IT-BASED CONFIGURATION AND DIMENSIONING OF CUSTOMER SPECIFIC PRODUCTS – TOWARDS A FRAMEWORK FOR IMPLEMENTING KNOWLEDGE BASED DESIGN ASSISTANT SYSTEMS

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ABSTRACT
Individual product solutions require practicable concepts and IT support for fast product configuration and design. Knowledge of possible design options and basic conditions is of great significance in the conception of this type of support. The goal is an integrated conception and implementation of knowledge based IT applications for engineering design.
Despite existing methodological support from software vendors, numerous questions still arise during requirements formulation, system evaluation, system integration into existing business IT environments, the creation of knowledge bases, the implementation of pilot process tasks, or definition of rollout and operation strategies.
Illustrated by a case study, this paper presents the first results of a research project that deals with the systematic examination of the aforementioned issues with the aim to develop a framework for the holistic concept and the practical implementation of knowledge-based assistant systems. The main components of the presented approach are a practical method, an assistant for the acquisition and formalization of configuration and engineering knowledge as well as a system-neutral, federated knowledge base.

Keywords: Product Configuration, Knowledge Based Engineering (KBE), Design Automation, Knowledge Acquisition, Knowledge Formalization

1 INTRODUCTION
Successful companies do not only focus on their products but also on the development process which includes the development of the production system as well. Innovative products and the capability to concurrently establish a flexible production system with configurable manufacturing and tooling devices led to the competitive advantage of Julius Blum (a company based in Austria), a manufacturer of lifts, hinges, pull-out systems for kitchen cabinets, and custom assembly devices. The research presented in this paper has been carried out at Blum with the main goal to develop an integrated concept as well as a practicable implementation of knowledge based applications for engineering design.
Stamping tools for manufacturing bent sheet metal parts for furniture hinges are used in a progressive compound method. Here, the workpiece is used in the form of a metal strip which is led through the individual tool stations and processed in several work phases (Figure 1). A standardized basic structure for tool stations is used per work phase which serves as a holder or base for the product specific stamping tools. The variants BOM of the tool station consists of 28 different items list positions that can be installed several times in each case. The parts catalogue consists of more than 200 components all managed in the company's PDM system. 8 new components to be manufactured individually are created out of the 28 different items list positions. A complete stamping tool set contains up to 15 tooling stations. Used standard parts vary in number and position. Hence, they have a strong influence on the geometry of new parts to be manufactured. Design directives take effect on the selection of standard parts as well as new parts. For instance, minimum wall thicknesses have to be taken into account or number and position of guide posts and strippers have to be calculated. Figure 2 shows a master model, containing all possible options of the tool.

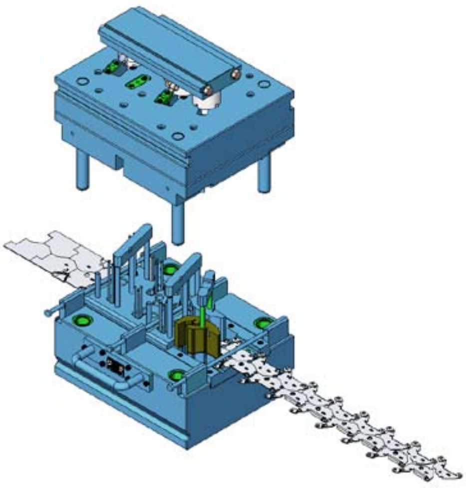

Figure 1. Tooling Station

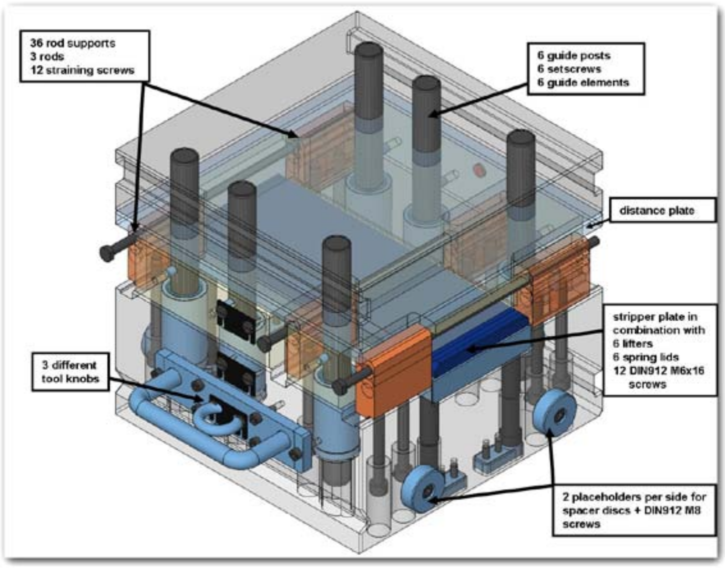

Figure 2. Mastermodel

Efficient and quick implementation of customer specific product solutions – which is always a requirement of customers – calls for comprehensive knowledge of existing functional modules including their configuration and combination options. Furthermore, for parts to be designed individually, design expertise and sound standing knowledge ensured by technical calculation is required. With an increasing number of customer specific options, the number of product variants escalates and the required configuration knowledge becomes more complex. Therefore, design departments are facing this situation by making strong efforts to look for appropriate means to master the situation. Besides necessary modularization, IT tools such as Product Configurators, Knowledge Based Engineering systems or Design Automation systems become more and more important (Figure 3).

Whereas in the past, especially large companies dealt with the context of mass customization concepts with IT support for job-based product customization, now increasingly SME companies are looking for viable software solutions fitting their individual needs through flexible and adaptable software systems. Experience and methodical analysis conducted at Blum show that the selection, procurement and implementation of an off-the-shelf software solution does not guarantee effective and beneficial process support. A holistic view in terms of methodology and functions is missing. Main obstacles are:

- Engineering design managers do recognize the potential of available solutions but find it difficult to approve projects due to some non-transparent conditions. There is a lack of method-supported, practical guidelines with problem-specific options.
- Experienced design engineers have a hard time understanding computer science biased concepts and representations. There is a lack of concepts to capture their expertise and transform this systematically into a formalized form that is machine-readable but still intuitively understandable to and manageable by designers.
- The basic tool of a design engineer is a 3D CAD system. For data management purposes there is primarily a PDM system integrated into the CAD environment. A potential IT support for the configuration and design process must therefore be integrated seamlessly into the design environment and communicate with these systems. Common of-the-shelf solutions do not take this adequately into account.

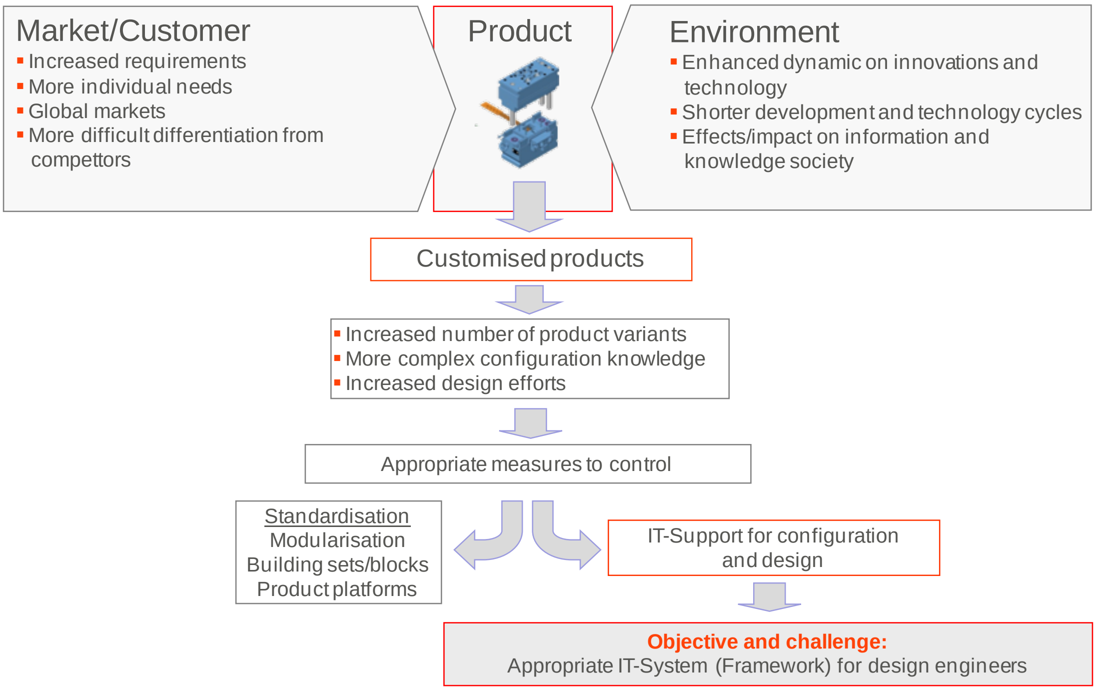

Figure 3. Approaches to master increasing product individualization

2 IT-SUPPORT FOR PRODUCT CONFIGUTATION

With respect to IT support for the development of customized products, a characterization of product types and their production concepts is helpful [1][2][3]. The product type expresses the degree of standardization and thus, at the same time, the customer's influence on product design. Four types can be differentiated: standard products without variants, standard products with manufacturer specific variants, standard products with customer specific variants and products according to customer specifications. The production concept describes the procedure during order processing.

- Make-to-Stock (MTS) or Pick-to-Order (PTO) – corresponds to classic production for storage, which takes place independent of customer requests and orders. It is typical for television sets and household equipment.
- Assemble-to-Order (ATO) – the basic thinking behind this is pre-production irrespective of the order connected to a customer specific final production or assembly. This is typical for cars and personal computers.
- Make-to-Order (MTO) – the product is partly composed of pre-defined components and partly made up of only pre-designed components. Accordingly, new components are also created in this concept. This is typical in machine or ship building, tool machines, and utility vehicles.
- Engineer-to-Order (ETO) – these products indicate a high degree of specialization and cannot be completely pre-designed. The product has a considerable number of new components that have to be designed in case of an order. This is typical e.g. for classic individual production, plant construction, complex machines for manufacturing special products

Lindemann and Baumberger characterize products using the three types: series products with a large number of variants, individualized products and special products [4]. In this context, individualized products are a bundle of products and their associated services containing both standard and individual components. According to the investigation on which this paper is based, it is noted that important drivers for individual products are specific customer requirements which frequently a request for additional functions, special service types, special interfaces, technologies, specific designs, or dimensions. Subsequently, the analysis in this paper focuses on the product types "standard products with customer specific variants" and "products according to customer specifications". Corresponding production concepts are MTO and ETO. A key characteristic of these product types is the combination of existing standard parts with the new or adapted design of individual parts.

IT systems that attempt to support design engineering using knowledge based methods from artificial intelligence (AI) have already been introduced since the eighties [5]. The IT supported configuration of products is the domain of the so called Product Configurators (PC), often connected to the objective of quickly providing a detailed quote to a customer. Knowledge based design is part of the subject area of Knowledge Based Engineering (KBE). Even modern CAD and PDM systems now offer functions to solve configuration and design tasks, although the degree of support in both the configuration and design dimensions is quite different. Figure 4 shows a classification diagram of the mentioned IT systems with reference to the level of knowledge based support. The objective of a fast, cost efficient implementation of individual customer requirements increases the desire for an ideal IT system resulting from the combination and further development of the different approaches. The proposed system is not a completely new development; it is rather a consistent combination and expansion of existing approaches and solutions from the domains of configuration and design.

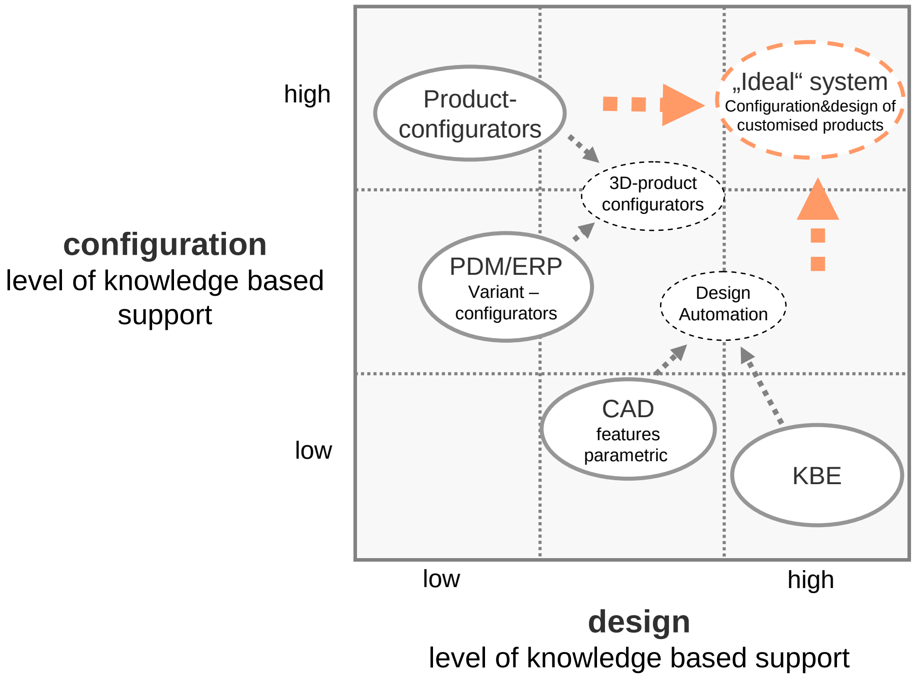

Figure 4. Classification diagram according to the level of knowledge based support with reference to configuration and design

3. FRAMEWORK FOR CONCEPT AND IMPLEMENTATION

The term framework in this particular context describes a productive work environment resulting from the in-process enhancements of basic market based solutions. Here, two work areas can be distinguished:

1. A methodological support in the form of an extended process model
2. A systematic engineering support system, which supports the role-oriented acquisition and formalization of configuration and design knowledge with an appropriate system-neutral, federated knowledge base.

3.1 Methodological support – Extended Procedure Model

For a basic approach towards the introduction of a knowledge-based application for engineering, it is essential to take heed of the research projects MOKA [6], KOMPRESSA [7], and KoViP [8]. There are also a large number of research papers and publications dealing with specific issues in the preparation process. Methods and approaches for knowledge acquisition, knowledge collection and knowledge formalization must be stressed here. [4][8][5][9]. Basically all introductory projects should go through the three phases: preparation, implementation and operation and take corresponding aspects into consideration [10][8].

Initial attempts at Blum to implement a KBE project have shown that, for the design and implementation of an IT support system, the above aforementioned sequence of methods are too general and offer little assistance to individual design options.

The models were therefore extended to comprise practical aspects leading to a holistic procedure method (Figure 5). Through a systematic "backward stepping" in the examined sample projects, the main stages were identified and broken down into process steps. At the beginning of a project, it is important to carry out preliminary analyses which provide the necessary basis for decisions concerning the project's feasibility and profitability. The acquisition and formalization of expert knowledge as well as knowledge about products is a complex and iterative process and therefore, must be well structured. The first part of the process deals with product components, structures and their descriptive attributes. The next part deals principally with the acquisition and formalization of (usually implicit) relationships and design knowledge. Subsequently, the formalized knowledge should be prepared for transformation into a marketable solution. Before the implementation, the future assistance system must be conceived. Here, the correct basic technology (market solution) has to be evaluated and the interface for integration into the system (e.g. CAD/PDM) determined. For the introduction and subsequent implementation and operation of the IT support system, there should be, with possible optimizations, a clear definition for the maintenance intervals of the data involved.
The field-tested guide consists of a description of all steps of each sub-process regarding task, outcome, possible problem areas and their design options and methodological support.

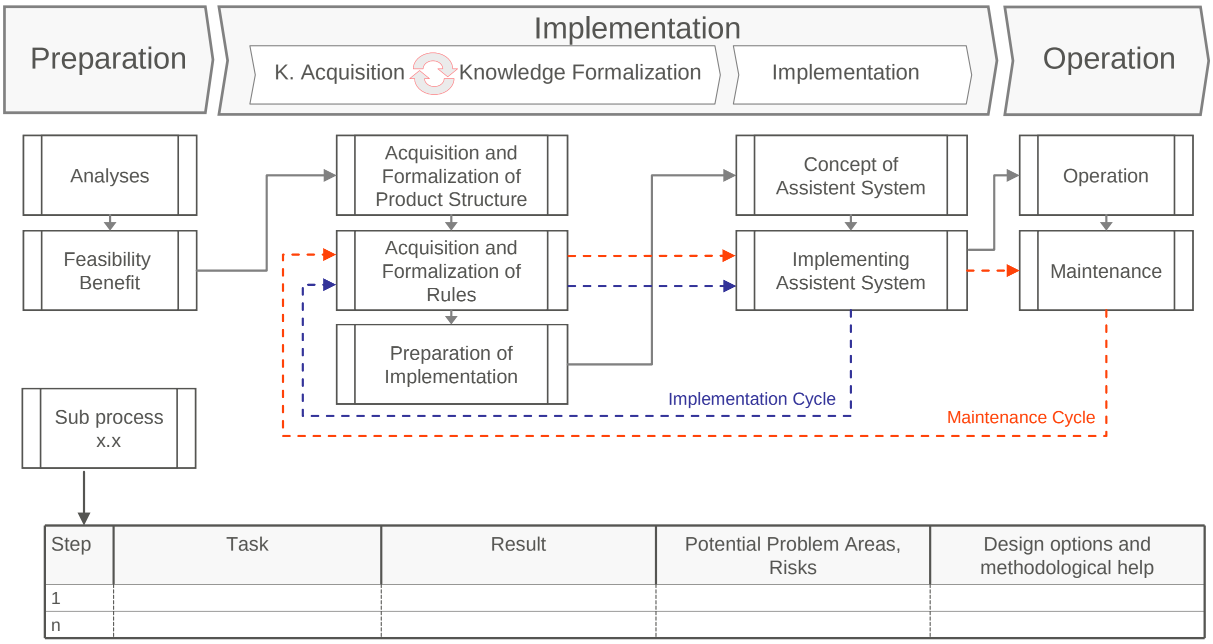

Figure 5. Holistic Procedure Method: Extended Process Model with methodological help for each process step.

3.2 IT-Support - Assistant for knowledge acquisition and knowledge formalization

The key element or respectivly the core function of IT support is the capturing, mapping, and transformation of expert knowledge (in the current case design knowledge) into a machine-readable form. From literature, numerous approaches to modeling knowledge of various kinds are known, e.g., [11][12]. In general, these models are created by a so-called knowledge engineer utilizing corresponding computer science methods.
Because of their ease of use and clarity, engineers widely use matrix methods for visualization and management of structures and relationships. The Design Structure Matrix (DSM) [13] as well as the Domain Mapping Matrix (DMM) provides an interactive dialogue platform with which experts (engineers) can work to establish rules for relationships. The rows and columns of the matrix represent the product components and the defined input parameters. This provides a good view of the structure as a whole, thereby assisting in defining the rules and relationships between the components taking into consideration the defined parameters. An assistant system (KAFA - Knowledge Acquisition and knowledge Formalization Assistant) extends the functionality of the matrix methods by providing a simple and intuitive means to enter the defined configuration and design logistics (Figure 6). To meet the demands of experts in the knowledge acquisition cycle, the basic idea is based on a division of the cell information into a formal and an informal section.

During knowledge acquisition phase, in a first meeting with the experts, the cells representing the cross-points of rows and columns will be systematically examined. If any possible constraints and relevant knowledge are acquired, a window can be opened to capture the information. A simple example is shown in Figure 6. Here, knowledge of the relationship between Component_2 and Component_n is captured. The window shows the already captured and defined attributes of the components. Component_2 has the attribute "Size" and Component_n has the attributes "Length" and "Width". Together with the informal description, a formal description (e.q. „If the Size is Small, then the Length of Component_n is 200mm") can then be coined. With this formal description and with the help of attributes and relationships, the rules can then be defined in the respective rule language (e.q. Size=Small->Length=200). The configuration model for a particular solution can then be automatically generated from the completed matrix together with all rules and the product structure which can also be generated with easy from the assistant system.

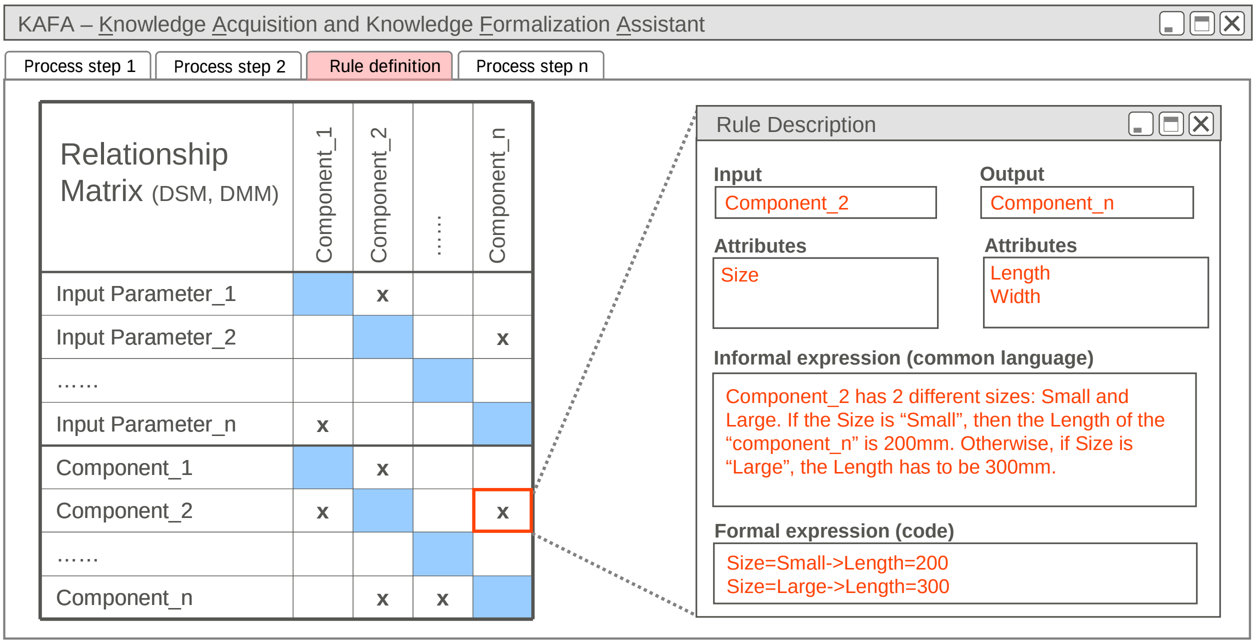

Figure 6. Concept View of KAFA (Knowledge acquisition and knowledge formalization Assistant) with extended knowledge object in DSM.

3.3 IT-Support - Federated Knowledge Base

The assistant system (KAFA) stores all collected information (product components, product structure, attributes, input parameters, rules, etc.) in a separate, system-independent knowledge base. Some of this information is stored in PDM systems and managed. Of particular importance are the variants that are well described in the material characteristics. During a configuration process, or independently (through construction or acquisition), new variants may arise. Since the inference mechanism (rule evaluation, conclusion) of each practical solution needs its own knowledge base which are initialized at startup, as a rule, these newly emerging variant must as a consequence, be constantly and manually managed by the knowledge engineer. One major challenge is is the question how the knowledge engineer would acquire information about the new configuration-related components. The solution approach to automation is a knowledge base developed for federated KAFA database (Figure 7).
The federated knowledge base acts as an integration component between the practical solution and the PDM system and ensures the updating of the application-specific variant tables. This can be done either at the start of the configuration by the application itself or in advance by an appropriate trigger function in the PDM system (such as parts-classification). The federated knowledge base may further act as a management system for all configuration models created, and represents the complete end product and expertise to build an IT support system. For automatic management of new standard components in the PDM system, further functions are required which must be considered after each configuration.

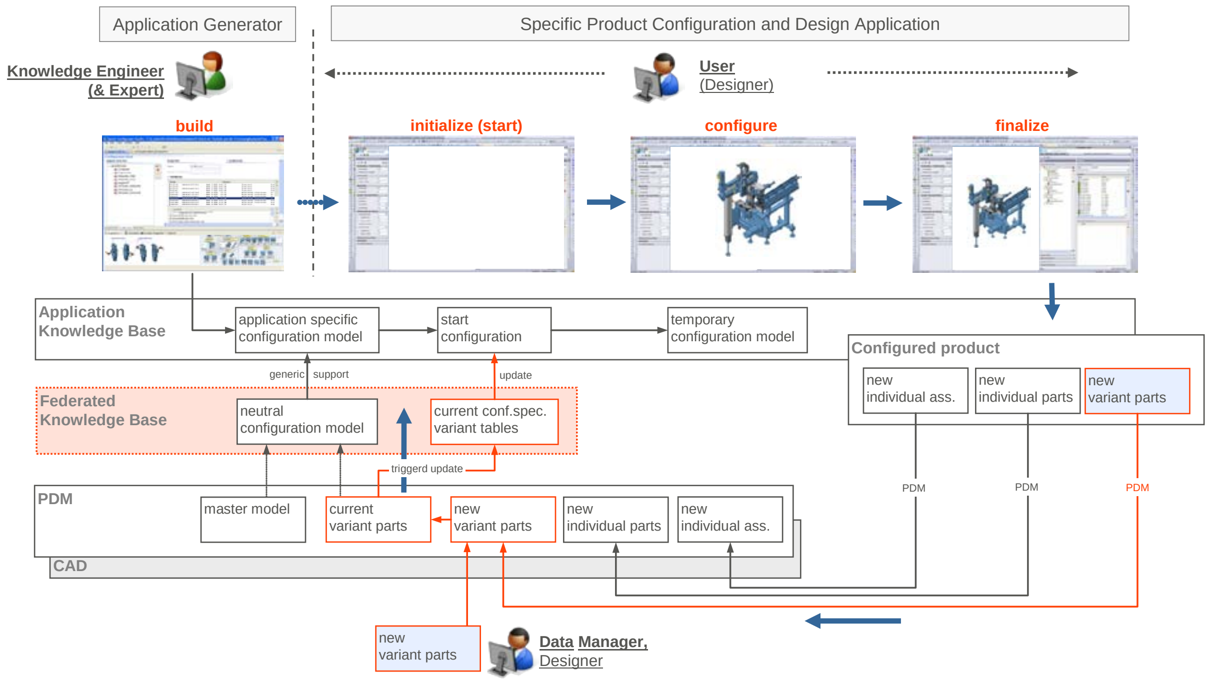

Figure 7. Concept of a federated knowledge base in the context of CAD, PDM, and other parts of a company's IT ecosystem

4. DESIGN AND IMPLEMENTATION OF THE ASSISTANCE SYSTEM

Using the framework described above, assistance systems for a variety of MTO or ETO production concepts can be created. The aim is always to support the product configuration and product design (PCD). Figure 8 shows a system context diagram with the essential building blocks. The base is in each case a PCD-market solution (e.g., KBE-System, Design Automation System, 3D product configurator system). This consists of an application generator and a specific PCD application created with the help of the framework.

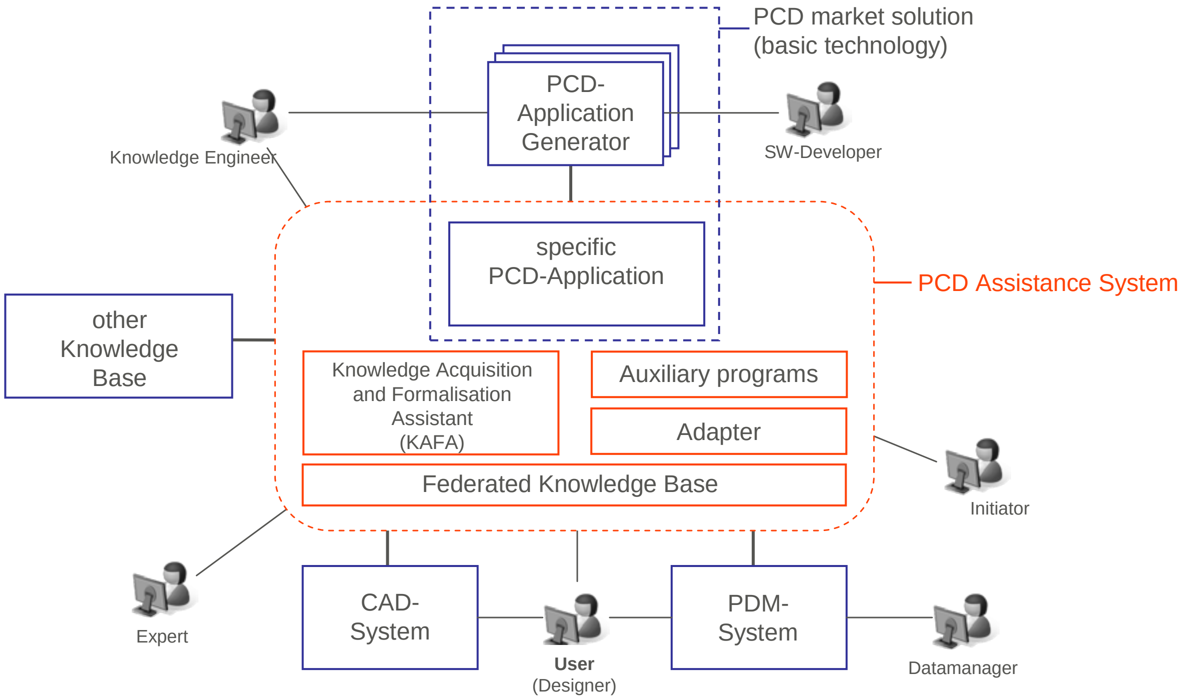

Figure 8. System Context Diagram for a PCD Assistance System

For seamless integration of a PCD application in the company specific IT environment, various interfaces and adapters are required. These tight couplings of CAD and PDM generate particularly high demands on those adapters. Furthermore, various assistance programs play an important role in the entire creation process. These are, for example, assistance to economic efficiency, knowledge documentation and CAD preprocessing. Together with the federated knowledge base, a holistic PCD assistance system is formed.

5. BENEFITS AND FUTURE PROSPECTS

The concept for the framework is currently in a prototype implementation. First validation in the work environment at Blum certifies the solution with practical benefits. In particular, the structured process model is used successfully as a guide for the systematic collection of product knowledge and expertise in new projects. For departmental managers, the identified problem areas as well as other design options form a basis on which commissioning decisions could be based.

The requirements for an equitable and practicable method for detecting and documenting dependencies are met to a large extend using advanced matrix methods together with the implemented extensions. Through a common view of the relevant IT support information, the existing communication gap between knowledge engineer and design engineer (expert) has been narrowed. In particular, the automatic integration of the PDM-based tool meets the important company requirement for a practical solution approach. The presented extensions are a major contribution to the rapid and efficient implementation of process innovations (customized tools and assembly systems) at Blum. This, simultaneously safeguards the design engineer’s knowledge for the company in an explicit form.

The demonstrated practical problems should also lead to further research in the field of knowledge based engineering design (e.g. standardized rule languages, practical configuration models).

REFERENCES

[1] Schomburg, E., 1980, *Entwicklung eines betriebstypologischen Instrumentariums zur systematischen Ermittlung der Anforderungen an EDV-gestuetzte Produktionsplanungs- und -steuerungssysteme im Maschinenbau*, Dissertation RWTH, Aachen

[2] Glaser, H., 1992, PPS - *Produktionsplanung und -steuerung. Grundlagen, Konzepte, Anwendungen*. 2. Aufl., Gabler., Wiesbaden.

[3] Schuh, G., 2006, *Produktionsplanung und -steuerung. Grundlagen, Gestaltung und Konzepte*. 3. Aufl., Springer, Berlin.

[4] Lindemann, U., Reichwald, R., Zäh, M. F., 2006, *Individualisierte Produkte. Komplexitaet beherrschen in Entwicklung und Produktion*, Springer, Berlin.

[5] Chapman, C., Preston, S., Pinfold, M. and Smith, G., 2007, Utilising enterprise knowledge with knowledge based engineering, *Int. J. Computer Applications in Technology*, Vol. 28, Nos. 2-3, pp.169–179.

[6] Stokes, M., 2001, Managing Engineering Knowledge. *MOKA: Methodology for Knowledge Based Engineering Applications, Professional Engineering Publishing*, Bury St Edmunds

[7] Lovett, P., Ingram, A., Bancroft, C., 1999, Knowledge Based Engineering for SMEs – *A Methodology, Proceedings of the 15th Annual Conference on Computer-Aided Production Engineering (CAPE’99)*, Durham UK.

[8] Ghoffrani, M., 2008, *Entwicklung und Einfuehrung eines flexiblen Softwaresystems zur Konfigurierung virtueller Produkte*, Dissertation, Universitaet Bochum.

[9] Colombo, G., Pugliese, D., Spurio, M. S., 2007, About the Integration between KBE and PLM, *Proceedings of the 14th CIRP Conference on Life Cycle Engineering,* Waseda University, Tokyo, Japan.

[10] Ehrlenspiel, K., Kiewert, A., Lindemann, U., 2003, *Kostenguenstig entwickeln und konstruieren*, Springer, Berlin, pp. 287 ff.

[11] Spur, G., Krause, F., 1997, *Das virtuelle Produkt. Management der CAD-Technik*, Hanser, München.

[12] Dengel, A. 1994, *Künstliche Intelligenz. Allgemeine Prinzipien und Modelle*, BI-Taschenbuchverlag, Mannheim

[13] *DSM web site*, http://www.dsmweb.org