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Multi-layer graph theory utilisation for improving traceability and knowledge management in early design stages

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Abstract

Decision making processes in design often challenges designers to prioritise specifications and variables in order to develop solutions that are closer to the product's requirement goals. Concerning to support their decisions, different tools and methods are used by engineers and designers allowing to reduce uncertainty in design. Nevertheless, many of these decision support systems are focused in late design stages, such as detailed design and manufacturing design, even if the possibility to influence a new product is higher in early stages. The issues regarding to those situations are often associated to design processes related to multi-physics design, where the modification of geometric-related variables might affect the performance of the solution, and the analysis of tracking the influence of the modifications might generate reprocessing and loses of time, specially when those relations are tricky and are not easily identifiable by analysing equations and a manual analysis of requirements must be performed. This article is centred in proposing a traceability model for early design stages based in graph theory. The proposal supports the information generated in design, from the input requirements (linguistic field) up to mathematical modelling and variables definition (real numbers field). This information is arranged into different layers, allowing a multilevel approach in terms of information management. The model also features a novel solution for weighting vertex in graph model, featuring a model that balances the direction of improvement, the importance and flexibility of any specification and how its behaviour will affect the design variables associated to it. The goal of the proposed model is to offer to designers, since the conceptual design stage, a method that can show automatically the level of correlation between any pair variables and specifications by the use of information trees and featuring chains that can connect them whether there is or not a connection via equations.

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Keywords: Traceability in design, traceability in early design stages, information management model, graph theory in design, decision support system

1. Introduction

One of the more natural aspects related to decision making in design recalls in coming ahead any unexpected interaction, which means, changing one *design variable* will not affect in a negative matter any other *requirement*. Managing this type uncertainty in early design stages is one of main facets to study within the XXI century demands.

In this connection, one of the approaches to handle with uncertainty management is increasing the traceability of the information at early design [1]. Those approaches stimulate the development of new technologies for early design stages, where the appearance of new tools it is being a constant over the last few decades. Likewise, its usage is highly motivated by the automation of different task at those design stages [2], and offering saves in time and money as well [3].

This article is centred in proposing a traceability model to be used in early design stages, offering connections within the evolution of the design parameters from marketing inputs, where inputs are in a linguistic manner (e.g. *"the product must be big"*), up to variables definitions (length, diameter, etc.). The purpose of this model is to generate sensibility and correlations index between the design variables and the success criteria of each requirement.

2. State of the art

For over a decade the development of tools for supporting early design stages, specially since the lack of tools at those stages is evident [4]; also, the development of tools and methods had empower to increase the success rate in market of new products up to 60% [3].

Associated to tools, also different design methodologies had also improved the work, allowing time reductions and better team work [5]. Under the frame of this article, three thematic areas are related: design methodologies, traceability and uncertainty.

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2.1. Design methodologies

Product design can be divided in four principal stages: clarification of the task, conceptual design, embodiment design and detail design [6]. Under the frame of this article, there will be considered as early design the first three stages, up to the definition of design equations, but not the final value of the geometric entities that are represented as variables in the equations. Also, in those stages it is important to recall how the information evolves from linguistic inputs, to fuzzy numbers and finally into real numbers [7].

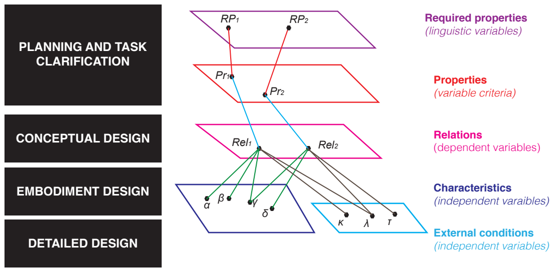

Fig. 1. Information evolution through design processes

From Figure 1, the proposal is centred into using the generated information from well know design methodologies in order to create a traceability tree to empower decision making in design. Within this frame of this research, the following nomenclature will be used: linguistic domain coming from marketing requirements will be called *Required properties*; *Properties* is the product behaviour that response to what designers want; the equations of the product will be known as *Relations*; finally the design variables are divided in two, *Characteristics* which are the parameters that can be directly influenced by the designers and *External Conditions* that can not be influenced and are defined by the external environment [8].

2.1.1. Clarification of the task

Related to the work made by the designer, several task are accomplished in order to traduce that linguistic information into technical requirements. For instance, tools like Quality Function Development (QFD) are used to perform this commitment [9]. Also, in terms of generating specifications of the product, functional analysis can be used in order to exploit the relationship of the product with the environment for this purpose [10].

In this phase, is very important for the model that a Functional Analysis be performed, and all the specifications written based in functions (i.e. functions result from *octopus diagrams* [10]). This will generate the $CdCF_0$[1]. After designers generate the specifications of the product, the QFD must be performed. This will allow to relate the requirements that are the result of marketing and user understanding with the technical specifications that the product must assure. This CdCF is related to the design criteria to each specification of the product.

[1]French for Cahier des Charges Fonctionnel, a list with the specifications of the product.

2.1.2. Conceptual design

The conceptual design is centred in Pahl & Beitz approach [6]. Nevertheless is important to consider the important to evaluate each function using the CTOC approach [11]. This approach treats each energy flow as: Converter-Transmitter-Operator-Control. Its usage is a key in order to simplify the functions by understanding how energy is transformed and which are the surfaces that act in the process. The goal of these stages is generating a FBD (Function Block Diagram) containing all the fluxes of energy, matter and information.

2.1.3. Embodiment design

In the edge of both phases, designers answer the relations that will engage the behaviour of the solution. Next, the CPM/PDD can be performed [12], generating connections between the equations and the variables and populating with equations each block of the FBD.

2.2. Traceability in early design

Within the last decades, different models had been proposed for early design. Baxter et al. had defined a traceability framework focused in optimising design solutions by analysing the performance of certain requirements [13]. Nevertheless at linguistic levels (requirements definition) many of those information management models deal with poor data traceability [14], and usually the information is only stored at a specific location but it is not exploited [15].

This leads to define the importance of developing tools that can assures high level of detail in the creation of the information links at early design stages [1]. Finally, according to Ouertani et Al., a good traceability tool should identify the dependence of the design of terms of variability, sensitivity and integrity [16].

2.3. Uncertainty in early design

Uncertainty is hooked up to decision making in design as one of the main characteristic of the profession itself; designers must somehow anticipate how their decisions will affect the performance of the product [17]. Naturally, design methodologies are developed to reduce this lack of awareness in decision making [7].

In terms of defining the type of information generated and shared, and understanding who, which, why and when would that information needed by other members of development team, there is a further complexity of design management. And whenever that information is not available, the level of uncertainty is increased because of the assumptions that are needed to be made [18].

For design activities, two types of uncertainties can be described: aleatory and epistemic. The first type is related to the natural randomness of the product characteristics and physical properties. Epistemic is related to the imprecision that happens because lack of knowledge [19]. Moreover, epistemic can divided into five categories: model, phenomenological, behavioural, ambiguity and interaction [20].

In order to treat uncertainty, Malmiry et Al. had defined a functional modelling approach, for early design that is handles both types of uncertainty by the use of CPM/PDD modelling [12]. Within the interpretation of functions, and its definitions into equations, this approach manages uncertainty by