A Product Structure Methodology to Support Configuration Design†

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Abstract

In engineering design, configuration design is one of the design activities which is concerned with selecting from a set of elements and creating an arrangement by defining the relationships between selected elements. For many industrial companies, the product structures are very complex in terms of a large number of elements with different relationships. Even for a routine design, it can be extremely difficult to configure a new product structure rapidly and correctly. If the product needs innovation, product structuring in addition becomes intermised with other aspects of design.

Current approaches to product structuring can be the bill of material (BOM) from manufacturing point of view, engineering data management (EDM) from document point of view or the concrete instances of design modelling. However many industrial facts identify that the current approaches are not good enough to support product structuring. There is therefore a need to develop a new approach to support product structuring.

This paper presents a product structure methodology and its representation in the computer based design system. The approach formalises the product information into the proposed structures in terms of the Product Family Classification Trees (PFCTs) and Product Breakdown Structure (PBS). Designer is allowed to access onto the PFCTs to make decisions on selecting elements, and configure them as an instance of PBS, i.e. a configuration solution. The contribution of the approach is to organise the product structure knowledge to support the designer to create a product structure rapidly and correctly.

Key words: product structuring, configuration, knowledge representation.

1 Introduction

In engineering design, any product or machine can be viewed as a technical system which consists of elements and their relationships. Configuration thus is regarded as

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the process of creating an arrangement from a given set of elements by defining the relationships between selected elements that satisfies the requirements and constraints. It is realised that configuration is to do with *relations* as part of design. In configuration design, therefore, a set of elements and their relationships are determined by the designer. Through this determination, the deisnger make decision on selecting elements and configuring them into a structure which describes the product in the logical way. The elements are put together with a set of relationships within them created through the configuration process.

As generic design activity, configuration design is viewed as the tasks of concerning different relationships, and interdependencies among product elements, design decision and options, so as to form a consistent configuration solution that satisfies all requirements an constraints. In other words, configuration design is the process of creating configuration solutions, in which it concerns with the element selection and the ways of configuring elements.

Configuration design takes place in each design stage. For different development stages, configuration design carries out individual tasks, i.e., it is concerned with different kinds of relationships within different decisions and elements. In the design stage, for example, the configuration process begins by examining the product family which includes all parts and elements, makes decisions on selecting elements from it, and combines these elements into a consistent artifact. In the manufacturing stage, configuration is more about assembly based on a sequence of orders or manufacture decisions.

For many industrial companies, the product structures are very complex. Even for a routine design, it can be extremely difficult to configuration a new product structure rapidly and correctly. If the product needs innovation, configuration in addition becomes intermixed with other aspects of design.

In practice many products reuse past designs or elements. Since most products are changed depending either on their functionality or on particular requirements, such as the assembly requirements, the products are renewed incrementally rather than being changed totally to a new one. Reuse and adaption of previous prodcuts is very important in the design process.

In a typical engineering company, there are a variety of sources contraining representation of the products and those usually include:

- Engineering Drawings;
- Bill of Materials (BOM);
- Assembly Drawings/Instructions;
- Maintenance Documentation;
- Instruction Manuals.

However many industrial facts identify that the current approaches are not good enough to support product structuring. There is therefore a need to develop a new approach to support product structuring.

The purpose of product structuring is to reuse previous design information and design solutions effectively. Precisely the objectives of product structuring is to allow designer to access rapidly to relevant design cases, extract information at right level and at the correct stage, as well as to use extracted information to configure/synthesise new designs. Another important purpose is to standardize product range for the market needs.

2 Configuration Knowledge

In order to structure and organise product inforamtion for configuration design, it should be clear the types of product information in terms of configuration knowledge. Various knowledge can be taken into account in configuration design. These knowledge includes:

- Elements and their relationships;
- Configuration Requirements i.e. goals;
- Configuration Constraints;
- Configuration Decisions;
- Configuration Solutions.

2.1 Relationships Between Elements

The configuration relationships are possible to be classified based on two different levels: *phenomenon level* and *knowledge level*. For a technical system, it maybe sufficient to consider any relationships between two elements as *spatial* and *functional* or both relationships in the phenomenon level. Nevertheless, looking at these relationships as the knowledge that can be capured by a computer support system, the configuration relationships such as the logical relationships are used in the knowledge level. In other words, the relationships in the knowledge level imply the relationships in the phonemenon level that can be represented into a computer support system. Figure 1 shows a classification of relationships both in the phoenomenon level and the knowledge level.

2.2 Configuration Constraints

Constraints in configuration design are shown as the restriction of the relationships between elements, variables or shapes for the product generation. These restrictions could be classified with respect to the relationships between elements. Figure 2 shows a possible classification of the constraints.

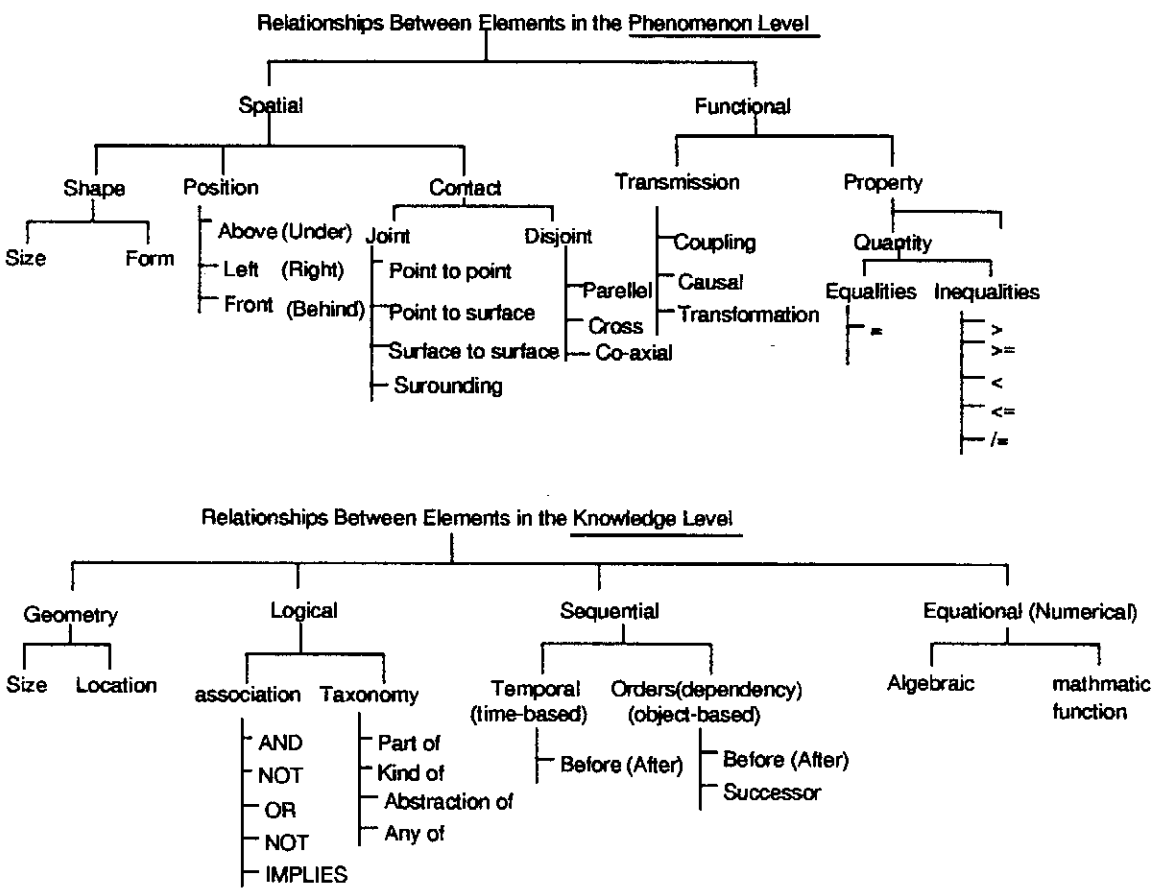

Figure 1: The Relationships between elements

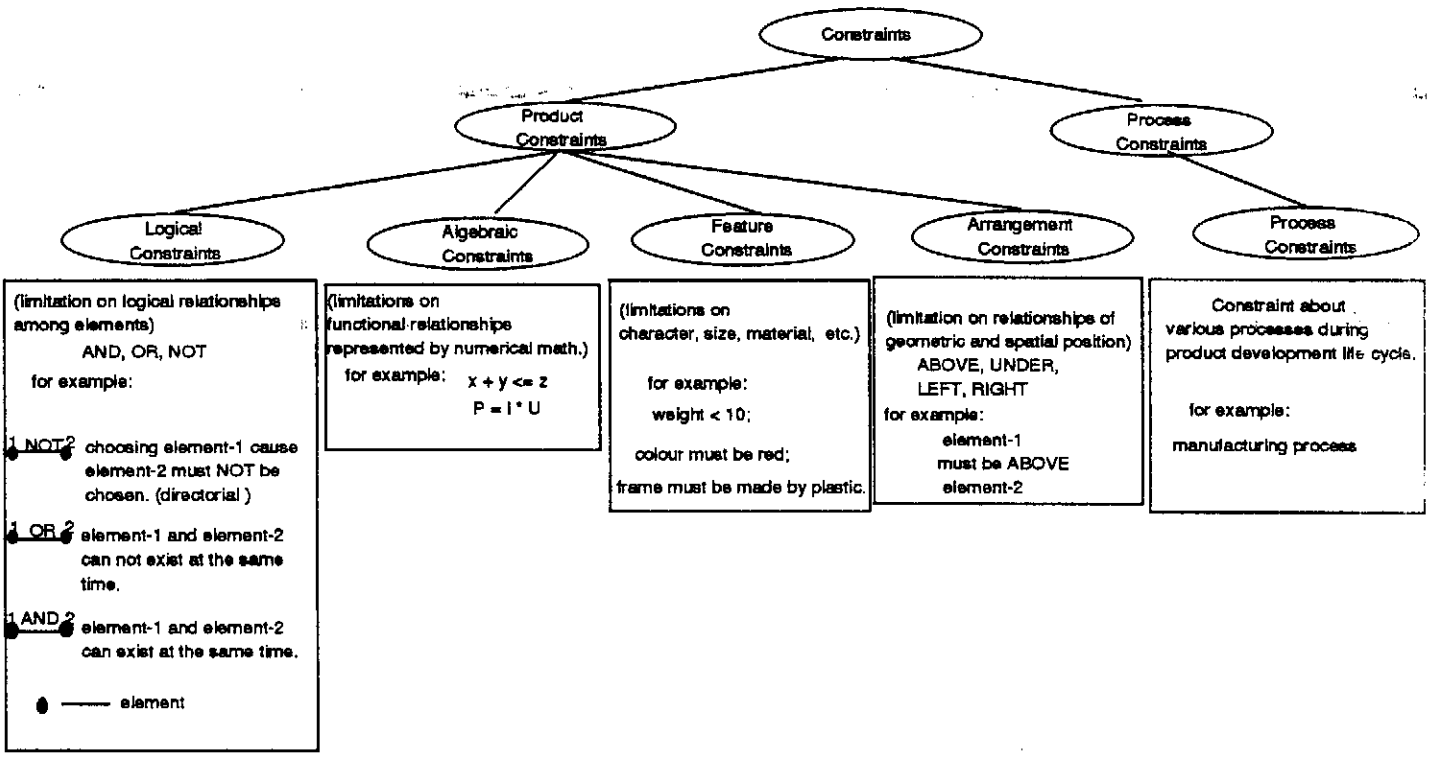

Figure 2: Classification of the constraints

3 A Product Structure Methodology

The role of Product structure methodology can be as follows:

- Be able to identify elements;
- Be able to present relationships between elements;
- Be able to categerise elements within their families;
- Be able to classify into a hierarchy;
- Be able to present constraints;

A product structure methodology has been developed during research into computer support for configuration design and management carried out in the CAD Centre, University ofStrathclyde. In this methodology, various types of product structure knowledge are formalised into two kinds of interrelated structures: *Product Family Classification Trees (PFCTs)* and *Product Breakdown Structure (PBS).*

3.1 Product Family Classification Trees (PFCTs)

A product range can be classified as the Product Family Classification Trees (PFCTs) which is the tree structures that represent a class of product and its modules from

an abstract level to product instances. Each node in the tree represents a product or modules class with its parts breakdown. The ancestor-descendant relationship of two classes is presented as "a kind of", i.e., a class of product is a kind of the superclass of product. Figure 3 shows the structure of a general product family classification tree. There could be more than one tree which represents a product range such as there could be several module family classification trees which are related to each other within a product family range.

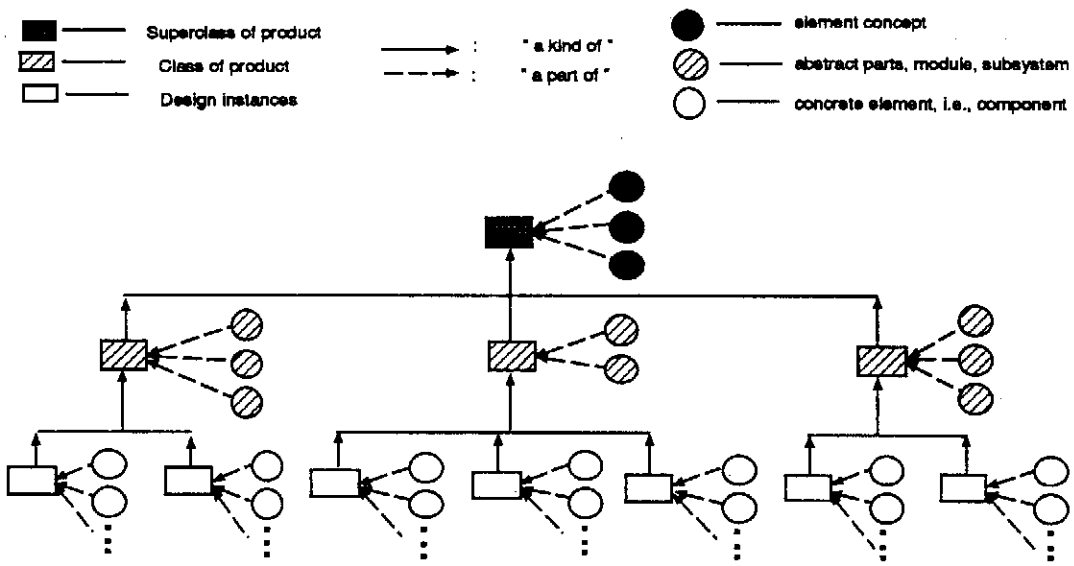

Figure 3: Product Family Classification Tree

It is possible to develop different PFCTs corresponding to different considerations. The criteria for developing PFCTs could be considered as follows:

- Based on functions;
- Based on customer requirements;
- Based on product performance;
- Based on application area;
- Based on customer group;
- Based on manufacture location.

3.2 Product Breakdown Structure (PBS)

Product Breakdown Structure (PBS) presents a set of product elements in a hierarchic structure(Figure 4). Each node in this structure stands for a module, a subsystem or a component. All the attributes, features and properties of modules, subsystems or components are recorded in each node slots. The ancestor-descendant relationship is presented as "a part of", such as a statement like a component is a part of a module or subsystem can be presented by "a part of" link between component and subsystem.

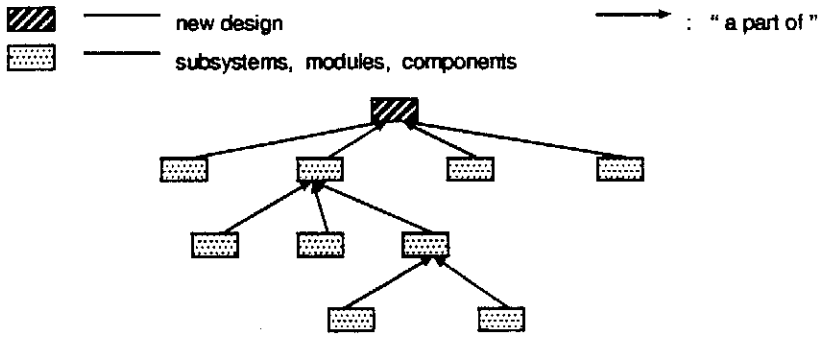

Figure 4: Product Breakdown Structure

There should be a set of PBSs for presenting a product or a technical system based on viewpoints of its considerations. A set of PBSs can be derived based on various considerations, i.e., the criteria for developing PBS could be based on:

- Product Funtions (also called Product Functional Breakdown Structure (PFBS);
- Product Assembly (also called Product Working Breakdown Structure (PWBS);
- Product features;
- Distribution;
- other design considerations.

4 Conclusion and Further Research

Configuration design is a generic design activity of creating a set of product structures i.e. configuration solution through selecting elements and defining their relationships. As the current situation of which the lack of organisation for the product information such as elements and their relationships, there is a need to develop a product structure methodology to support configuration design. The knowledge about configuration design has been investigated initially and a product structure methodology has been developed to support configuration design. By using this methodology, designer can be guided to select elements, i.e., he or she is known where to go. On the other hand, these structures are good for reuse in which the reuse of existing product information is regarded commonly as an effective design activity in the product synthesis.

Further research on these structures is beeing considered in the future. Some issues on the relationships between these structures, how these structures affect each other and the mapping mechanism that convert one to another based on the design requirements, are visible to be the further research focus.

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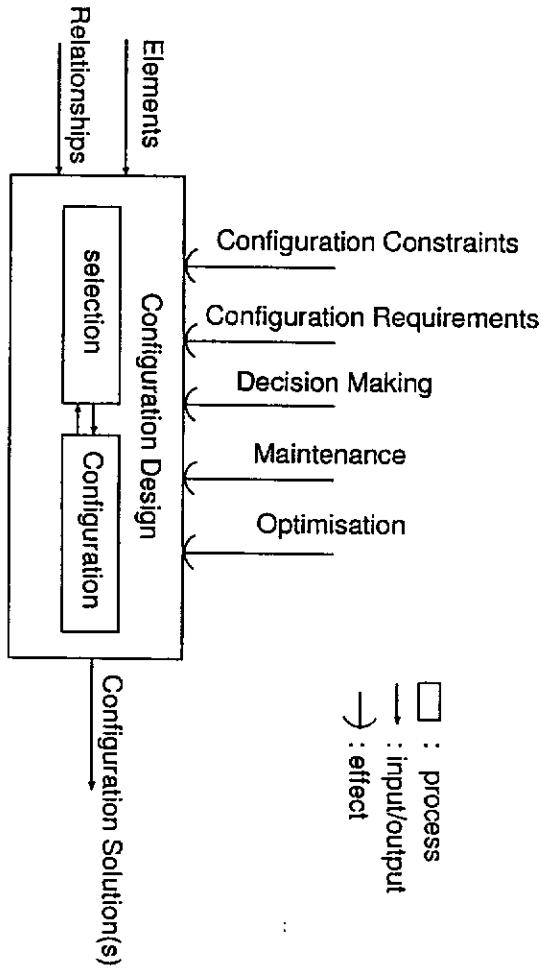
What is Configuration?

Configuration is a process:

from a given set of ***elements***, to create an ***arrangement*** by defining the ***relationships*** between selected elements that satisfies the ***requirements*** and ***constraints.***

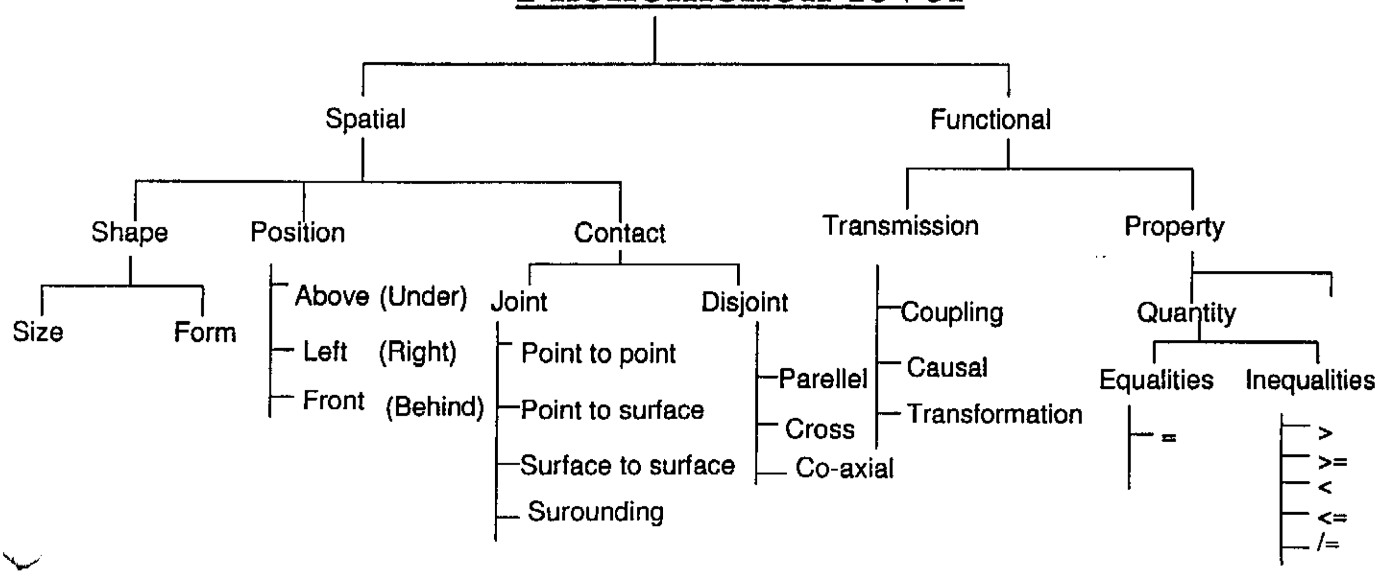
Configuration Design Process Model



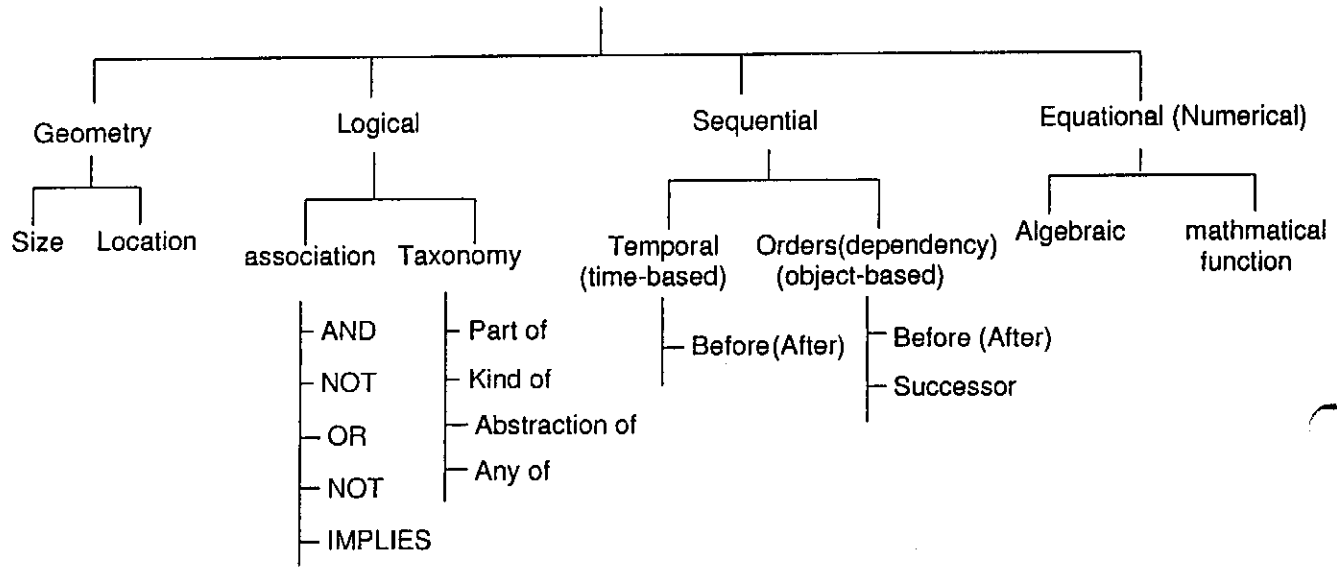
Configuration Knowledge

- Elements
- Relationships
- Configuration Requirements
- Configuration Constraints
- Configuration Decisions
- Configuration Solutions

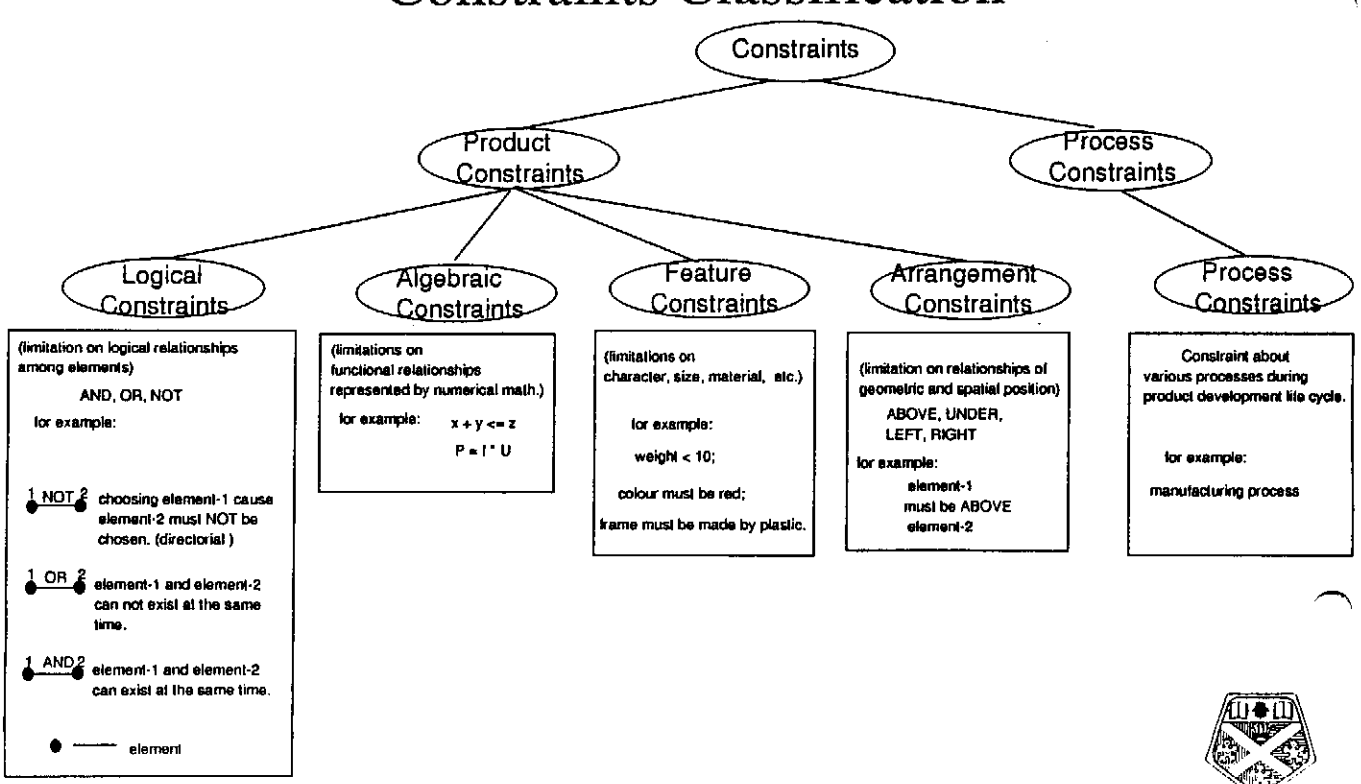
Relationships Between Elements in the Phenomenon level



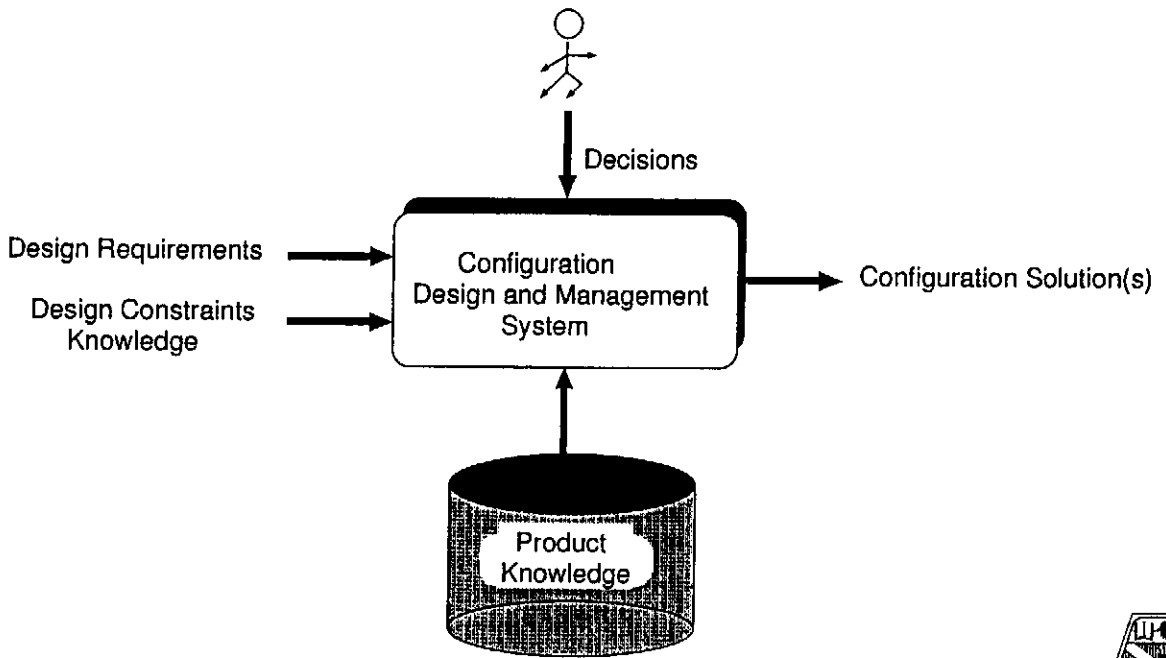
Relationships Between Elements in the Knowledge level



Constraints Classification



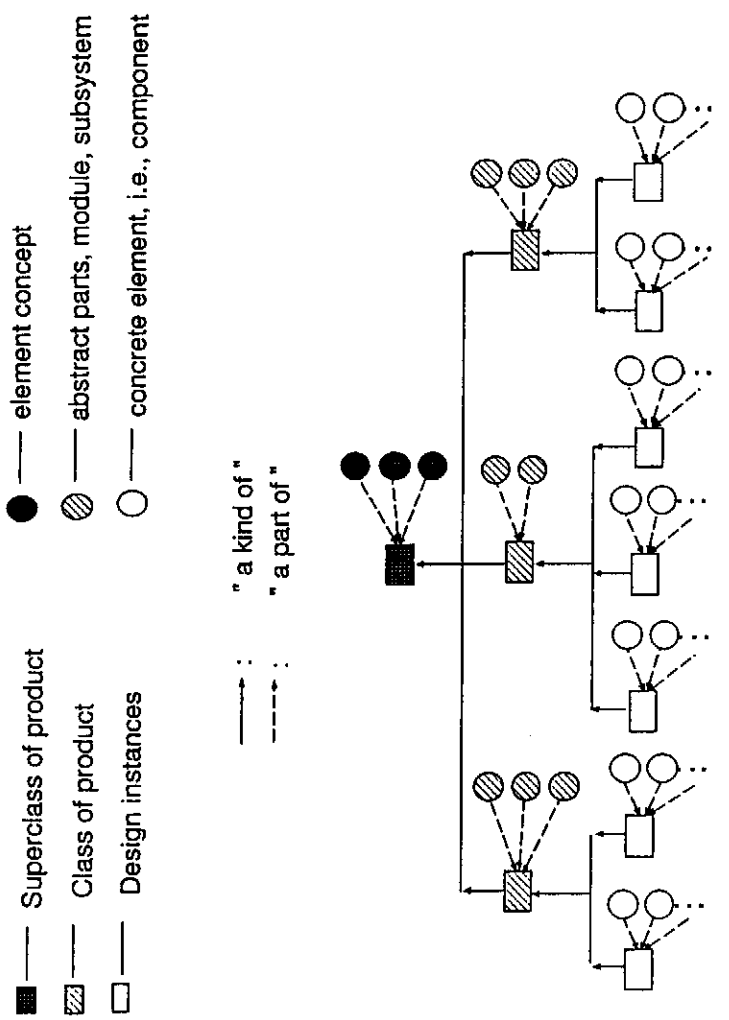
System Input/Output



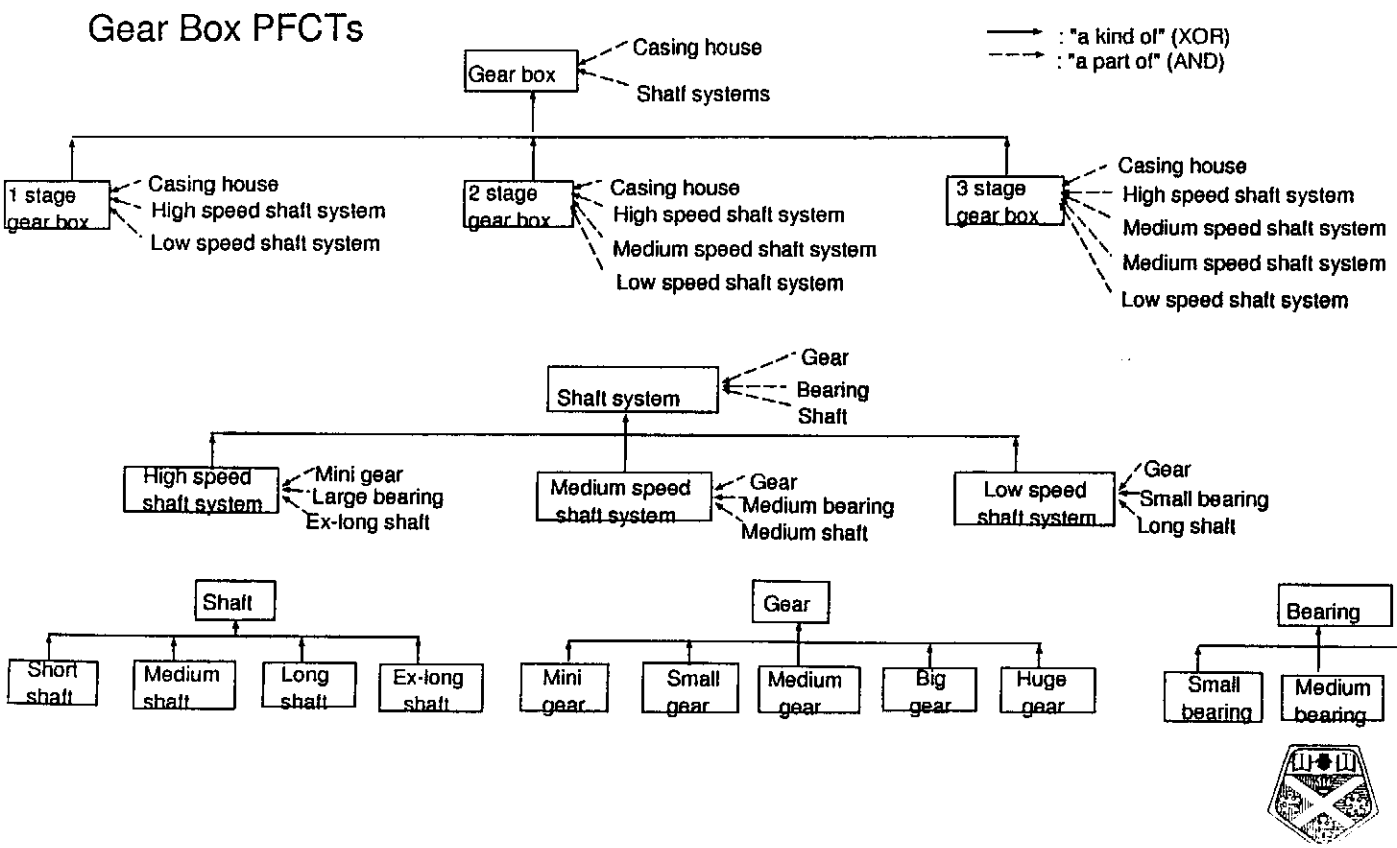
Role of Product Structure Methodology

- Be able to identify elements
- Be able to represent relationships between elements
- Be able to categorise elements within their families
- Be able to reuse product information at different levels of details
- Be able to represent constraints

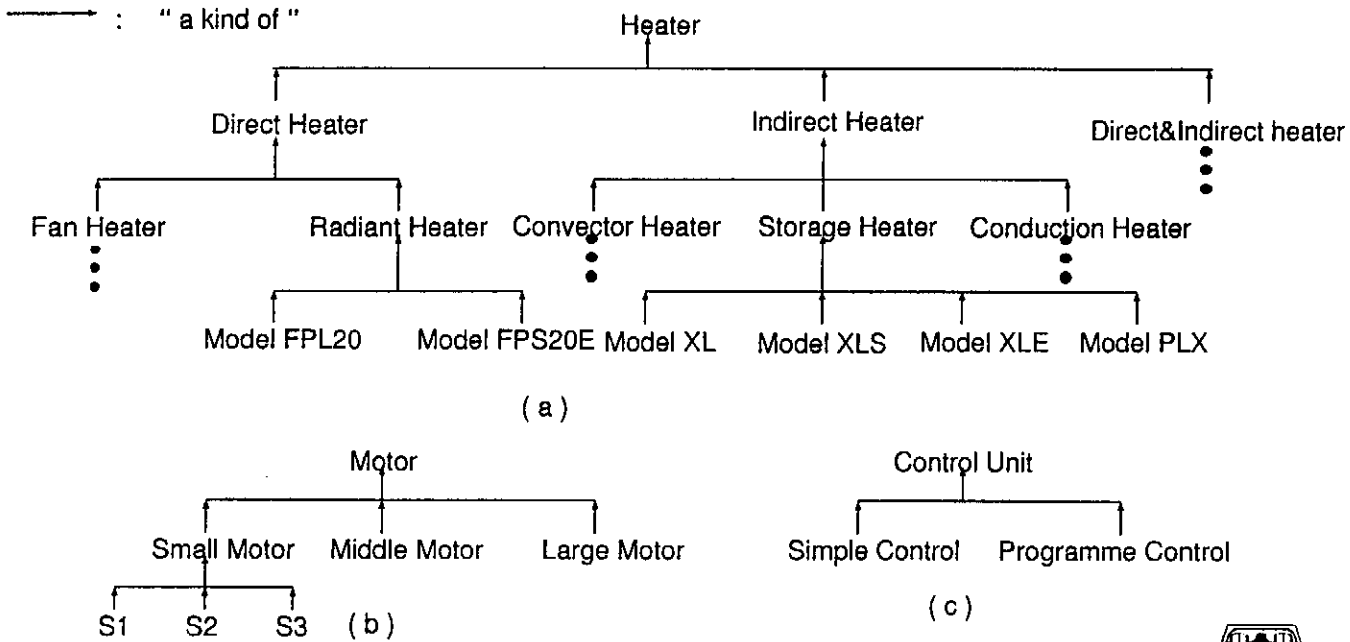
Product Family Classification Tree (PFCT)



Gear Box PFCTs



Domestic Heater Classification Trees

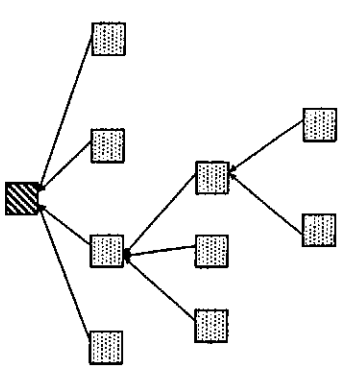


Product Breakdown Structure (PBS)

— new design

— subsystems, modules, components

—: " a part of "



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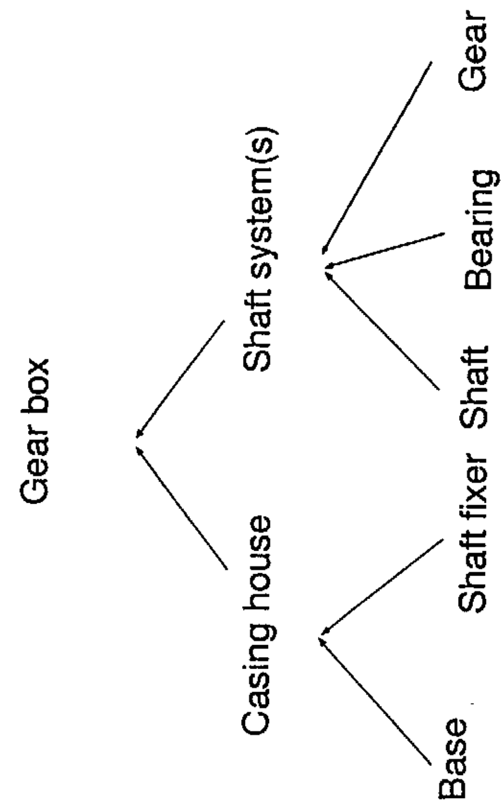
The Gear Box PBS

→ : "AND" logical relation



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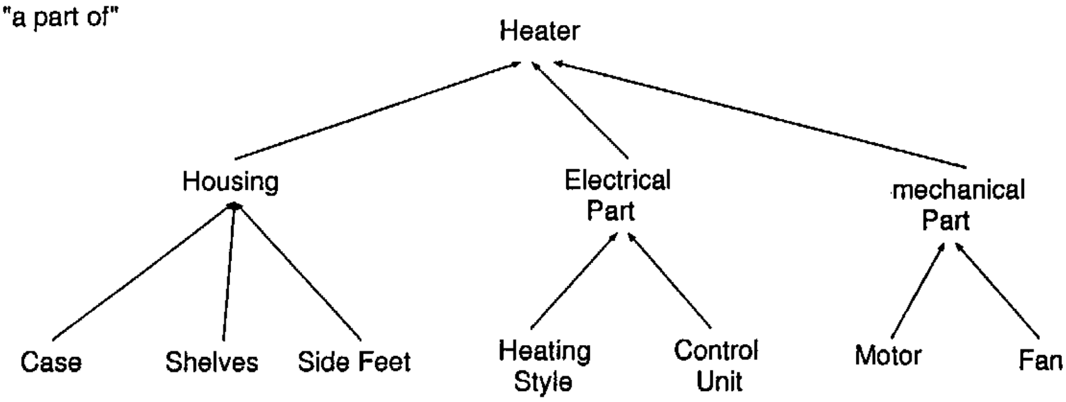
Domestic Heater PBS

→ : "a part of"



Constraints Examples

- Logical Constraints (presented as a set of *disjunctive clauses*):
  - XOR:
    - » (V(wall_mounted.false)(side_feet.false))
  - AND:
    - » (V(1_stage_smallgear.false)(2_stage_medgear.true))
- Feature Constraints:
  - gap(gear_a, gear_b) must be 2cm

Criteria for Developing PFCT

- Based on function
- Based on customer requirements
- Based on product performance
- Based on application area
- Based on customer group
- Based on manufacture location

Discussion

- Advantages:
  - Guidance of configuration selection (you know where to go)
  - Assist configuration structure creation
  - Support configuration management
  - Good for reuse product information at different levels of details
  - Rationalisation of product
  - Sales configuration rapidly

Criteria for Developing PBS

- Based on function (PFBS)
- Based on assembly (PWBS)
- Based on character (PCBS)
- Based on materials (PMBS)
- Based on distribution (PDBS)

Conclusion

- Configuration design is a design activity which to do with elements identification and their relations
- An investigation about nature of configuration design has been discussed
- A methodology for product structuring has been developed to support configuration design
- The methodology benefits to other aspects of design activities

Issues For Further Research

- What are the relationships between these structures?
- How do these structures co-operate to support configuration and synthesis?
- What are the information content and data flow within the structures?
- and how is the information related to these product structures in the design process?