Application of knowledge-based engineering methods for standardization and quality assurance in ship structural design

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SYNOPSIS

Within the research project KonSenS, the prospect of knowledge-based engineering applied to ship design is analyzed. With an improved integration of knowledge, geometry and manufacturing information an improvement in product quality is achieved. A reduction of design time as well as manufacturing costs can be reached. Series effects can be explored. The integration of KBE methods into CAD systems allow for automatic quality assurance. For standardized tasks decision support is given.

INTRODUCTION

The development process in the maritime industries is characterized by a complex interaction of many partners working in parallel. From the initial concept up to the final design diverse and often conflicting requirements need to be taken into account. This requires a constant exchange of a significant amount of information. Also, shipyards are faced with high requirements regarding quality. Methods for quality assurance in design and production have to be developed.

Today, in the CAD/CAM environment there is no close integration of the knowledge and information needed to develop the final design with the geometry and manufacturing information used for production. While the latter is handled with sophisticated CAD/CAM solutions, for the former a diverse range of applications and methods is used.

As a result, the information needed by the designer is available in different formats and from different sources. Often, media breaks require that the information given e.g. in a document is interpreted by the designer and applied in the appropriate context. With such procedures there is not only an increased risk of misinterpretation. Also, knowledge reuse in the design process as well as

Authors' Biographies

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automatization is prevented. Search and retrieval of information is time consuming; the diverse range of knowledge sources present in the industry today increases this problem.

Knowledge-based systems are applications that capture the knowledge available for a problem domain and consolidate this knowledge in a machine-interpretable way. A "single source" solution is achieved hereby integrating documentation, knowledge and the CAD model in one location. In ship design these systems can be used e.g. to document best practice recommendations or for standardization and automatization purposes, see [1].

Thorough and sound documentation is a preventive means for quality assurance. Standards help to apply high quality solutions to specific problems. Also, peer-review within a department as well as external review, e.g. by a class society, is used to assess and guarantee the quality of existing solutions.

With knowledge-based systems preventive quality assurance is not restricted to the documentation of best practice recommendations and standardization. With an integration into a CAD system, measures can also be taken to support the selection of high quality solutions within a CAD system or via Stand-aloneClients.

In the collaborative research project KonSenS the University of Rostock is working on the problem of modelling requirements and algorithms needed in ship structural design. With the help of knowledge-based methods the objective of this project is to achieve an enhanced automatization and a higher quality of the final product. Means for preventive quality assurance are developed.

In this paper the use of knowledge-based applications for ship structural design is examined. Based on a formal introduction to knowledge and quality, the use of KBE in a networked environment and for quality assurance is demonstrated. Methods for integrating documentation, standards and the CAD model are shown; means for automatization or preselection of best practice standards are explained.

KNOWLEDGE, QUALITY AND THE DESIGN PROCESS

Knowledge

As in all other engineering processes, in ship design one factor that determines the result is knowledge [2]. Today, with the focus placed on high quality, low costs and a short time to market, a thorough and extensive understanding of all possible aspects is a key factor for success. A lack of understanding may lead to cost intensive effects at a later design stage, in production or in operation. But what is knowledge?

Knowledge is comprised of individual pieces of information called facts. A fact is an atomic entity, i. e. an entity that is self-supportive and not related to other entities. Information is defined as a collection of facts with additional relationships and rules between facts. This network of facts defines the information base.

Using deductive reasoning and experience the essence of the information is extracted from the information base leading to knowledge. Here, experience represents knowledge the designer has gained e.g. from . previous reasoning, experiments or observations. Therefore, the extraction of knowledge is always bound to the background of the person. Different conclusions may be drawn from an identical information base.

From a theoretical standpoint different types of knowledge can be identified. These are:

- Structured knowledge: given in a predefined format; additional meta-information available
- Unstructured knowledge: no predefined format available; understanding requires additional knowledge about the context not stated explicitly
- Explicit knowledge: described using facts and relations
- Implicit knowledge: a common understanding of a team; not stated explicitly

In a collaborative environment the constant exchange of information and knowledge is mandatory. As mentioned above, knowledge is extracted from an information base. Hereby, the information given is set in relation to already existing knowledge, the context and the problem at hand.

For an effective exchange of knowledge in a company precautions should be taken to optimize a formalized representation of information required for operation [3]. This enables the employees to search for and acquire knowledge in a structured way. Structured knowledge with additional meta-data gives a machine-interpretable representation. Also, the extraction of implicit individual knowledge from key persons and its preparation lead to a reduced dependency on these persons.

In the marine business a formalized representation of knowledge can also be used to simplify the reuse of proven solutions and to document quality standards.

Quality

Today, quality is an important factor in shipbuilding determining the success of a shipyard. Here, the shipyard needs to satisfy the expectations of the contractor with respect to the quality of design and manufacturing; performance criteria have to be met.

In general, quality is an indicator depicting to what extent a chosen solution is able to satisfy a given set of requirements. For vessels performance criteria are defined by conditions imposed on the vessel by external factors, e. .g.

- the operation profile (e.g. cargo capacity, range of operation, ship speed)
- the conditions of operation (e.g. environmental loads, maneuverability)
- competitiveness (e.g. cost of operation, maintenance)

Mostly, these requirements are defined by the contractor. As a result the design needs to satisfy additional requirements to cope with the external requirements, e.g. with respect to:

- fatigue, strength
- compartmentation

All these requirements have to be addressed in the design. Solutions must be developed to satisfy the performance criteria without introducing negative side effects. Often, a compromise needs to be found. Here, the design quality is a (subjective) indicator that shows how good the respective compromise is.

In addition to design quality the quality of the final product, the ship, depends on the manufacturing quality. This describes whether the final product can live up to the design solutions developed.

While on modern shipyards manufacturing quality is rarely an issue, design quality is an import factor that determines competitiveness. For this purpose, shipyards apply quality assurance methods to guarantee and improve the quality of the final product. These are:

- Standardization and documentation of proven solutions
- Ongoing internal review of the design work performed
- External review of the design, e.g. by class societies
- Local and global simulations and numerical calculations

In general, the methods for quality assurance can be classified into two categories. Preventive quality assurance is used to identify proven high-quality solutions and to define the fields of application. With these methods the probability of suboptimal design decisions is reduced before work on the design is carried out. Quality testing is used to verify an existing solution with respect to design errors or suboptimal solutions. If necessary, the existing design is modified and retested. The application of quality assurance methods in the different design stages in ship design is shown in Fig 1.

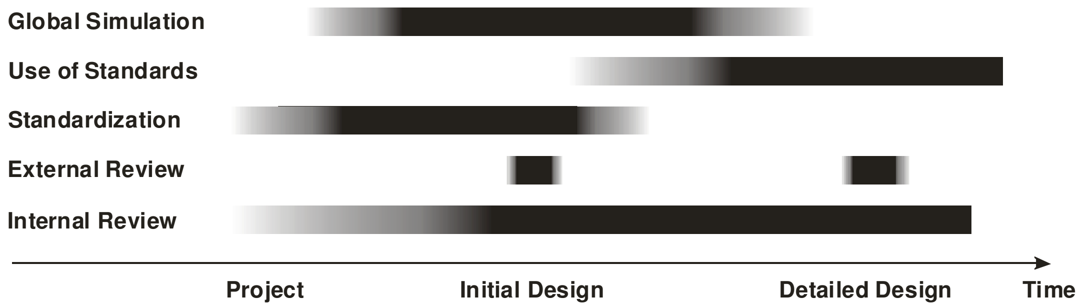

Fig 1 Methods for quality assurance in ship design

The testing of a design with respect to all requirements is a complex task involving many interrelated aspects. It requires thorough experience in and understanding of ship design. In contrast, preventive quality assurance can be used to reduce the likelihood of design errors caused by misinformation, unfamiliarity, for example, with yard standards, or inattention.

Today, for preventive quality assurance the following actions are normally taken:

- training of employees
- documentation, e.g. of best practice recommendation, previous experience etc.
- standardization of tested solutions for given design tasks
- standardization of proven methods to derive optimal solutions

In addition, an IT-based system for quality control cannot only document and distribute standards, but can also be used as a tool to automatically check in real time which conditions are imposed by standardization on a given problem. Optimal solutions are suggested. Therefore, KonSenS is also working on the development of automatic, rule-based tools for preventive quality assurance as part of the research project .

THE EFFECTS OF STANDARDIZATION

As described above standardization is a useful tool for quality assurance. With standardization a definition of proven state-of-the-art solutions is achieved. The essence of the experience gained from previous shipnewbuildings is described.

As shown in Fig 2 standardization is a tool to reuse proven solutions, to reduce the number of different parts used and as a guide for new employees or external design agents.

With standardization it is ensured that optimal solutions for design problems are chosen. A guideline is defined helping the designers to use identical solutions for identical problems. Hereby, the number of different parts used in a design can be reduced; series effects can be explored. Such series effects reduce the costs related to manufacturing, storage and delivery of parts. An optimization of construction and manufacturing processes can be achieved.

Also, standards and complementary documentation can be used as a source of information for engineers not familiar with the problem domain. With the documentation in-house training can be supported; design agents can benefit from the documentation and get an insight into the particulars, e.g. yard standards etc., of the shipyard.

With the reuse of proven solutions the workload of the designer is eased, see [4]. Instead of determining the correct solution for similar problems over and over again, with standardization for a specific set of design problems the field of application of valid solutions is defined. Here, the field of application describes the context a standard can be applied in. E.g. a standard regarding the use of brackets can define the type of connection (e.g. stiffener-stiffener), the size of the stiffeners to connect and bracket instances suitable in this context.

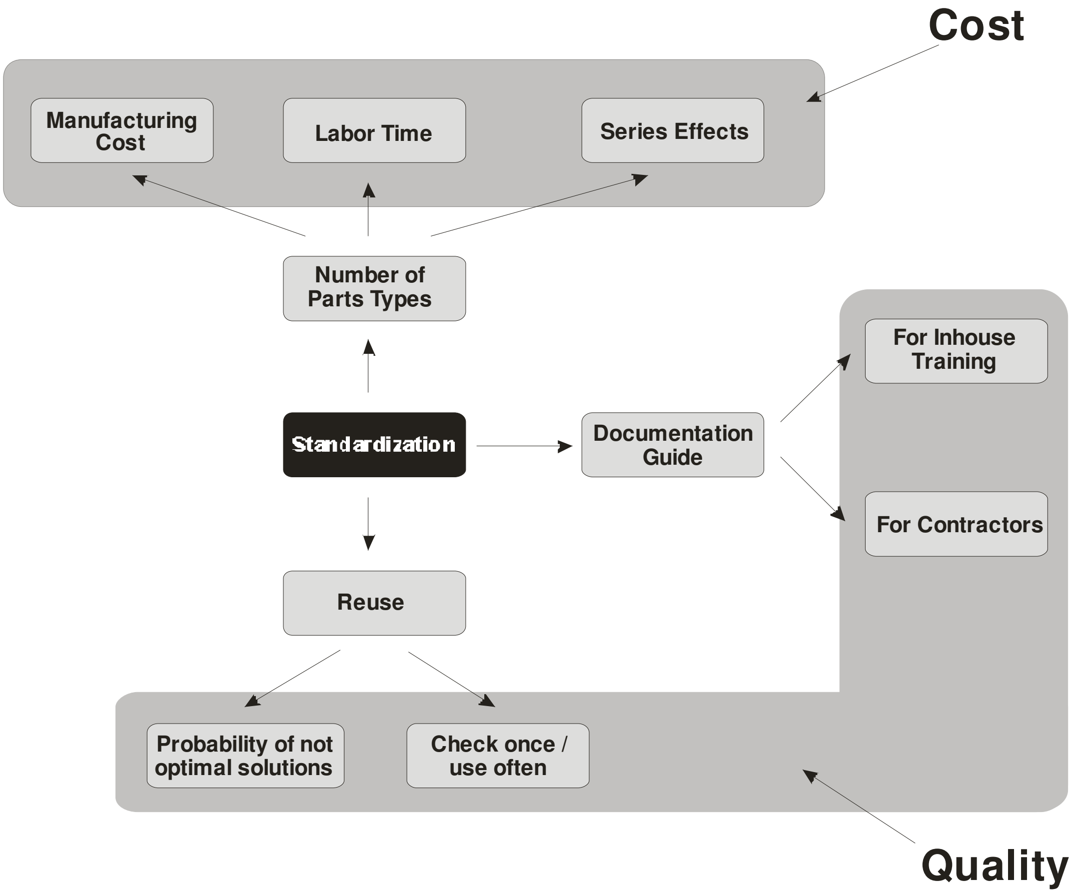

Fig 2 Effects of standardization

Also, with a software-enforced application of standard solutions the probability of errors due to negligence or unfamiliarity with the problem domain can be reduced.

For this purpose, an application server is developed within the research project KonSenS, Fig 3. The system offers an information server that provides information about design procedures, standards and documentation. Using a platform- and system- independent design, the client-server solution offers a flexible and centralized infrastructure. With the help of adapter interfaces to CAE-Systems or other applications present in the heterogeneous environments found in many shipyards it is possible to consolidate and centralize the management and configuration of different applications inthe system. A stand-alone client can be used to access the data stored in the application server directly.

With the application server holding the standards used for a shipnewbuilding and with the integration of the system with the CAD system as shown in Fig 3, the system can be used for preventive quality assurance. Standards like parts catalogs or listings of preferred solutions are stored in the application server. Here, these parts cannot only be linked with documentation items, but can also be related to other parts. A classification of the type of relationship is possible; constraints can be imposed. Simple algorithms can be defined to describe the applicable domain. This allows to define possible solutions, e.g. a certain combination of parts.

For this purpose standardized parts are stored in a database. Documentation and suggestions by other users, e. g. annotations, comments etc., are also stored in the application server. A rule module allows for the definition of either self-contained rules, which can be used by the engineer interactively, or as rules applied for dimensioning or selection of specific standardized parts. The functionality of these modules is made available for client applications via SOAP and XML-RPC. Interfaces for search and retrieval of applicable solutions or for information are offered.

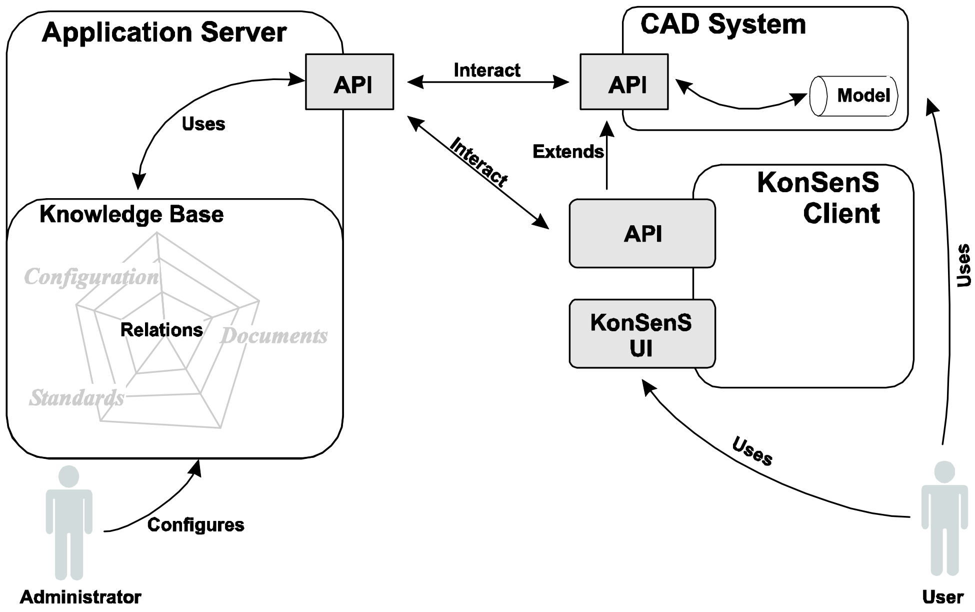

Fig 3 Conceptual model of the application server and the client-server interaction

KBE-BASED STANDARDS CONFORMANCE

While such a centralized data repository alone offers benefits with respect to information retrieval and knowledge acquisition, see [2], the different parts of the application server are connected to each other using semantic web technologies as shown in Fig 4, see [5], [6]. This provides a tight integration of the information available; constraints, e. g. on the applicability of standard solutions, can be imposed. Furthermore, with an appropriate client the analysis of the CAD model worked on is possible. The information retrieved can then be applied for context-sensitive design.

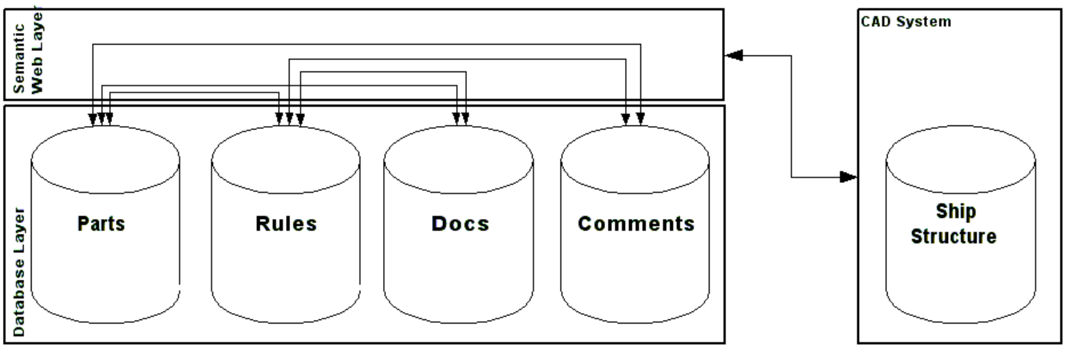

Fig 4 System design and interaction of application server and CAD system

For this purpose a knowledge model describing the design context and linking standardized parts to the model is imposed. This model is based on the semantic web technology. In the knowledge model a feasible solution can then be linked via relations to additional context information. A simple example is shown in Fig 5.

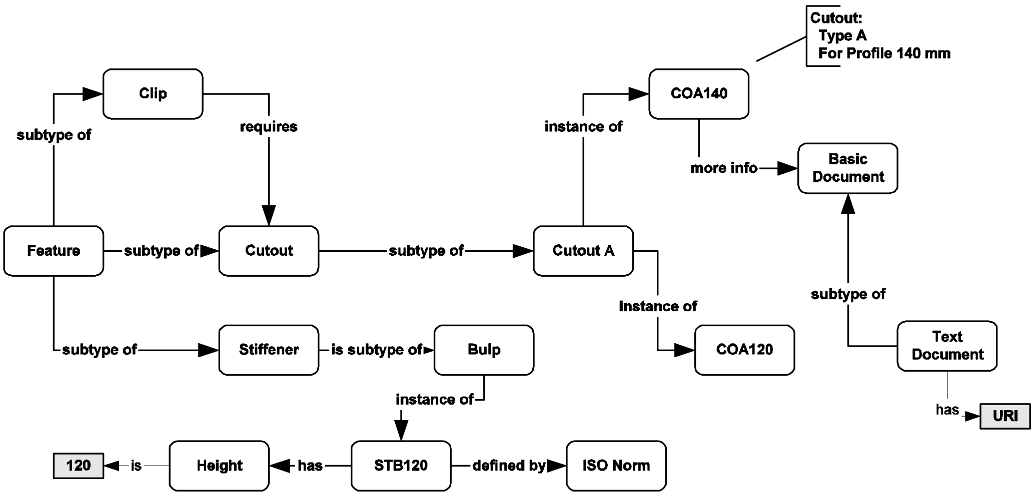

Fig 5 Simple model for the relations between stiffeners, clips and cutouts

In the research project KonSenS the knowledge model is developed using the ontology web language (OWL) standard, see [8]. This standard allows for the definition of an extended taxonomy of so-called concepts. These concepts can be set into relation to other concepts with respect to cardinality or boolean logic. Furthermore, with more advanced standards (e. g. SWRL or RML), complex rules or relations can be modelled.

For ship structural design, concepts for relevant structural parts or combinations of parts as well as relations are defined. The function of parts as well as context-relevant information can be modelled. On the client side, sophisticated methods are developed to integrate the CAD-system into the ontology allowing for an exchange of information.

With qualified “links” from a solution to the context the definition of a permissible domain for this solution can be achieved. For example., it is possible to specify the requirements to be fulfilled by a design solution . Conversely, if the context is known, the server can supply possible solutions. This eases the workload of the designer.

As part of the CAD model additional meta data can be stored to add further information about the context. This meta information is then used to constrain solutions or for additional quality constraints. For example a bulkhead adjacent to a tank is marked as watertight. For subsequent operations on this bulkhead this context information is used e.g. to prevent the use of non-watertight clips or of holes.

For the interaction of the system with the engineer or the CAD system the notion of tasks is defined. A task represents an action performed frequently by the designer in ship structural design. For each task the work-flow, i. e. the order of necessary actions to reach a solution, is defined; information needed as part of the solution process is identified. Also, information about the applicability of a certain solution with respect to the context is given.

In Fig 6 a generalized interaction of the engineer with the KBE-enabled CAD system and the corresponding communication between CAD system and application server is shown.

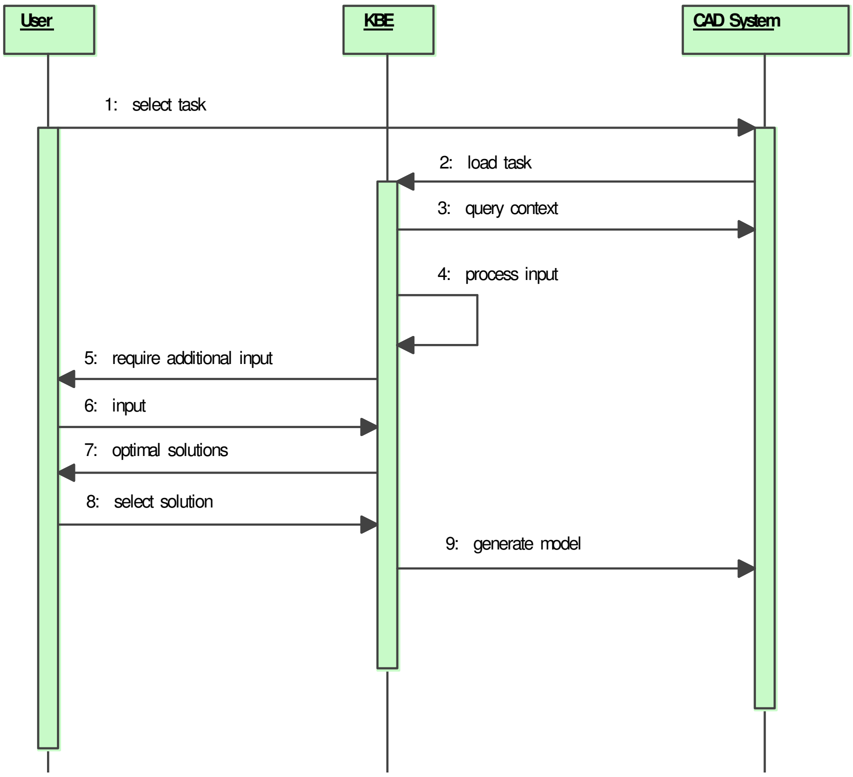

Fig 6 Sequence diagram depicting interaction of user, CAD system and KBE back end

Similar to a design process based on a conventional CAD system, a knowledge-enabled CAD system offers the engineer an interface to select the action to be performed. With an analysis of the context additional context information is derived from the geometric model present in the CAD system. With this information the knowledge model stored in the knowledge base is queried and possible solutions are presented to the end user. If needed, additional input from the user is requested. This leads to a significant reduction of the amount of information that needs to be entered by the user. Hence, a reduction of design time can be achieved.

With an extended version of the system the knowledge model available might help to improve automatization and further reduce the design time needed. If the configuration of the KBE system is tuned to the particulars of the CAD system used, the creation of complex, yet standardized solutions like bulkheads can be reduced to the execution of the appropriate sequence of tasks. Here, the design process is split into individual tasks; for a given part the order these tasks are executed in is defined. As an example, for the definition of a girder, the tasks are as follows:

- Define geometry of girder
- Create notches, cutouts, clips
- Create stiffeners
- Create holes

With this approach the engineer selects and executes the appropriate tasks for the required design.

In the future an additional assessment of the solutions provided by the application with respect to manufacturability, cost, strength and other factors is planned. As possible scenarios for application the fully automatic creation e.g. of holes or of notches could be achieved if the context is fully defined.

As shown in Fig 7 the effort in analyzing, defining and implementing the knowledge model for these parts requires additional effort with respect to the conventional design. After deployment savings with respect to cost and engineering time needed can be gained.

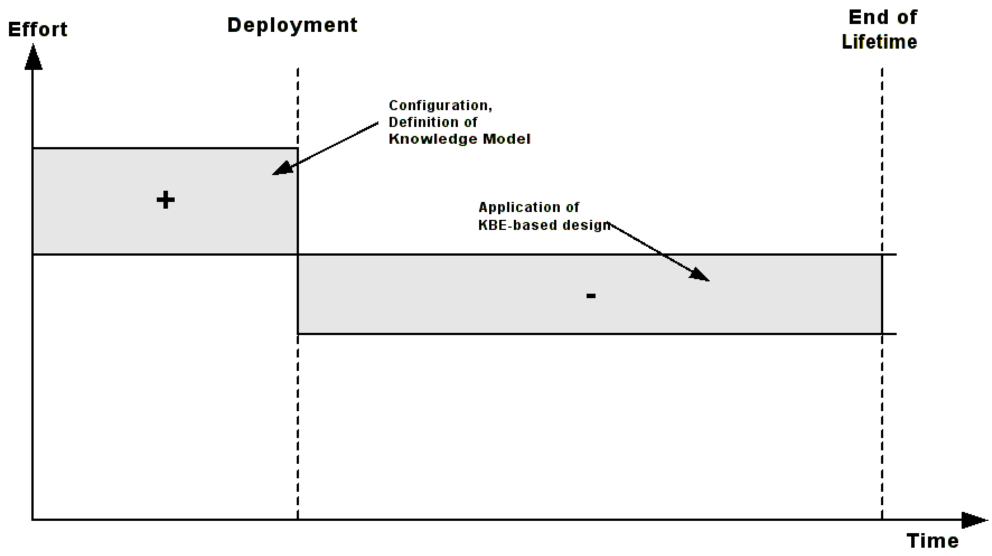

Fig 7 Time vs. effort for the application of KBE-based methods

For complex parts the effort required to capture the context of the problem domain completely can be large. While efficient and high quality tools can help a strong background and experience in knowledge modelling and the problem domain is required. Complexity and the lifetime of a standards solution are factors that determine the economic viability of the KBE-based approach for each problem.

DESIGN AGENTS, COLLABORATION AND NETWORKING

In the maritime industry design agents often work as subcontractors on projects of one or multiple shipyards [7]. For each project the design agent's CAD system needs to be configured according to the shipyard's requirements. Also, the engineers at the design agent need to familiarize themselves with the appropriate standards and regulations.

With the system, the access to documentation and standards can be granted, Fig8. Furthermore, the advantages of the system can also be used by the design agent via network connection. With the standards stored on the server in a platform-independent way it is possible to create instructions for automatic preconfiguration of a CAD environment.

Because standard catalogs are stored platform- and system- independently in the information base these standards can be used to configure the CAD system of the design agent according to the specification provided by the system, i. e. the requirements of the shipyard. For this purpose, the information server is able to export the configuration in a platform-specific format that is then used to configure the workspace. This enables the design agent to reproduce the settings used on the shipyard with little effort.

Also, with the networked solutions chosen for the system, access to documentation and standards used at the shipyard can be given to the design agent. The decision support provided enables the design agent to perform its task according to the standards of the shipyard. The time needed to get familiar with the specifics of a shipyard is reduced.

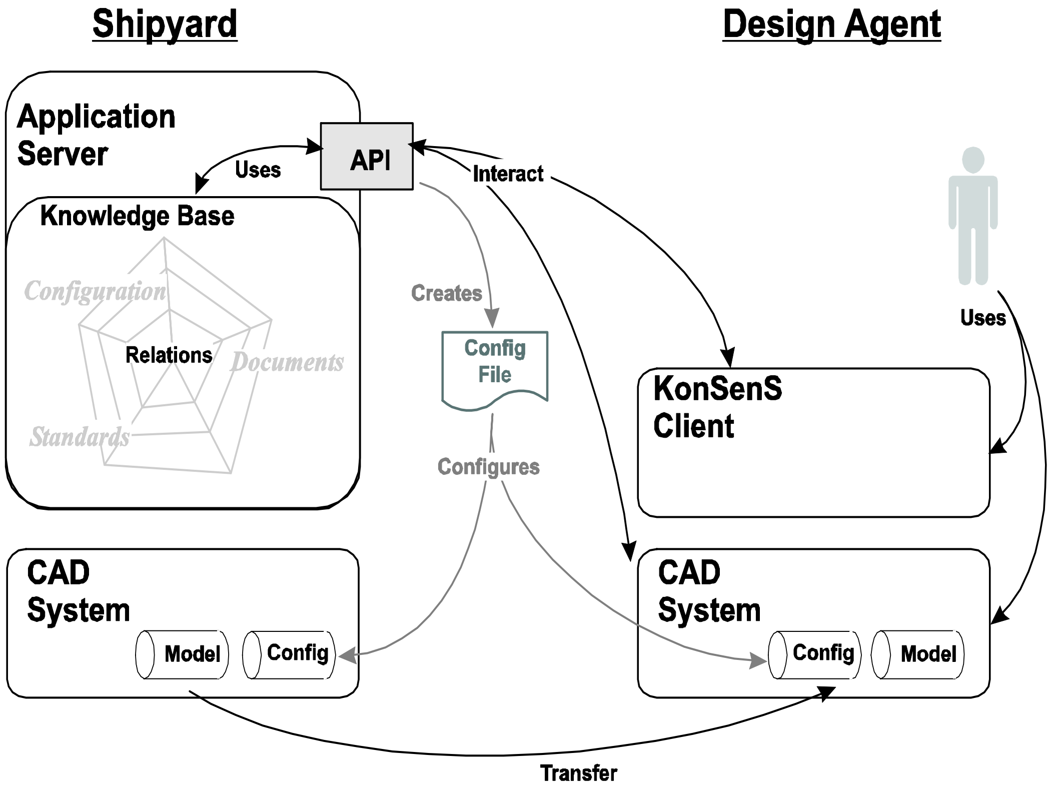

Fig 8 CAD system configuration and knowledge base access

SUMMARY AND CONCLUSION

Knowledge-based methods offer the means for the storage of domain specific information. The linking of individual pieces of information into a web of knowledge allows for classification; the context of such a piece of information can be defined.

With knowledge-based methods, the integration of CAD data and other information can be achieved. Knowledge and information can be made available to a team of engineers. The definition of standard solutions and parts is possible.

With the software components described the knowledge base can be used for context-sensitive design. For a given problem only applicable solutions are presented to the user hereby reducing the probability of design errors. Quality control can be achieved with validation of solutions based on the knowledge available; series effects can be explored. Design agents can use the knowledge model to understand the solutions preferred at a specific shipyard. The standards available can be used for the configuration of the design agent's CAD system.

An improved quality assessment of solutions presented with respect to multiple criteria would help the engineer to choose correct solutions. The application of the knowledge model for advanced automatization and for the definition of complex parts needs to be explored in greater detail.

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