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A Task Oriented Approach to Documentation and Knowledge Management of Systems Enabling Design and Manufacture of Highly Customized Products

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Abstract. A rapidly growing approach in product design and manufacture, with great potential to improve customer value, is mass customization. The possibility to design and manufacture highly customer adapted products brings a competitive edge to manufacturing companies and is in some areas a necessity for doing business. In this paper, an approach for documentation and knowledge management of systems supporting the design and manufacture of customized products is explored. As the governing framework and models are updated and refined due to shifting prerequisite, the system and hence the solutions generated for a single specification will change over time. This affects product management and the ability to meet legislation and customers' requirements regarding documentation and traceability, as well as the company's ability to provide services, maintenance and supply spare parts. A solution has been developed for an industrial case with required functionality for capturing, structuring, searching, retrieving, viewing, and editing a system's embedded information and knowledge. The objective is to enable and facilitate system maintenance and updating and support the reuse of functions and system encapsulated generic design descriptions in future systems.

Keywords. Customized products, system maintenance, documentation, knowledge management

Introduction

The ability to efficiently and quickly design and manufacture highly customized product can provide a competitive advantage for companies acting on a market with shifting customer demands. A business model based on highly customized product requires advanced application systems for automating the work of generating product variants based on different customer specification in the quotation and order processes. There are examples of companies adopting this approach for many years, nevertheless, as these and other companies want to cut lead time and be able to increase the customization level, more effective use of the systems is required. From a scientific viewpoint, most research has focused on system functionality and in some cases on system development whereas methods to support efficient maintenance, updating and reuse of these systems are not fully developed.

In this paper, an approach for documentation and knowledge management of systems supporting the design and manufacture of customized products is explored. Two different life-cycle perspectives have to be considered when addressing documentation and management – a knowledge perspective and a product perspective.

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The knowledge perspective includes the adaptation of rules and models to changes in production technology, new product knowledge, new markets, changes in legal requirements, etc. Issues related to flexibility, stability, quality assurance, traceability and documentation of a system's different constituting parts and underlying knowledge can be critical unless adequate measures have been taken in the development phase. The product perspective focuses mainly on documentation, traceability and version control. As the governing framework and models are updated and refined due to shifting prerequisite, the system and hence the solutions generated for a single specification will change over time. This affects product management and the ability to meet legislation and customers' requirements regarding documentation and traceability, as well as the company's ability to provide services, maintenance and supply spare parts. Of central importance are issues relating to methods of generating and managing documentation such as engineering calculations and simulations combined with the principles of traceability from the product to the underlying knowledge and vice versa, and versioning of rules, models and systems.

The scope and the purpose of this research originate from industrial problems and needs which have been identified within research projects carried out in near collaboration with industrial partners. New concepts, perceived as prescriptive models, have in this work been introduced, evaluated, and refined, which is in accordance with the design modeling approach [1].The focus of this paper is a case study carried out in collaboration with industry. A solution has been developed for the industrial case with required functionality for capturing, structuring, searching, retrieving, viewing, and editing the system information and knowledge. The objective is to enable and facilitate system maintenance and updating and support the maintenance and reuse of general functions and system encapsulated generic design descriptions.

1. Case study - automatic design of seat heaters

A general tool, ProcedoStudio, has been developed and evaluated in collaboration with a manufacturing company. The tool has been used for setting up a pilot application system for automatic design of seat heaters to be used in the quotation process. The scope of the system was to support automatic variant design of heating elements for car seat heaters based on varying customer specifications and seat geometries. A heating element consists of a carrier material, a wire and a connecting cable. The wire is laid out and glued in a pattern of sinusoidal loops between two layers of carrier material (Figure 1). The pattern design is based on company-aggregated knowledge. Approximately 75 new variants are designed on a yearly basis and hundreds of requests for quotations are replied. Accuracy in quotations and short quotation preparation lead-time are key success factors for the company regarding quotations. Of great importance is also that the final design should comply with the initial decisions made in the quotation preparation. This requires decisions that are correct compared to the final design and the existence of tools for documentation.

Figure 1. A car seat with a heating element in the backrest.

In Figure 2, the principle system architecture for the automated system generating variant designs of car seat heaters is depicted.

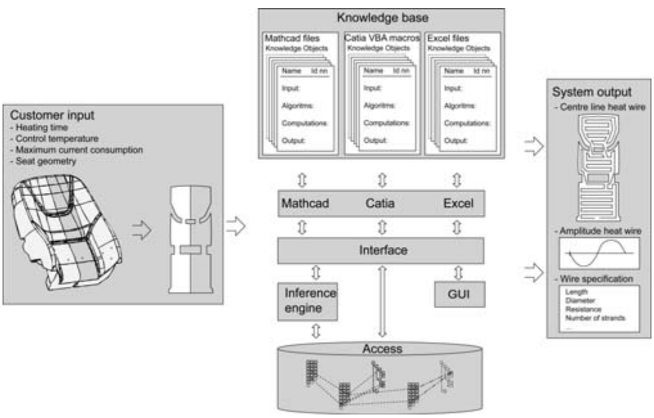

Figure 2. Principle system architecture [2].

The system is feed with customer-specific input (parameter with associated values together with a 2D outline of the heating element). The main output include a pattern for the heating wire's centre line, an amplitude factor for the sinusoidal loops, the wire specification, detailed manufacturing preparation and a cost estimation. The application for car seat heaters corresponds to a knowledge domain modeled as a KnowledgeBase in the tool. Presently, there are 20 KnowledgeObjects for input specification, file management, electrical calculations, geometry design, manufacturing preparation, and cost estimation. The number of variables managed by the database is 66, although the total number of variables residing in all of the KnowledgeObjects is of much higher figure. Application programs used are MS Access 2007, MS Excel 2007, MathCAD 13, and Catia V5R18. Screenshots from the running system are collected in Figure 3. Fundamental system principles and functions are:

Implemented with a modular architecture.

Resides upon a database.

Based upon a CoTS-approach.

Supports process oriented modeling.

Includes an adaptive user interface.
Incorporates functions to ensure system completeness and functionality.
Based on the separation of knowledge and execution.
Supports documentation of design rational associated to rule statements.
Installed as a client-server solution.

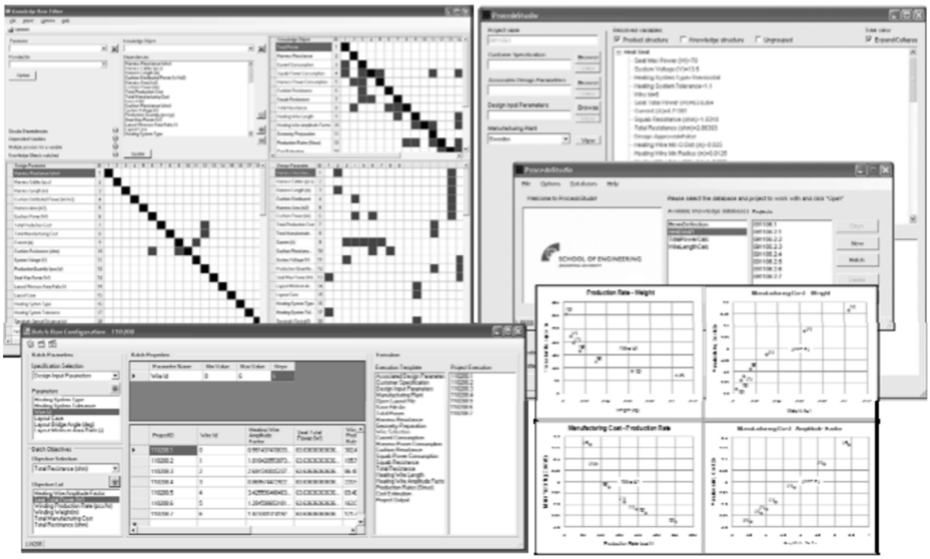

Figure 3. Screenshots from the system for automatic design of seat heaters.

The system output has been compared with final designs of seat heaters. One example is illustrated in Figure 4. The system generated pattern and wire data are shown to the right in the figure. Although not generating the same pattern type as for the final design, the precision is acceptable and more accurate compared to what can be manually estimated in the quotation preparation.

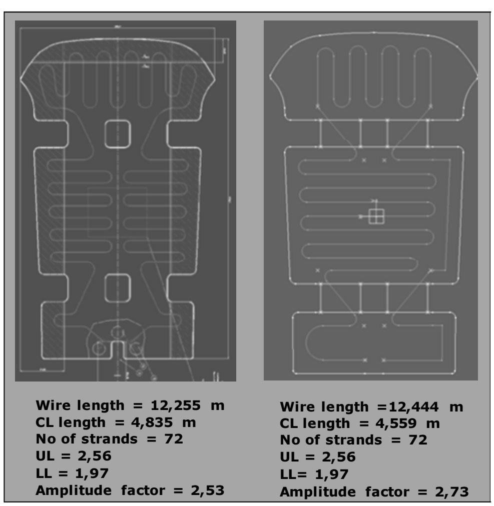

Figure 4. Comparison between a final design (left) and system generated design (right) [2].

1.1. Problem - maintenance and reuse

During the practical use of the system in the company, the lack of assistance from either documentation work about the whole system or management of knowledge could bring out some obstacles when the engineers from the company reuse existing knowledge and information without some helps from original developers. As a result, it will significantly delay company's developing activities, and engineers would be faced great challenges to finish with design tasks and quotation process. From a long-term point of view, reuse of the existing knowledge is a critical issue, since there will be introduction of new product, new variant of existing product, new manufacturing process and additional or modified design rules due to new insights or changes in standards or legislation. In order to deal with these "New" factors, the adaptability of entire system need to be considered, and some supportive documentation work and management of knowledge need to be accomplished for achieving the goal of maintenance of the system, updating and reuse of system embedded information and knowledge. Hence, it is essential to bring full comprehension of the system. This includes both an overview of entire system and detailed relationships between different knowledge and information residing within the system.

2. Theoretical foundation and candidate solutions

Two concepts that are important to consider when developing a support that enables access to preceding decisions and argumentations for a design are design rational and traceability. These concepts are briefly described in the following section followed by an inventory of candidate solutions for system development.

2.1. Design rational and traceability

Design rational is the set of reasons behind the decisions made during the design of an artifact (e.g. a product or an application system). The access to design rational can support development of new artifacts, modification of existing artifacts (design changes) or the reuse of an existing solution in a new context. The realization of a design rationale system includes methods and tools to capture, structure, manage and share information across organizations, processes, systems and products. The requirements concerning the scope and the granularity of design rational to be captured depend on future needs. These can be difficult to foreseen, however, a limitation has to be set as is not feasible to capture everything during the design process. Two different approaches to represent design rational are Argumentation-based and Template-based [3]. Argumentation-based representation uses nodes and links whilst Template-based representation makes use of predefined standard templates. The selection of approach will affect the scope, the granularity and the structure of the captured design rationale; however, the key factor for successful implementation of a design rational recording tool is simplicity [4].

The development of a design automation system is preferably a part of, or integrated with, the development of the actual product. Four sub-processes can be identified within such a development process resulting in four different outputs: the product design, the design space, the system adapted definition of the design space, and the system implementation. Traceability, defined as "…the ability to describe and follow the life of a conceptual or physical artifact." [5], across these sub-processes is essential. The artifact of concern in this study is mainly the design automation system. The design automation system encapsulates product knowledge that has been expanded and transformed into different levels of completeness and generalization throughout the four sub-processes. Traceability, both forward and backward, across different knowledge levels would support the work of pursuing affected objects when changes occur in the premises of a design or the work of using an existing solution in a new context; i.e. knowledge traceability, defined as "…the ability to follow the life of a knowledge component from its origins to its use." [5], is required.

2.2. Candidate solutions

A supporting tool could either be realized by the development of a special purpose application or by the use of an available application with functionality suitable for the purpose. A special purpose solution can be based on either four principles: Systems Modelling Language (SysML) [6], MOKA [7], Product Variant Master (PVM) [8] and CommonKADS [9]. Four candidate applications with some relevant functionality are: PCPACK [10], Design Rationale Editor (DRed) [4], Product Model Manager (PMM) [11], and Semantic MediaWiki (SMW) [12].

When comparing the four stated principles, SysML seems as an easy way to show the rationale, requirements, constraints and rules by using the concept of the block diagrams, while CommonKADS looks more like a dominant method to manage the knowledge. In CommonKADS, all the information from design to delivery is shown in a simple way. Storing the experience, geometry and data that are related to a product and show them within different classes and views are outstanding for MOKA. When it comes to reducing costs, risks and lead time in a project, providing a way of developing and maintaining KBE makes MOKA more specific. Product variant master (PVM) gives a general overview of the product according to sub or super parts with the relations between different components which all can be seen on a big piece of paper. Regarding the three specific applications, PCPACK has an integrated suite of ten knowledge tools designed to support the acquisition and use of knowledge. Analyzing knowledge from text documents and structuring knowledge using various knowledge models makes PCPACK a powerful system. DRed is a simple and unobtrusive software tool that allows engineering designers to record their rationale as the design proceeds. It allows the issues addressed, options considered, plus associated pro and con arguments (arguments for or against an answer), to be captured in the form of a directed graph of dependencies. PMM is a tool built upon the principles of PVM. PMM is an easy tool to learn with an intuitive structure and graphical notation. However, support for advanced queries, revisions, and authorization are not included. Improved data structures by using categories and access to information according to user's specific queries are the advantages of SMW. Support for revisions and authorization are also supported by SMW.

3. Solution

Based on the required system functionality and the comparison above, the foundation for a system realization can be outlined. The system has to be able to provide a general view with all relations and constraints. This is supported by all of the four general principles outlined in the previous chapter, however, additional elements have to be added to support structuring of design rationale and relations to other domains and supporting documents. Of great importance is also the functionality and the mechanisms enabling querying or aggregation of information within and across the documentation together with support of versioning and authorization control, this is all supported by SMW.

The main focus is on the mapping between the scattered system associated and encapsulated knowledge and information which are presented in Figure 5.

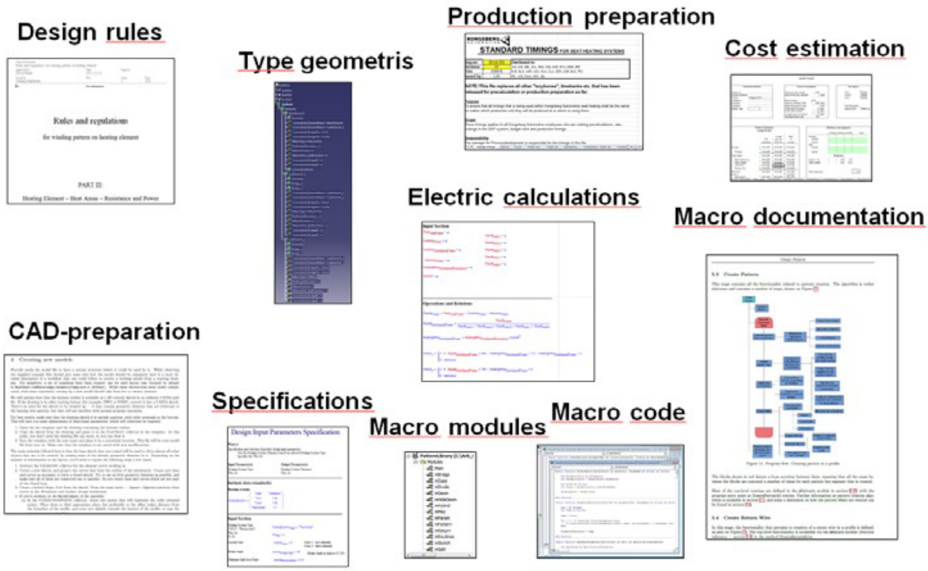

Figure 5. System associated and encapsulated knowledge and information.

There are two main approaches to structure the knowledge, either based on the product structure or the design process. Depending on the system for implementation, both views can be supported and even other views introduced. In this case, the design process was selected as the master as it would result in a higher level of granularity of the system encapsulated information and knowledge than a solution based on the product structure. In the planning of the system, all design tasks were documented and their relation modeled using the principles of Dependency Structure Matrices (DSM). The DSM was analyzed using a tool for partitioning with subsequent manual work resulting in two principle sub-process that can run separately until the final task except for one parameter that has to be transferred (Figure 6). These tasks can also be re-grouped into a limited number of main activities. For the macro generating the wire layout, a subsequent detailed process description was required to enable a clear overview of the execution flow combined with a very detailed description of the macro modules, procedures and functions.

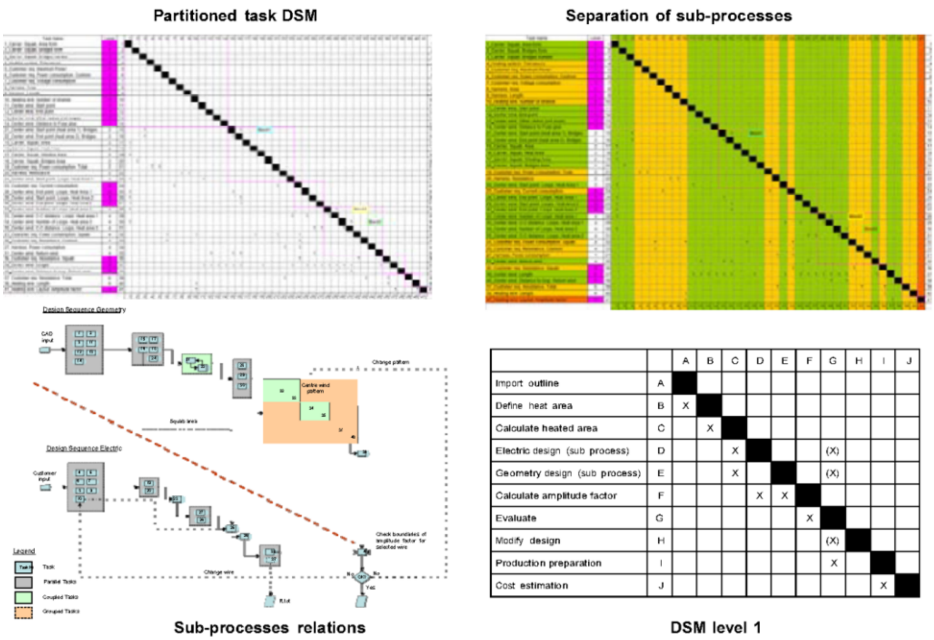

Figure 6. DSM modeling

The structure of the information and knowledge entered into the system is based upon the principle information model presented in Figure 7 and the main page of the prototype system is depicted in Figure 8. The main principle of structuring the knowledge and information is to sub-divide the process into different tasks and functions at different levels to be able to support both a contextual meaning and the access to detailed descriptions. The Rational class can be used to describe why a Process/Task/Function exists or in detail describe the set of Input, the set of Output, and the transformation associated with a specific Process/Task/Function. The SupportingObject enables traceability to reports, protocols, guide-lines, standards, legalizations etc. The information model also describes the main content of the wiki pages, i.e. it defines a template.

Wiki pages for the electric calculations, process planning and cost estimation were quite easily done whereas the documentation of the macro for the wire lay-out required a lot of effort due to its size and amount of internal relations. One main principle of the automatic system for design of seat heaters is to sub-divide the design process into design tasks and use applications to define executable files that automate each and one of these tasks. The applications preferably provide means to enter text and illustration for the purpose to, in natural language, describe the principles of the defined algorithms. The macro, although, was programmed in CATIA VBA with no support to sub-dived the macro into number of separate files and to add illustrations to the code. The macro was, however, divided into modules that were copied into separate wiki pages and annotated with descriptions and figures. Links are one of the most powerful tools in Semantic Media Wiki and were extensively used to create relations between different pages allowing for mapping between concepts. The search facilities also provide a means to find and track knowledge and information in the domain which support both detailed selection and aggregation of information.

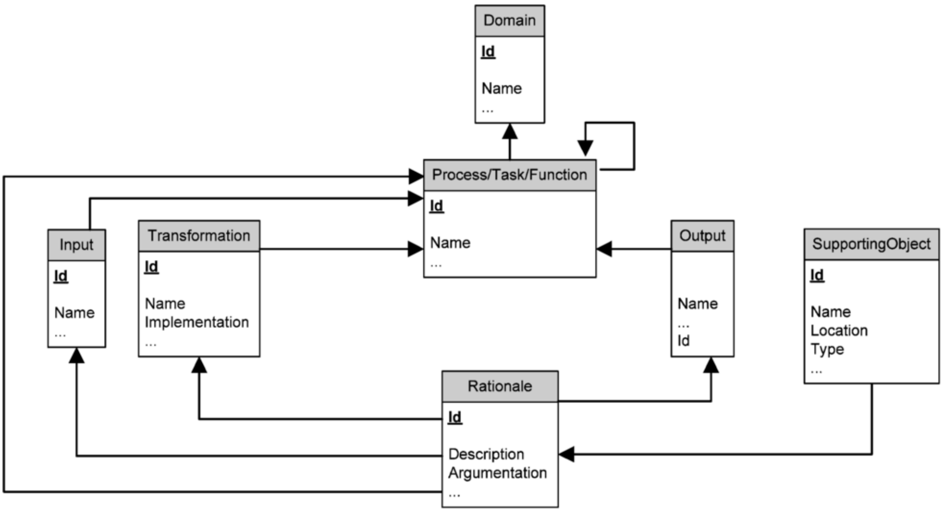

Figure 7. Principle information model

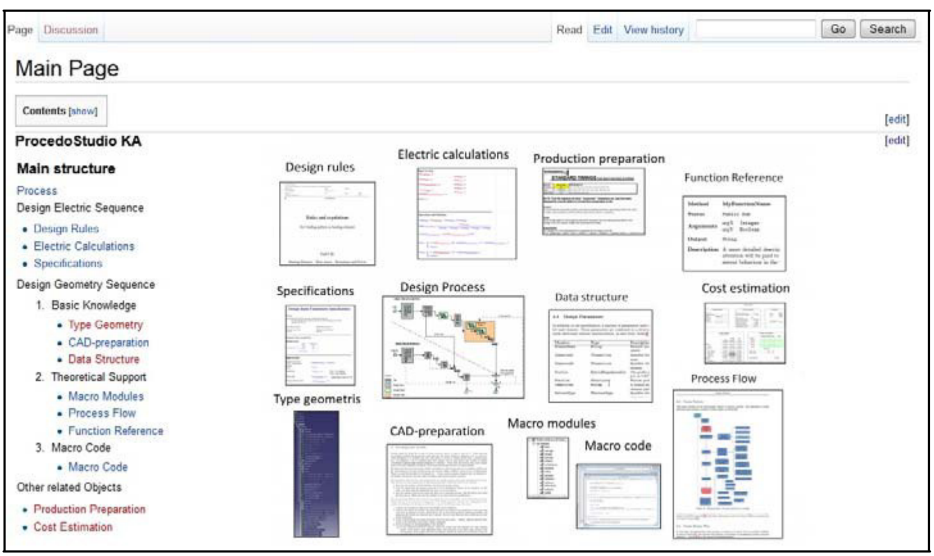

Figure 8. Main page of the system [13]

4. Conclusion

In this paper, an approach for documentation and knowledge management of systems supporting the design and manufacture of customized products has been explored. The main objective was to develop a support that enables and facilitates system maintenance and reuse of general functions and system encapsulated generic design descriptions. A principle solution and a prototype system have been outlined and discussed. One of the central parts is that the knowledge and information have been structure based upon the design process. Semantic Media Wiki has more or less all require functionality to set up a system, including history management, access management, linking tools and advanced search mechanisms. To fully validate the presented explorative work and its feasibility entail future studies and improvements that requires the development of systems targeting other domains - this will be subject for future work.

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