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A FEATURE BASED APPROACH FOR CONCEPTUAL DESIGN

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1. Introduction

Conceptual design has been recognised as an important part of design process, but receives weak computer support due to complex and informal data, that is hard to retrieve, store and maintain with computers. Beside geometrical data, it is important to capture, represent and process the function and the behaviour of a product. This should already be done in the early phases of the development process in order to support the flow of information without loss along the process chain and assist designers in all phases of the product development by providing intelligent and intuitive computer support.
The presented approach is a feature-based modelling of product semantics and function that takes place already in the conceptual design phase. Features are then the information carriers that allow modelling the relationships between requirements of a product, its functional descriptions and physical solutions. They will also bring this information to the downstream applications and will allow, for instance, to keep track of the consistency between the concept, the design, and the manufacturing of a product. Existing approaches towards a feature-based integration of different phases of the product development to support concurrent engineering include extracting and mapping different views of a parametric representation of a product, expressed in terms of geometric form features [De Martino & al, 1998], [Golob &al, 1999]. Products semantics are there expressed in terms of explicit geometric or functional constraints [Brunetti & al, 1996], [de Kraker & al, 1995]. Product semantics as it is handled within the conceptual design is not supported. The aim of this paper is to come up with a concept to represent the conceptual design information, for supporting the product semantics along the development process, and finally to improve concurrent engineering and top-down design by supporting an early feature-based prototyping of the different views to the overall product model making use of captured feature information to the largest extend possible. Major prerequisite of such an approach and therefore focus of this paper is a suitable representation scheme to store, manage, and retrieve product semantics including conceptual data.

Design Process & Conceptual Design

Product design is an iterative, complex and decision making process. It has been analyzed by many researchers and a number of design methodologies have been developed. Internationally accepted representative of the European school of design is the *Systematic Approach to Engineering Design* proposed by [Pahl & Beitz, 1996], which is the starting point for the work presented. It divides the design process into four phases:

- task clarification,
- conceptual design,
- embodiment,
- detail design,

after which certain decisions will have been made. The steps between the phases are approximate and are based on iteration and recursion.

The first phase addresses the clarification of the design task and results in a detailed design specification. The second phase is that of the conceptual design, shown on Fig. 1. It starts by an analysis of the specification in order to identify the essential problems to be solved. The design problem is then formulated in an abstract, solution-neutral form. This makes the solution space as wide as possible, in order to avoid prejudices that may tempt the designer to decide on a certain solution before other alternatives have been considered. The problem may then be decomposed into sub-problems and function structures established. Solutions to the sub-functions are then sought. This process is supported by creative, conventional and systematic methods. Morphological matrices are used to combine sub-function solutions into system solutions. Afterwards, promising system solutions are further developed into concept variants. Finally, use-value analysis is used to evaluate the concept variants, and the "best" concept is selected for further development. Systematic approach emphasizes heavily the importance of decision taken in the conceptual design phase, because it is very difficult to correct fundamental shortcomings of the concept in the later design phases - embodiment and detail design.

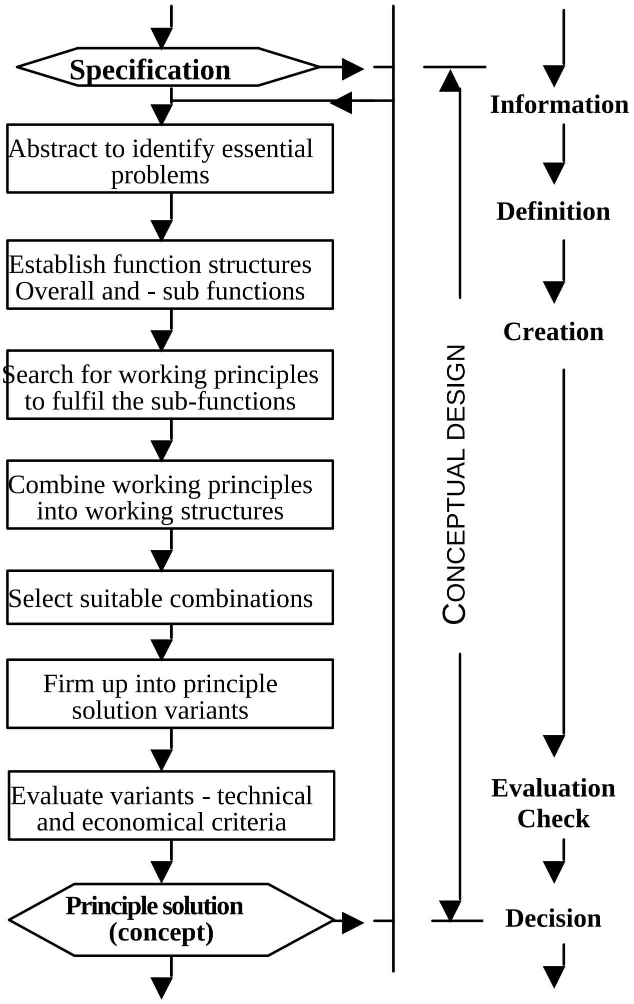

Figure 1. Steps of conceptual design

The concept design phase is followed by the embodiment design phase. A feature-based approach to embodiment design has been reported in [Bachmann & al, 1993]. During this phase the designer develops the layout and the form of the final system. It is also the phase where CAE and simulation software are typically used nowadays, even if due to the shortcomings of today's CAx systems engineers have to start with modelling details in CAD in order to perform analyses. Support to the embodiment design is provided by means of rules, principles and guidelines. Finally, in the detail design phase, detailed product models (e.g., CAD models, and production documents) are completed.

3. Feature definition

According to the results of FEMEX (Feature Modelling Experts) working group, (see, for instance, [Vajna & Podehl, 1998]) a feature is defined as follows: A feature is an information unit (element) representing a region of interest within a product. It is described by an aggregation of properties of a product. The description contains the relevant properties including their values and their relations (structure and constraints). Furthermore, it is defined in the scope of a specific view onto the product description with respect to the classes of properties and to the phases of the product life-cycle. Finally, a feature is described by properties out of several different classes of properties, thus relating these (classes of) properties to one another. There are four special aspects in the definition above: (1) It is necessary to find a structure of properties suitable to express conceptual design information like function, working principle, physical effects, and solution principles in terms of such product properties. (2) A feature is not limited to physical elements and exists only in the world of information models. (3) “Properties” are the base in the definition and at the same time the basic implementation mechanism. (4) “Classes of properties” and “product life-cycle phases” are distinguished in the definition above. Some properties are meaningful in more than one phase, for instance, geometry – in different phenotypes – is considered in nearly every phase of the product life-cycle. The product information expressed in terms of properties aggregated by different features in different application contexts is therefore the key mechanism to integrated product development.

3.1 Information in Conceptual Design

Effective computer support during conceptual phase of design process is obtainable via properly structured information. Due to highly complex and informal data used in this process, feature-based representation seems to be most appropriate to achieve this goal. Following, the basic information units managed in the early phases of the design process are presented and an information structure is discussed for handling these information units that is suitable for implementation purposes.

3.1.1 Requirements

The requirements list results from the very first task clarification phase and describes the general constraints a product has to or should fulfil. An important prerequisite to enable automatic validation of proposed solutions against given requirements is a structured and formalised description of these requirements that has to handle the following information:

Representation of requirements

- name
- type ∈ {Demand, Wish}
- class ∈ {functionality, manufacturability, economy, user / environment}
  - ↳ subclass{geometrical, kinematical, forces, energy, material, signal, ..}
- qualitative/quantitative
- properties - geometrical {size, height, width, length }
- operator

3.1.2 Product Function

In technical systems conversion of energy, material and/or signals is performed. This conversion can be described as flow through the system, where one is the main flow and others, if any, are supporting flows. For the design of a technical system, a clear attitude between the input and output must be defined in form of the function of the system. This function is an abstract formulation of the task. The overall function can often be divided into sub-functions, and function structures can be established. With further sub-division of the sub-functions, basic functions - also called generally valid - can then be recognised. These functions, according to the definition by Rodenacker and Krumhauer (see for instance [Pahl & Beitz, 1996]) are change, vary, connect, channel and store. They represent a conversion of type, magnitude, number, place and time, respectively.

Functions are usually fulfilled by physical, chemical or biological processes, whereas mechanical engineering solutions are based mainly on physical processes. Selected physical effects and the

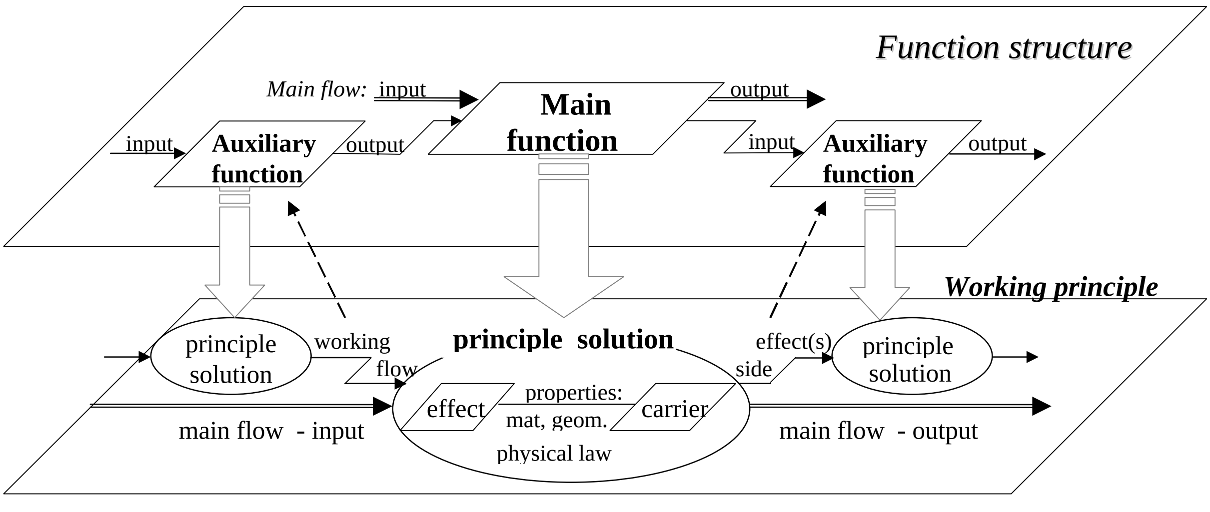

Figure 2. Function fulfilled by working principle.

determined material and geometric characteristics result in a working principle that fulfils each function. If a function cannot be fulfilled with a simple effect, a structure of effects has to be used instead. In the embodiment design phase qualitative and quantitative parameters such as surfaces, dimensions and material properties are defined according to the physical laws given by the effects.

Figure 2 shows the mapping of a function structure into a working principle. To fulfil the main function of a product, an appropriate principle solution has to be selected. A principle solution is defined by an effect, an effect carrier, properties and physical laws. To perform the main function, auxiliary functions may be needed to supply supporting flows, to eliminate side effects or to meet given requirements Auxiliary functions could be solved by the same or by additional principle solutions. In the functional structure sub-functions therefore have to be related with the principle solutions.

Intuitive, systematic and contradiction-oriented methods are used for searching the solutions for sub-functions taking into account existing solutions. For this, classifications schemes are very useful, as they allow retrieving known solutions according to selected criteria like the type of energy and physical effects: (mechanical, hydraulic, pneumatic, electrical, magnetic, optical, thermal, chemical, nuclear and biological) [Szykman & al, 1999].

Physical effects are realised by the working geometry and by working motions. Working geometry is defined by arrangements of working surfaces. These can be varied in respect of and determined by type, shape, position, size and number. Working motions are determined by type, nature, direction, magnitude and number. Finally, basic material properties are defined by their state (solid, liquid, gaseous, space), their behaviour (rigid, elastic, plastic, viscous), and their form (solid body, grains, powder, dust).

For efficient capturing, storing and retrieving product data on the functional level, we use the following representation of function and function structure.

Representation of function	***Representation of flow***
• Intent - purpose • Type (change in){ ↳ change (type), ↳ vary (magnitude), ↳ channel (place), ↳ connect (number), ↳ store (time)} • Class{main, auxiliary} • **Flow** => reference	• Type{material, energy, signal} • Class{main, working, side} • Orientation{input, output} • Properties ↳ material{solid{body, grains, powder, dust}, fluid, gas, space} ↳ energy{mechanical, thermal, electrical, magnetic, acoustic, optical, chemical} ↳ signal {measure, data, value, control impulse, message, ...}

A function structure is a nonempty set of functions and their interrelations.

A feature-based representation scheme for capturing the product function must provide a means of explicitly modelling the sub-function structure as illustrated in fig. 2. Within such a function model functions are represented by function features, which not only represent the static function information mentioned above, but also carry the knowledge about its intent and its concretisation in terms of principle solutions.

Representation of function structure
• Main function • auxiliary flow(s) and related sub-functions ↳ input/output(value, unit)

3.1.3 Principle Solution

A principle solution consists of a chosen effect and the appropriate effect carrier. Usually, the same effect can generate several principle solutions, depending on material and geometrical properties; for example, the thermal dilatation effect can be combined with a solid body or a fluid as the carrier. The relation between function and principle solution is rarely one to one. Some principle solutions can solve several functions at once, however, a lot of functions cannot be solved by only one principle solution. In this case, a principle solutions structure is needed, which represent the working principle.

As the number of known physical effects is deterministic, some authors have collected related principal solutions for use in a design process [Roth, 1994], [Koller & Kastrup, 1998]. These catalogues of principle solutions are structured appropriately for a computer implementation.

> ***Representation of principle solution***
>
> **Identification** (name, description, sketch)
> - functions
> - effect {list of effects for each type}
> - type ∈ {mechanical, fluid, electrical, optical, ...}
>   - effect carrier ∈ {solid, fluid, gas, space}
>   - material and geometrical properties
> - input, output
>   - (for mechanical effects) type ∈ {force, path-volume, speed velocity, acceleration, torque, angular speed, angular acceleration, mass, temperature-heat, time, frequency, amplitude, sound, light, stress, ... material A, mat. B, mat. mixture AB}...
> - physical laws describing the relations between the input and output.

3.1.4 Working principle

An appropriate structure of principle solutions, which fulfils the main function of a product, is a working principle. Together with given requirements, a working principle determines the embodiment of a product. Due to links/connections to auxiliary functions and a hierarchical structure of data, a working principle describes the principle solutions structure and implicitly also the function structure.
Note that auxiliary functions may have a sub-structure themselves.
In the introduced representation scheme the principle solutions and their inter-relationships in terms of input/output parameters and their properties which make up a working principle are kept within a working principle model, where each principle solution is connected to the one or more functions it realises. In this way it is possible to establish a parametric relationship between this working principle model and the function model.

> ***Representation of working principle***
> - function to be fulfilled
> - principle solution used
> - input/output (value, unit)
> - auxiliary flow(s) provided by auxiliary function(s), if they are needed
> - side flow(s) or effects and the auxiliary functions(s) to handle them

3.1.5 Embodiment

The embodiment represents the materialisation of a concept where the overall layout of a product is determined. Embodiment is defined by geometrical properties - shapes, and properties of material from which part or parts are built. Both are influenced by a working principle and requirements. Shapes consist of working surfaces, required by working principle and free surfaces. General dimensions are defined either by physical laws governing various effects used in working principles, or from requirements, or by material properties according to a strength and stress analysis, for instance. Usually, the physical realisations of a working principle require more than one part per solution. Therefore, an assembly model should contain information about embodiment.

> ***Representation of embodiment***
> - working principle
> - requirements
> - assemblies / parts
>
> ➯ interrelations/positions
> ➯ geometrical properties (working and free surfaces, dimensions and material properties
> ➯ calculations(physical laws describing relations between material and dimensions)

Principle solutions, as mentioned above, are defined by effects and effect carriers, where each effect carrier has to be considered as a starting point for detailing the layout of an assembly that, once the design is finished, has to have a representation in the assembly model of a product. Therefore, to capture the assembly information obtained during the embodiment design phase, the assembly model is extended and related to the working principle solutions model. The extensions are a means of representing the product structure and critical relations between assemblies instantiating the parametric relations between principle solutions, which are either basic functions or physical laws manipulating and controlling the input/output parameters of the functions and their principle solutions, respectively.

4. Conclusions

The paper presents a result of an ongoing research towards a feature-based conceptual design system that will be able to capture the relevant product semantics of the early design phases and to allow reusing this information in later phases for the purpose of consistency check and significant user support. Therefore, the paper introduced in the systematic approach to engineering design process and FEMEX feature definition as an underlying base for the semantic description of products because of its characteristic to include not only geometric properties of a product, but also all other relevant information like function. Consequently, this paper presented a structural description of the product information handled within the conceptual design phase including information units like function, flow, working principle, physical effects, and requirements and their interrelationships.

In the future, the results of this research will be used by the authors to come up with a representation scheme for conceptual features in order to realise a prototype realisation of a system that has the following capabilities: enabling co-operative design on Web, easy expression of design ideas, and enforcing the systematic approach in design process. In addition, work will be undertaken to combine the feature-approach with conceptual 3D sketching and feature recognition, intuitive interaction based on gesture sketching, and with functional feature recognition.

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