

KNOWLEDGE-BASED METHODS FOR EFFICIENT MATERIAL HANDLING EQUIPMENT DEVELOPMENT

Dirk Jodin

Christian Landschützer

Graz University of Technology, Institute of Logistics Engineering

Abstract

This paper focuses on the Knowledge-based engineering (KBE) method and general Knowledge-based technologies for automated design of material handling products. As in vehicle and aerospace engineering this is a widespread technology, the authors try to introduce the main benefits of KBE for the material handling equipment design. The benefits of KBE, as faster and more accurate (safer) product development, customized products and knowledge of employees captured within a knowledge management system, let KBE hold many promising possibilities within, to deal with nowadays demands on engineering development, driven by cost reductions and time shortcuts.

The authors introduce the actual stage of KBE and its methodologies within engineering development complemented by some critical remarks. There will be shown three different examples of realized KBE projects for material handling equipment, focusing on different levels of automated system design. There's the fully automated design of wire rope drums, driven only by some few input parameters specified in a graphical user interface (GUI). Furthermore the automated basic assembly layout for drive components of an AS/RS is shown. The automated layouting and basic design work for shelves and AS/RS within a complete storage systems by a GUI driven input procedure shows the advantages of KBE, for here e.g. in a very fast basic layout design for early stage cost estimation.

The authors will give an outlook of forthcoming work and present ideas to develop an appropriate methodology or working environment for the use of knowledge technologies in material handling design. They focus on the necessary steps and sources to provide, capture and use engineering knowledge and will introduce ideas for software tools to support the use of captured knowledge in automated material handling design.

1 Introduction

Knowledge-based Engineering (KBE) is a well proven method for the development of components and machines. KBE combines the Computer Aided Design Process (CAD) with knowledge out of rules, formula and databases. So it's possible to create an automated or half automated design process. KBE tries to collect all information available in the product lifecycle to make it reusable. It's a technology able to merge capabilities of conventional Knowledge-based Systems with those of Computer Aided Design and Engineering. Hence it has to be a blend of artificial intelligence, CAD, mechanical engineering know-how and software engineering in its most sophisticated occurrence.

The well-known benefits are time and cost reduction and better quality in general. KBE is useful for redesign, for the development of variants and for quick changes of details. These are typical tasks in designing material handling equipment. So the development staff of the Institute of Logistics Engineering began to proof the possibilities assigning those methods to this area. The focus moves from components to equipment. Not only the development but the system design comes in the foreground. Technical solutions in logistic systems are the result of combining right machines of transport, storage, identification and handling.

Technical Logistic Systems are mainly determined by capacity and throughput so it's necessary to get an overall optimum dimensioning. In the opinion of the authors this is a strong reason to bring the method of KBE in this area. For example an automated storage-retrieval system (AS/RS or stacker crane) design will be formed by the needs of tote capacity and the throughput. The number of aisles, the size of the rack and the aisles are not a finding of design creativity but of rules and formula. Also the principle design of a sorting system like the number of merges, the number of terminals, the lengths of the conveyor, can be developed full or semi automatically by a Knowledge-based System. It would be better described by Knowledge-based Layouting (KBL) than KBE.

2 From Knowledge-based engineering (KBE) to extended-KBE (xKBE)

The chapter describes KBE and its actual stage, lists papers and literature sources and will lead from this actual stage towards a new classification of KBE tasks – the KBx approach – towards a new way how to collect and use data, information and knowledge for design automation, introducing the xKBE methodology.

2.1 Knowledge-based engineering - an overview

With 75 % of total product costs determined by engineering and design [7] this is one of the key fields for product cost reduction. To understand how KBE is an appropriate way it is necessary to describe design work and major steps of product development.

2.1.1 Design work and its development

Nowadays design engineer has to manage a huge load of data, information and knowledge for successful product design. Despite handling his CAD-system he should be expert in engineering calculation with tools and manually, CAE-simulation tools for simulation of strengths and dynamics, product data and lifecycle management systems (PDM and PLM). Therefore also having a good overview of production facilities, supplier capabilities and demands on product style brings multidisciplinary knowledge together in the person “design engineer”. Obviously not all those demands can be satisfied with the same quality. Thus very early approaches were made, to handle this load by creating intelligent systems that support the engineer within his familiar environment – the CAD-system.

With incipient 2D-CAD-systems part libraries took place to straighten product development but had only advantages in the reuse of previously designed parts like copy/paste. In the 1980ies easy calculation procedures were integrated in the CAD-system i.e. for shaft calculation or simple stress calculations. The next major evolutionary steps were the 3D-CAD-systems with parametric modeling. Now having geometry, parts and assemblies only represented by accessible parameters, design became more open to design-automation without storing amounts of static variants in huge libraries. The feature technology complements the parametric design by providing macro-like commands for widely used design operations. With strategies like top-down-design for large assemblies and skeleton-models, this is the way of design work until now and maybe for many further years.

Bringing those capabilities of CAD together with modern information technology, knowledge management and general knowledge engineering leads to the KBE-approach in various occurrences.

2.1.2 KBE systems

There are KBE systems integrated within CAD environment on the one hand (“augmented CAD”) and as an actual trend from aerospace and automotive industry “full KBE” systems (realized via object oriented special software tools) on the other hand. Various methodologies have been developed to implement KBE-technologies into engineering (detailed information within: [1], [2], [5], [6], [10], [11], [12]), but less of them were successful [23]. Realized KBE-solutions aren’t reported maybe therefore, as

the use and the know-how of the KBE-development is so sensitive, that major companies – wherein the authors know successful KBE-solutions – do not publish their strategies.

This section here tries to differ between different stages of KBE and introduces the methodology behind full KBE in form of MOKA [3], [4] with not focusing on software details. There are attempts to standardize KBE development via the creation of a common language, following the trend that CAD becomes more Knowledge-based with convergence of KBE and PLM [6]. Problems resulting from data conversion between CAD and CAE, producing large efforts as described in [12] by introducing a common data model, are not taken into concern here.

2.1.2.1 Augmented CAD-KBE

Augmented CAD-KBE is found in many different CAD environments and has different scopes of operation [5]. Well known commercial products are Knowledge Ware within CATIA and Knowledge Fusion within NX [2]. It has the major advantages, within the scope of semi-automated design. First that there are no complex data interfaces between various software environments and second that the design engineer is the expert for KBE-development, understanding demands and use of the KBE-solution better than any software-engineer. But all approaches together have some common partly negative characteristics:

- No full generative modeling and therefore manual adjusting effort.
- No exploitation outside their KBE language and therefore not web-based frameworks.
- Lots of editing effort and “unfriendly” scripting languages.
- They only do better donkeywork and are non-reactive to new technologies.

But beside all those factors of limitation it’s always a decision with consideration of intellectual and monetary effort, which features are must haves and which are complementary. An investment into a full KBE system is nowadays only seen in automotive and aeronautic sectors [8] with their fast innovation times as subsumed in the following statements [2] for KBE:

“Jaguar cars reduced the design time for an inner bonnet from 8 weeks to 20 minutes.”
“British Aerospace reduced the design time of a wing box from 8000 hours to 10 hours.”

2.1.2.2 Full-KBE - the MOKA-methodology

Full-KBE systems work as highly advanced object-oriented software programs which apply knowledge to design processes by using different visualization tools [1]. The systems must drive the way of design automatically by using various validation rules and should not criticize pre-generated results leading towards engineering process automation. Depending on the state of detail regeneration full-KBE must not follow every modification (i.e. FEM meshes must not regenerate during design work). To

visualize dependencies and relationships the hierarchical tree is used (comparable to BOM) with its physical properties via objects and sub objects.

The functionality of the KBE-development process and major steps therein is described here, following the Methodology and tools Oriented to KBE Applications – MOKA [3, 4, 11] (used for development of the commercial software PCPACK [13] and used by Airbus and Fokker; with aerospace industry as one of KBE key user [9]). MOKA is a standardized method from the late 1990s, to reduce lead-times and costs of KBE development and provides a methodology for developing and maintaining KBE systems [2]. It is structured in six phases:

1. *Identify:*
defining scope and purpose of KBE with assessing the technical feasibility.
2. *Justify:*
assessing the risk, estimating resources and costs and developing business cases.
3. *Capture:*
means knowledge acquisition from experts to create an informal model as a structured representation of forms. This informal model can be used to create a knowledge management (KM) and splits up into an informal product model (representing the product structure with constraints) and an informal process model which captures design engineers activities and all rules of each stage.
4. *Formalize:*
uses the informal model from the capturing process. To build the formal model it's necessary to use a graphical, object oriented representation of engineering knowledge one level above application code, written in the modeling language i.e. MML the MOKA Modeling Language. The formal product model specifies the knowledge items from informal model with different views focusing on structure, function, behavior, technology and geometric representation. The design process model is the process flow of the KBE system, taking into account the constraints, the operating system and the types of specialists involved in the process.
5. *Package:*
means generating, testing and debugging code of the formal models.
6. *Activate:*
means distribution of the KBE system to end-users and training.

Beside MOKA further methodologies are mentioned in brief without description, as they are following quite similar phases. There are also KOMPRESSA [23] from Coventry University, KNOMAD [22] and DEE [22] from Technical University Delft.

2.2 General remarks on KBE

The two following paragraphs are a synergetic view of Verhagen's broad literature review [11] with the main focus to identify actual stage and shortcomings, general literature resources as mentioned and experiences of the authors in generating the solution described in chapter three and discussed with many engineering experts from various branches.

2.2.1 Actual stage, shortcomings and challenges of KBE

As VDI 5610 [18] describes capturing knowledge from the engineering experts is one of the main important but also difficult tasks in building the basis for a KBE-system by collecting data, forming it into information to make it reusable knowledge – MOKA step 3 (see 2.1.2.2). Depending on appeals by the management the engineer has it in hand, how much and what kind of information and knowledge he wants to reveal. Once knowledge is captured by interviews, its formulation and implementation isn't as critical as the capturing itself. But capturing knowledge for (automated) reuse can be seen independently from developing a KBE-system, wherein the authors will introduce their demands in chapter four.

As Material Handling Equipment Design and Engineering isn't as well equipped with manpower as engineering in automotive and aerospace industry, it isn't astonishing that KBE and all its fields of developing and application are rooted in those branches. KBE-solutions in the material handling world are used, but can only be seen as augmented CAD-KBE (chap. 2.1.2.1) with automation of time consuming "donkey-work".

Trying to close the gap between full-KBE and augmented CAD-KBE it is necessary to sketch the actual stage and to define future prospects. The actual stage can be subsumed in five points, which are the key findings of Verhagen's literature review of about 500 research and application papers [11].

1. Nowadays KBE is case-based ad hoc development of KBE applications and more improvisation than use of methodologies. Therefore the impact of methodologies seems limited!
2. A tendency toward development of 'black-box' applications can be seen with knowledge being used without context.
3. There is a lack of knowledge re-use especially for higher-level knowledge (project constrained reasoning, solution generation strategies...) which often remains not captured. Reasons are no data exchange standards and design being the only transfer instance.
4. There's a failure of KBE cost assessment.
5. There isn't a (quantitative) framework to identify and justify KBE development, which specifies criteria for suitable tasks for KBE.

All those findings meet with the authors perspectives and findings of realized KBE-solutions and those seen in companies of the material handling sector. This leads to some research and development challenges, to make KBE useable in everyday engineering business:

1. Methodological support [11]: Methodologies must merge from case-based development of methodologies to methodology-guided projects, support by good tools (where actually a lack of them can be identified). They should provide automatic conversion from informal and formal models and a good “round-trip” for maintenance.
2. Making tools more useable for engineers: As developed by software-engineers, common full-KBE tools don’t meet engineer’s way of thinking (seeing products structured in form of Bill of Materials and represented in modern PDM-systems more than in small software-input-boxes).
3. Moving beyond black-box application [11]: Engineering knowledge must be decoupled from software code. Key technologies are seen in the use of semantics to re-use existing domain knowledge models in single apps instead of rebuilding them.
4. Material Handling Equipment Design and its engineering is different in various ways from Engineering in automotive and aerospace sector, where design tasks are often repeating in form of adoptions of previously used designs (i.e. when the actual car generation has to be replaced, the principle design structure of a car remains the same). In material handling engineering one has to differ tasks into three layers of engineering which will be introduced in chapter 2.3 – the KBx approach.

KBE can be seen as a way of working, to meet nowadays demands on engineering, where retention of knowledge is critical. If systems become more transparent with good knowledge re-use and if the full automation of every design task isn’t the major goal (like attempts of finding the solution of a button-pressing-design-generation-software in the 1990ies), KBE is an appropriate way to do engineering work in Material Handling Equipment Design.

Therefore the authors introduce considerations about the effectiveness of design automation by KBE in different areas of Material Handling Equipment Design in chapter 2.3.

2.3 The KBx approach and the xKBE-methodology

To make KBE successful it’s necessary, as a key result of literature review, to differ between the various degrees of automation in design work. Design work in material handling is completely different if one has to design a wire-rope drum or if one has to layout a complete storage system. There are certain tasks more or less predestinated for

KBE so that with a determination that reflects this degree of automation the authors will talk about KBx. The manifestations of automated design in KBx will then have a clear database, interconnections and goals for varying applications. Focusing on the three successfully realized applications of design automation in chapter 3, and assessing efforts of building automated designs, the authors introduce a way to differ between Knowledge-based:

- Engineering (KBE)
- System Design (KBSD)
- Layouting (KBL)

which have very different scopes of use, functions, powering knowledge and application (table 1).

Table 1: KBx-definitions

		KBx		
		Knowledge-based engineering approaches at different detail design levels		
		KBE Knowledge Based Engineering	KBSD Knowledge Based System Design	KBL Knowledge Based Layouting
traditional KBE	scope of automated engineering	components, parts, machines	machines and systems	systems
	functions	full automated (detail) design of parts and subassemblies	full automated master and layout design of assemblies and systems, specification of machinery	full automated layouting of systems, specification of systems
	use for	- customizing machinery - tailored products - product families	- dimensioning motors - defining interfaces - CAD top-down design - CAE models (structural, dyn.)	- space requirements - early cost estimation (bidding) - drafting bill of material
	CAD domain	detail geometry models	reduced geometry for CAE	shrink wrap geometry for layout
	data, information and knowledge sources (beside employee know how and workflows)	- standards, best practice - production facilities - manufacturer data engineering theory	- standards, best practice - supplier and engine data eng. and mechanics theory	- standards, best practice - manufacturer database - customer rel. management logistics theory
	practical applic.	wire rope drum chapter 3.1	AS/RS chapter 3.2	HRL-tool chapter 3.3
xKBE	2.0 knowledge sources	web services, online databases, knowledge management systems		
	2.0 technologies	wikis, semantics		
	practical applic.	tagged standards and technical docs, relation matrices (chapter 4)		

The by interviews captured knowledge (necessary to develop KBx solutions) in form of best practice, CAD-methodologies and general engineering know-how meets with those from standards, knowledge-databases (like company wikis), supplier data and PLM-databases for CAD. These are the powering sources of data, information and knowledge which are the informal base for development of a KBx-solution. With every

material handling design solution driven by the two main parameters throughput and capacity, the various sources of knowledge for KBx can be seen in table 1 as an information basis.

Bringing all those information together makes common known KBE more powerful and better structured for development and maintenance. Retaining on the wide spread expression “KBE” the authors will name the new methodology, bringing together different classes of information, extended KBE (abbrev. xKBE). xKBE can be seen as a way how to and where from recovering information, how to merge it with information from other instances (classes). It’s neither a fixed process nor a complete methodology but a way of thinking and bringing information together, to support the design engineer with accurate information at the right stage in the design process. Thus it can be seen as a technical book 2.0 or a Knowledge Management System with connection to engineering. xKBE is now the data, information and knowledge basis and the way how to use it that can power automated design solutions for KBx. Chapter 4 will introduce some demands for a software (the xKBE-app), how to work with xKBE out of an engineer’s way of use and view.

3 Three successful applications using Knowledge-based technologies

Three by the authors realized projects for automated design solutions are shown in brief to demonstrate differences in knowledge technologies implementation depending on the stage of detail, underlining the classification of KBx.

3.1 The wire rope drum (KBE)

This full KBE-solution starts with a GUI specifying only the main parameters for the rope design [17], [20], [21]. The whole calculation and design process, using different standards [15], [16], is implemented in the calculation program which delivers steering parameters for CAD-detail assembly and part design.

Wire rope drums are a good example of how KBE can work and lead to success. The number of variants isn’t really big and many design features are regulated by national or international standards. Figure 1 shows possible variants of the rope drum for chocking a first layout step.

As the xKBE-methodology postulates data, information and knowledge must be brought together in a user friendly way with good documentation, this is realized for the wire rope drum KBE in different levels of design depth. Several GUIs lead the engineer towards the fully automatically generated drum by specifying principle data first (drum type selection according to figure 1 and configuration in figure 3 a)) and finally editing some detail design parameters before ending the process. This means i.e. adjusting some chamfers or roundings, which aren’t important for technical functionality and therefore

causing too much effort for automation (figure 3 b)) remain manual effort, supported by from the KBE-solution provided information.



Figure 1: Variants of wire rope drums.

The overall success of a KBE-solution is, as mentioned above, a direct function of finding the necessary degree of automation and ends here with manual work. The overall development time of a fully calculated and approved drum could be reduced with the use of this KBE-solution from four weeks to five hours.

As every calculation or database selection can't or shouldn't be done in the CAD-environment, several other software has been used as shown in figure 2, to make the captured knowledge more accessible. This figure also shows the interconnections of software domains.

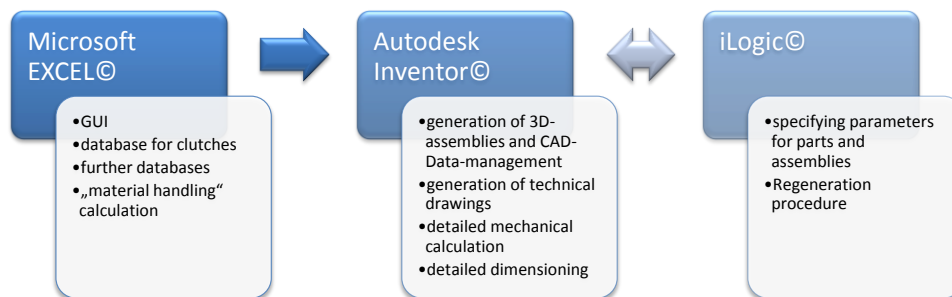


Figure 2: domains of KBE for wire rope drum.

3.2 The AS/RS (KBSD)

This chapter describes the automated dimensioning of drive parts of an AS/RS which are mainly determined by performance parameters resulting from throughput-demands such as maximum speed and acceleration and is therefore a good example for KBSD [19]. This augmented CAD-KBE-solution is realized for PTC ProEngineer© assemblies. The solution delivers master assemblies and skeleton models for CAD top-down-design. Furthermore all dynamic loads for dimensioning the major structural parts and drives are calculated. Figure 4 shows the main process behind this KBSD-solution to generate also a 3D-draft model for drive dimensioning, reduced FEM-geometry generation and estimating a bill of material (BOM) in an early design stage.

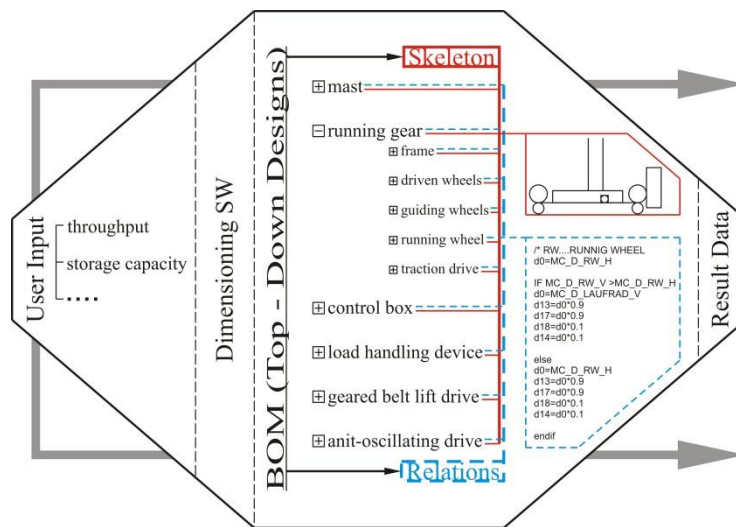


Figure 4: KBSD process of an AS/RS.

Three main calculating processes behind the KBSD (figure 4), with captured knowledge from general and specific standards, are realized and PTC MathCad® for a convenient use and good documentation:

1. Evaluating the drive power (traction drive, lift drive) and decision whether or not anti-oscillating drive is necessary (depending mainly from mast height) using guidelines [14].
2. Sizing of the general machine elements (geared belts, bearings, gear boxes, screws...) using manufacturers' instructions and engineer standards.
3. Dimensioning of machine parts such as beams, sheet metals, shafts, welding seams [15].

Necessary preliminary calculations are made on basis of multi body dynamics for figuring out dynamical loads on all automatically engineered elements and parts from calculation process two and three (figure 5 b)).

Figure 5 a) shows the stage of detail as delivered from the KBSD-solution, here depicted as a 2D-wirframe-drawing. One can see the major parts and dimensions, which are adjusted automatically as well as whole subassemblies are added or not if needed (the top-anti-oscillating drive).

According to table 1, the AS/RS is a good demonstration how KBSD works and is used. It isn't in practical use yet, but has potentialities within to straighten the customization process of AS/RS for tailored customer solutions within a manufacturer's portfolio. As general design of such machinery doesn't change any years, the degree of design automation seems appropriate according to the KBx-approach, holding effort and benefit in balance.

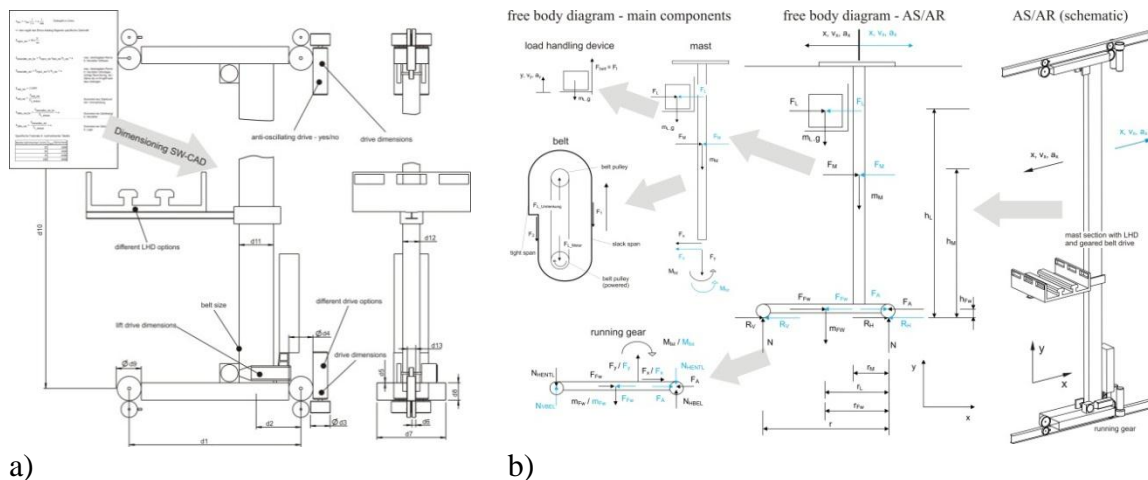
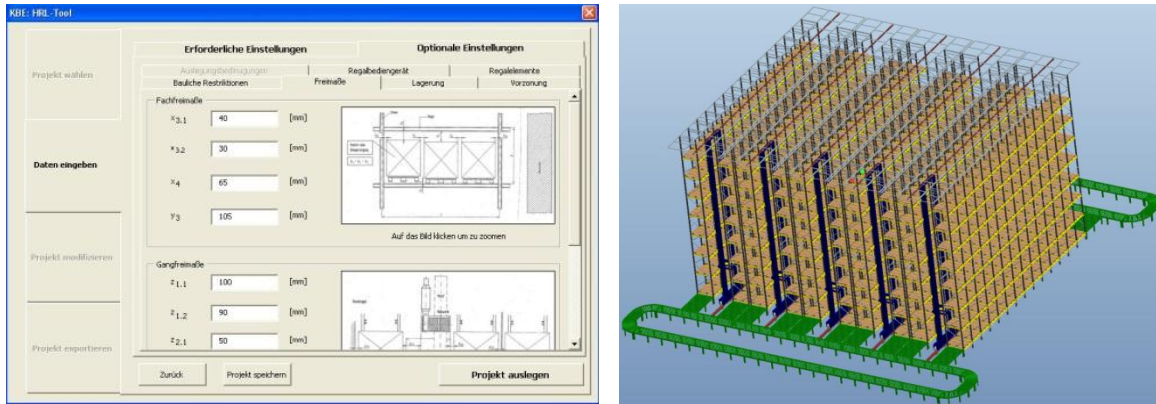


Figure 5: a) main assembly with control dimensions,
b) free body diagram for KBSD of an AS/RS.

3.3 The storage system with the HRL-app (KBL)

The HRL-app is a Knowledge-based Layouting application for ProEngineer© for rough planning of AS/RS storage systems basing on a large database including 123 AS/RS-systems from 14 manufacturers [24]. It allows choosing from this wide database-set and delivers exact throughput as well as all major dimensions and a partly filled draft of BOM of the whole storage system including shelves by specifying only desired capacity, throughput and type of load carrier. Therein a complete new CAD-assembly with top-down-design is generated which easily allows to check the necessary design space and provides a rough view of required parts in an early stage of system design (BOM). The HRL-app works project-based and allows managing various sets of different drafts for a specific logistic scenario for final comparison. Suggestions for the optimum use of manufacturer's machinery are made by the HRL-app, by only defining the maximum



a) b)
 Figure 7: a) CAD-screenshot of HRL-app AS/RS-storage system generation
 b) input GUI for manual input of aisle and bin dimensions.

4 A framework for applying KBx-design: ideas for the xKBE-app

All common known methodologies for KBE as described in chapter two are customized for aerospace and automotive engineering with their large staff of developing engineers and highly developed CAD and CAE IT-structure. As literature review has shown, there's a lack of qualitative KBE development with actual KBE-solutions developed as black box applications. The authors will sketch some ideas for adapting those technologies to Material Handling Equipment Design with automation in a three-level approach (KBx) for detail, machinery and system design. The way to merge data, information and knowledge from various sources (table 1), necessary to develop automated design as KBx, has been named xKBE. To manage all this information demands and ideas for the xKBE-app are outlined here, for further development with software specialists.

4.1 Challenges and demands for the xKBE-app

As key findings from the development process of the three KBx solutions in chapter 3 the authors identified:

- Handling the powering data, information and knowledge:
 - Only a small team can interact, having widespread engineering information (design, manufacturing, layouting, cost calculation) not captured in knowledge management systems to meet within the responsible engineers.
 - Knowledge is fixed in CAD or steering software (EXCEL, MathCad) and is underlying data format problems of different software versions.

- The knowledge isn't accessible outside those software and doesn't come together with demands of companywide knowledge reuse (i.e. in form of wikis...).
- Documentation becomes an additional effort without knowledge reuse.
- Deriving steering rules:
 - There are too many rules, to manage them with "non intelligent" systems, as i.e. by static data model diagrams, or mind maps... [20].
 - Various different stages of reasonable and economic use of automated design work (KBE, KBSD, KBL = KBx) needs different details of knowledge retrieval by automated systems
 - The developing engineer must not see each available information to derive steering rules and calculations (i.e. searching for standards in web-based sources delivers as many as possible but not the best available information).
- Material Handling Equipment Design
 - has long life(innovation)cycles but often very customized products (more KBL than KBE).
 - has different demands on CAD-models (use in design, styling, simulation, mock-up, visualization/animation).
 - standardization in design for efficient purchase competes customized and tailored solutions, often promoted by sales department.

All these challenges must subsume with those common known ones from chapter two making KBx successful in Material Handling Equipment Design.

4.2 ideas and intended scope of use of an xKBE-app

The xKBE-app which can be seen as the technical book 2.0 and working environment for the use in KBx-solution development, bringing Knowledge Management and Knowledge-based engineering together: xKBE-app = KM + xKBE for developing KBx-solutions.

Powering sources for the xKBE-app (*S*), technologies (*T*) and use cases (*UC*) can be:

- *S*: web databases (common parts)
- *S*: special know how from wikis or technical databases (ebooks, best practice guides, methodologies...)
- *S*: captured and formalized knowledge of employees
- *T*: web server architecture for powering database, including all rules and relations.
- *T*: semantic web technologies enabling different detail depth of presented information - (a good principal overview in [26])
- *T*: categorizing knowledge and rules in classes, adapted from xKBE knowledge

- *UC*: mandatory graphical visualization of simple database relations:
 - relation graphs,
 - filtered views (classes),
 - ontology and arrangement views
 - layers for viewing representing classes of rules
- *UC*: different ways of use/work process:
 - change management,
 - project view,
 - documentation,
 - development of rules!

Figure 8 shows some first expressions of how the xKBE-app should look like. The actual stage of realization is powered by an apache web-server with a web-browser-based front end (GUI) and will remain draft for internal use at the institute. Figure 8 is graphic only, the actual front end isn't quite well designed. A scheduled use case in the near future is administration of technical standards in Material Handling Equipment Design, to show interconnections between documents and classification of them. Therefore many available electronic resources are analyzed, tagged and categorized partly automatically to build a first database within xKBE. This solution will be more powerful than common literature administration tools, by providing manual applicable filters beside of full text search.

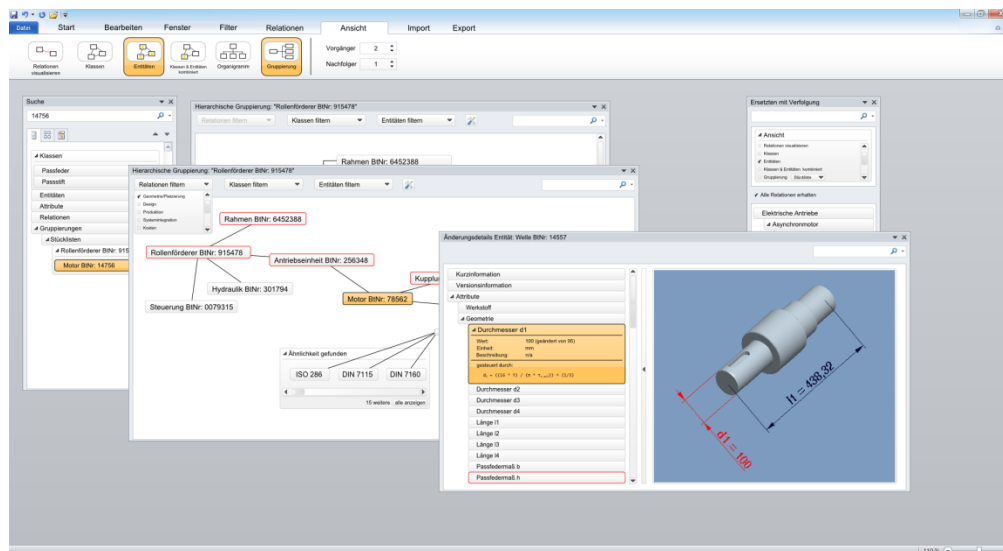


Figure 8: possible look and feel of an xKBE-app (in german), showing the change process of a main drive leading to changes in shaft dimensions, with additional views of required information (standards, supplier, integration in assemblies and machinery).

Examining the whole development of the xKBE-app the major responsible part of the institute can be seen in the development of xKBE-apps contents. Much principle work has been done here analyzing several machinery from material handling in regard to the use in KBx. The other responsibility of the institute in this project will concern the look and feel – suitable for the development-engineer (designer) – of the app more than technical realization of the underlying information technology. The realization seems to be a highly advanced software project to be possibly realized with partners at Graz University of Technology. Commercial tools with adequate functions are barely available from aerospace sector, but are very much customized for i.e. cabin design [25]. Therefore the authors see possible fields of interest in general engineering design for the xKBE-app.

The overall scope of functionality of the xKBE-app finally depends on how the addressed user will use the app. When filled with company specific information beside general technical information and supplier databases the xKBE-app will then provide the engineer with appropriate information at nearly every stage in the KBx development process.

5 Outlook

The further research in extended KBE (xKBE) can be seen horizontally and vertically (according to table 1). Horizontally will mean determining and examining various technical logistic equipment for use in xKBE. Actually there are investigations in Sorting-Systems [27]. Vertically will mean proving ideas in the area of Knowledge Management (chapter 4), structuring of basic expertise and know-how and defining use cases.

References

- [1] Canals, N. S., *KBE – KNOWLEDGE BASED ENGINEERING*, Rapid Product Development RPD 2006, Aida, S.L. (2006).
- [2] Milton, N., *Knowledge Technologies*, Polimetrica S.a.s., Monza (2008).
- [3] Brimble, R. and Sellini, F., “The MOKA Modeling Language, Knowledge Engineering and Knowledge Management Methods, Models, and Tools,” *Lecture Notes in Computer Science*, Vol. 1937/2000, 49-56 (2000).
- [4] Public Annual Report (MOKA EP 25418), available at:
<http://web1.eng.coventry.ac.uk/moka/Documents/reports/publicreport98.pdf>,
accessed: 2011-04-26.

- [5] Cooper D., van Tooren M. and Mohamed, W. M. W., “Keys to Success with Knowledge-based Techniques,” *Proceedings of the Wichita Aviation Technology Congress & Exhibition*, SAE 2008-01-2262, 1-14 (2008).
- [6] Fan, I.-S. and Bermell-Garcia, P., “International Standard Development for Knowledge-based Engineering Services for Product Lifecycle Management,” *Concurrent Engineering*, Vol. 16, No. 4, 271-277 (2008).
- [7] Chapman, C. B. and Pinfold, M., “Design engineering—a need to rethink the solution using knowledge based engineering,” *Knowledge-Based Systems*, Vol. 12, 257-267 (1999).
- [8] D. Cooper, G. LaRocca, Knowledge-based Techniques for Developing Engineering Applications in the 21st Century, available at: www.genworks.com/downloads/kbe2007.pdf, accessed: 2011-04-26.
- [9] LaRocca, G. and van Tooren, M., “Enabling distributed multi-disciplinary design of complex products: a knowledge based engineering approach,” *Journal of Design Research*, Vol. 5, No. 3, 333-352 (2007).
- [10] Lovett, P. J., Ingram, A. and Bancroft, C. N., „Knowledge-based engineering for SMEs a methodology,” *Journal of Materials Processing Technology*, Vol. 107, 384-389 (2000).
- [11] Verhagen, W. J. C., Bermell-Garcia, P., van Dijk, R. E. C., Curran, R., “A critical review of Knowledge-Based Engineering: An identification of research challenges,” *Advanced Engineering Informatics* (2011), doi:10.1016/j.aei.2011.06.004.
- [12] Gujarathi, G.P. and Ma, Y.-S., „Parametric CAD/CAE integration using a common data model,” *Journal of Manufacturing Systems* (in press), 2011.
- [13] PCPACK 5, available at: <http://www.epistemics.co.uk/Notes/207-0-0.htm>, accessed: 2011-04-26.
- [14] Rules for the Design of Storage and Retrieval Machines, available at: <http://world-of-engineering.eu/dl/FEM9.311%20Engl.pdf>, accessed: 2011-04-28.
- [15] Shafts and axles, calculation of load capacity, available at: <http://www.beuth.de/langanzeige/DIN-743-1/de/25916415.html>, accessed: 2011-04-28.

- [16] DIN 15020-1: *Hebezeuge; Grundsätze für Seiltriebe, Berechnung und Ausführung*. Beuth, Berlin (1974).
- [17] Thoresson, J., *Knowledge Based Engineering of Hoisting Drums*, Master Thesis TU Graz, Graz (2010).
- [18] VDI 5610 Blatt 1: *Wissensmanagement im Ingenieurwesen; Grundlagen, Konzepte, Vorgehen*. VDI, Düsseldorf (2009).
- [19] Landschuetzer, C, Jodin, D. and Wolfschluckner, A., “Knowledge Based Engineering – an approach via automated design of storage/retrieval systems,” *Proceedings in Manufacturing Systems*, Vol. 6, Bukarest (2011).
- [20] Landschuetzer, C and Jodin, D., „Knowledge-Based Engineering (KBE) für Hubseiltrommeln,“ *Kranfachtagung*, 20, 35-52 (2012).
- [21] Landschuetzer, C and Jodin, D., „Knowledge-Based Engineering in der Technischen Logistik,“, *Hebezeuge und Fördermittel*, 52, 38-41 (2012).
- [22] Curran, R., Verhagen, W. J. C., van Tooren, M. J. L, van der Laan, T. H., “A multidisciplinary implementation methodology for knowledge based engineering: KNOMAD,” *Expert Systems with Applications*, 37, 7336-7350 (2010).
- [23] Lovett, P. J., Ingram, A. and Bancroft, C. N., “Knowledge-based engineering for SMEs - a methodology,” *Journal of Materials Processing Technology* 107, 384-389 (2000).
- [24] Pichler, A., *Knowledge Based Engineering of Storage Systems*, Master Thesis TU Graz (in press), Graz (2012).
- [25] PACE product matrix, available at:
<http://www.pace.de/products/product-matrix.html>, accessed: 2012-04-03.
- [26] Reichenberger, K., *Kompendium semantische Netze*, Springer, Heidelberg (2010).
- [27] Landschützer, C., Jodin, D. and Fritz, M. „Knowledge-based Engineering and modern CAE for sorting systems,“ *Proceedings in Manufacturing Systems*, in press, Bukarest (2012).