concept solution, each causal branch having sub-causal branches (sub-requirements). In Fig. 3, the initial functional requirements taken from the product goal are called "Given Functional Requirements" (GFRs) to distinguish them from "Introduced Functional Requirements" (IFRs) which are derived from GFRs. IFRs include ideas, information, possible solutions, constraints, criteria and sub-requirements. Fig. 4 shows the descriptive framework constructed to support designers. The framework represents the process of a designer deriving IFRs. The final outcome of applying the framework is a concept solution which describes the embodiment of the product.

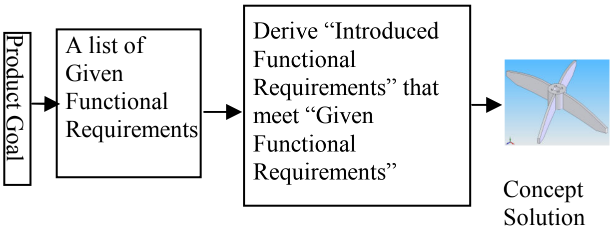

Fig. 3. The product design process

The framework is a design methodology that provides a graphical representation and enables designers to view their design decisions with reference to time. The flow of new information and utilisation of knowledge throughout the design process are described by the designer when he decides on the appropriate IFRs to meet the GFRs. This provides a platform for the designer to review such information or to re-examine his earlier decisions. This should be a useful facility as accessing and reviewing information are important in design. The designer is encouraged to categorise GFRs and IFRs into three types, namely requirements, constraints, or criteria.

An IFR is considered a requirement if the designer thinks he uses words like "need", "require", "add", "remove", or other command verbs. For example, the statement "apply load on top of the device" is considered a requirement. A criterion is a statement that has a range description with pre-defined values, e.g. "to be between 5 and 15 mm in height". A constraint is a statement that has a value limitation. For example, "need to fit into a 5mm gap" is a constraint as it means the device cannot exceed 5mm in size. The differentiation of types of IFR is useful, as when similar design issues are encountered in other design tasks, similar constraints, or criteria can be applied.

If the designer feels that such categorisation is cumbersome and distracting, he does not have to use it. This gives the flexibility to the designer to express his IFRs. The main structure of the framework is to provide a focus for the designer to decompose the GFRs in order to achieve the final concept solution. The final descriptive design framework is a time-dependent framework. It captures IFRs based on the time when they were created in order to satisfy the GFRs. The triangular symbols in Appendix 1 represent the initialisation of GFRs. The heights of these triangular symbols are adjusted (to higher positions) to cater for the fitting in of the IFRs that were derived during the design process.

The x-axis allows the visualisation of the time for every initialisation of GFR or IFR during the design process and does not follow any scale. This is to reduce the length of the graphical representation which may continue for months.

All IFRs that are thought of by the designer are created as grey circles (if they are of the "requirement" type) with arrows pointing vertically downwards towards the GFR (triple line) as exemplified by $IFR_{4.1}$ in Fig. 4. These grey circles are created with "work in progress" or "WIP" status (e.g. $IFR_{4.3}$) and will keep that status until they are accepted or rejected by the designer. The grey circles will turn into black when the corresponding IFRs become accepted (remain in a higher position with their arrows pointing downwards) or white when they are rejected (moved downwards with arrows pointing upwards). Thus, all black and white circles were once grey circles. If the newly created IFR requires more sub-IFRs to address it then similar grey circles will be created but these sub-IFRs will have arrows that point towards their respective parent IFRs as shown in Fig. 4. This means that for an IFR such as $IFR_{2.2}$ that has sub-IFRs (e.g. $IFR_{2.2.1}$ and $IFR_{2.2.2}$), the grey circle moves from its initial upper position to a horizontal position with its arrow pointing horizontally towards its related GFR (GFR_2) before turning into a black circle when it is accepted as shown in Fig. 4. When a sub-IFR such as $IFR_{2.1.1}$, requires more IFRs to address it then its arrow remains horizontal and points towards its parent ($IFR_{2.1}$) but it also moves to a higher position to accommodate its sub-IFRs ($IFR_{2.1.1.1}$, $IFR_{2.1.1.2}$ and others) (refer to Fig. 4). Some IFRs are created after the solution is found, for example, $IFR_{2.2.4}$ and $IFR_{2.2.5}$ which stay on the extreme right of the solution "Si". There are possibilities that IFRs are proposed after a solution is found in order to improve on the solution. Any IFR proposed and accepted after the initial solution is found would be included as an accepted IFR and the GFR thick triple line will shift to accommodate it as shown for $IFR_{3.1.3}$ in Fig.4.

5. Conclusions

Empirical investigations have suggested that different designers have different styles of designing and that current design methodologies are rarely applied in practice. This has led to the conclusion that designers want the freedom to design according to their preferences and approaches. Based on this, a descriptive design framework was derived to support designers without affecting their normal working.

The core of this descriptive design framework is built upon capturing the thoughts of a designer when he derives multi levels of "introduced functional requirements" to meet "given functional requirements". In capturing these thoughts, some elements of the design rationale are also recorded. The framework can be extended to accommodate additional prescriptive and normative tools to provide further support to the designer if required.

Acknowledgements

The authors are members of the EU-funded FP6 Network of Excellence for Innovative Production Machines and System (I*PROMS).

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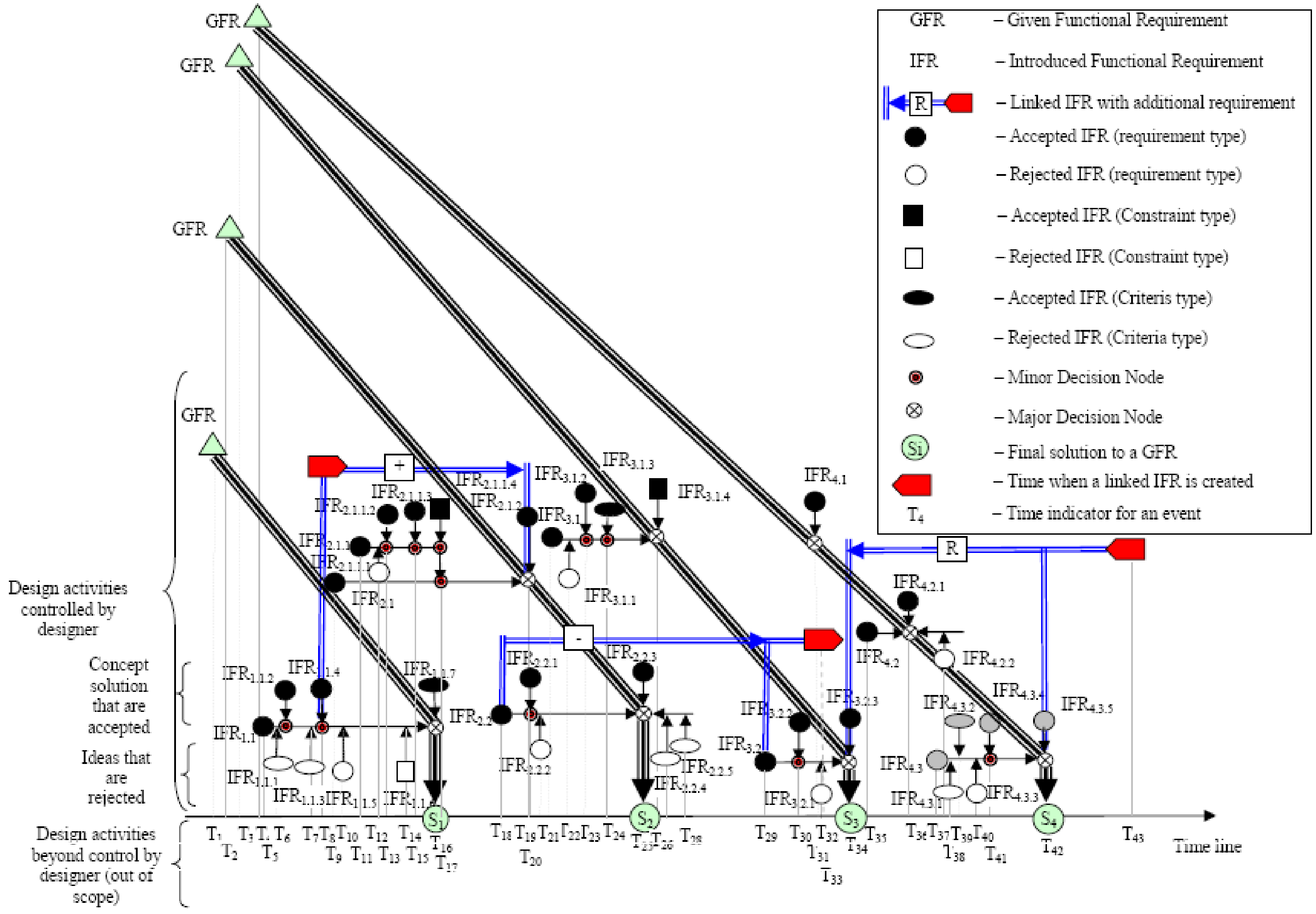

Fig. 4. Concept of Descriptive Design Methodology that allows a designer to design according to his preference and approach