Knowledge Modeling in Ship Design using Semantic Web Techniques

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Abstract *In ship design the design process is comprised of a complex interaction of many partners. A constant exchange of information is required. Today, a tight integration of the knowledge needed for development with the geometric model is not available.*

An improved integration of knowledge, geometry and manufacturing information can achieve an improvement in product quality and a reduction of design time as well as manufacturing costs. Stemming from research into future internet technologies semantic web techniques are one means for knowledge modeling.

As one objective of the research project KonSenS the prospect of knowledge based engineering applied to ship design is analyzed. A consolidated information server is used to manage documentation and standards. An integration into a CAD system is used to improve standards compliance. Decision support is given for standardized tasks hereby easing the workload of the designer.

1 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.

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

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

Knowledge based systems are applications that capture the knowledge available for a problem domain and represent this knowledge in a machine interpretable way. In ship design these systems can be used to e. g. document best practice recommendations or for standardization and automatization purposes. Also, knowledge can be extracted from key persons and made available to other members of the team.

For the world wide web the development of the so called semantic web techniques, Daconta (2003), is geared towards the definition of machine readable and more powerful relations between bits of information. Such relations allow for a tight integration of all pieces of information needed for ship design. Once accepted by the public this allows for a more precise search and retrieval of information; automatic deductive reasoning is also supported.

In the collaborative research project KonSenS the University of Rostock is working on the problem of modeling 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.

In this paper the use of semantic web techniques for ship design is analyzed. Based on a formal introduction to knowledge modeling a description of the techniques available and their capabilities is given. The application of semantic web techniques in ship design is described.

2 Knowledge

As in all other engineering processes, in ship design one factor that determines the result is knowledge. 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 or in operation. But what is knowledge?

Data, Information & Knowledge As mentioned above knowledge is comprised of individual pieces of information called facts, Franken (2002). 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 from e. g. previous reasonings, experiments or observations. Therefore, the extraction of knowledge is always bound to the background of the person. Differing conclusions might be drawn from an identical information base.

Types of Knowledge From a theoretical standpoint different types of knowledge can be identified, see Riempp (2004).

Structured knowledge is given in a predefined format, i. e. the semantic of the knowledge is given as meta-information. Examples in ship design are parts libraries or class rules. For unstructured knowledge no meta-information is given. Evaluation of this type of knowledge is only possible if information about the context is available, i. e. additional constraints apply but are not defined explicitly. In ship design the experience of the designer, some informal notation or comments enables the engineer to abstract the required knowledge; for automatic evaluation the determination of the context and constraints is difficult.

Explicit knowledge is knowledge that can be described using facts and relations. The transfer of this kind of knowledge is possible with only little danger of misinterpretation. Implicit knowledge is knowledge that is not defined explicitly but nevertheless available. Often, implicit knowledge forms one foundation a team or society is based on. In ship design, experience and general agreements are examples of implicit knowledge.

Finally, in most companies some knowledge is bound to certain persons as individual knowledge and not available to all employees of the company. If such an employee leaves the company the knowledge is no longer available. In contrast, social knowledge is shared by a team or society, i. e. all members of the team are able to understand and apply this knowledge.

Knowledge Exchange & Management 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. Therefore, for each person knowledge is represented as a different mental model. For knowledge exchange to take place the mental model is

transformed to a set of information that is transfered to another person. Then, the other person uses it's background to abstract the knowledge from the information depicting a new mental model.

For knowledge exchange to take place the partners have to agree on a common language and have to share a basic set of already existing common knowledge. Or from a more theoretical standpoint, the transfer of knowledge can only take place if a common syntax and semantics is agreed upon.

For an effective exchange of knowledge in a company precautions should be taken to optimize a formalized representation of information required for operation. 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 leads to a reduced dependency from these persons.

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

3 Semantic Web & Semantic Web Techniques

For a machine interpretable representation of knowledge not only is it necessary to store individual facts electronically but also to add additional information about the relationships between these facts. Here, relationships can either describe simple dependencies between facts but can also impose more complex constraints defined by cardinality constraints or rules.

For an IT based evaluation of relationships and facts applications need to know about the problem domain, i. e. some basic definition of the syntax, semantics and concepts used in a problem domain needs to be available. For knowledge modeling the syntax and semantics is mostly given by the modeling standards used. For each given problem domain the concepts and the relationships between these concepts are defined in a taxonomy or ontology.

Taxonomies and conceptual models spawn a loosely coupled mesh of concepts and creates parent-child relations between concepts The type of relationship between concepts is not identified. An ontology takes the approach used for taxonomies to a higher level and adds e. g. support for relationship types and constraints between concepts.

The semantic web working groups of the World Wide Web Consortium (W3C) were established to work on standards for the domain and application independent modeling of knowledge. The objective of the working groups is to create the means to structure individual facts and to put them into context. Also, improved search capabilities, automatic deduction and reasoning based on information available on the internet are addressed.

For this purpose the W3C published a series of XML-based standards as shown in Fig. 1. Based on XML and XML Schema for the definition of content and syntax the semantics are described using the Rich Description Framework (RDF) or Topic Maps (TM). For ontology support the Web Ontology Language (OWL) standard is available. Upon these models inference engines or description logic (DL) can operate to query the information model and to extract additional information using deductive reasoning or first order description logic.

3.1 Different Levels of Information Models

As mentioned above the standards developed for the semantic web cover different aspects of knowledge modeling and representation. From the basic document in XML over relational mod-

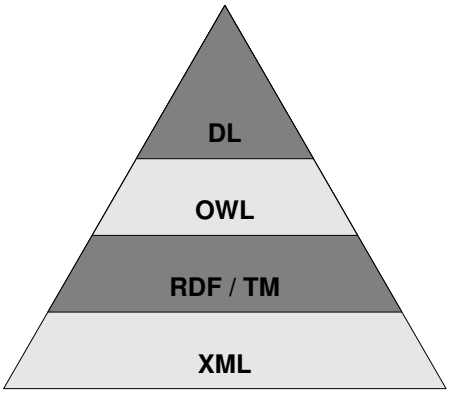

Figure 1: Semantic web standards

eling using topic maps or RDF to full fledged description logic different levels of complexity needed for information modeling are covered. In the following some aspects relevant for knowledge management are explained.

Topic Maps and RDF The Topic Map and the Resource Description Framework, Powers 2003), standard originate from two standards organizations, ISO and the W3C respectively. Because these standards cover similar aspects and a conversion from TM to RDF or vica versa can be achieved, Garshol, in the following only topic maps are examined.

In Fig. 2. an example for a graphical representation of a topic map that can be used in ship design is shown. With this simple knowledge model the relations between stiffeners, cutouts and clips are defined. Attributes with resource identifiers (URI) are used to link to objects not stored in the topic map.

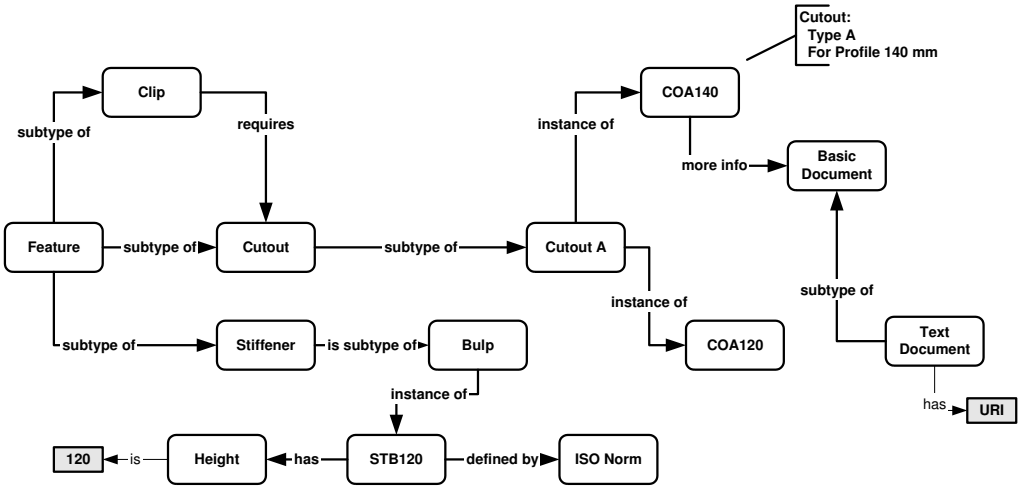

Figure 2: A simple topic map model for the relations between stiffeners, clips and cutouts

Stemming from the work on electronic indexes topic maps are a subject-based classification technique. As the name implies topic maps are organized around the notion of topics, which usually

represent primary concepts important for a specific problem domain, the so called subjects.

The description of subjects is done using the basic constructs names, occurrences and associations. In a topic map every object or thing itself is a topic with one or more given names. The name is used to create an unambiguous identification and can be used for human interaction or machine interpretation. For classification purposes topic types, which itself are also topics, can be assigned to topics. This makes it possible to group certain topics relevant for a specific context.

Information objects like documents, class standards or parts of a CAD/CAM model are not stored in the topic map but a topic may link to an information resource using the occurrence construct. This enables a software designer to store information in the most suitable way for a given task. CAD/CAM objects can be stored in the CAD/CAM system, documents in the document management system.

With associations relationship between topics are defined. While associations only express that some relation between two topics exist, association types are used to classify and group the relationships according to their type.

One advantage of topic maps for software development is that it allows the development of applications in which only an incomplete application data model is known at design time but is configured or extended by the user.

Ontology Support Topic Maps and RDF are tools for relational modeling. But similar to the mostly keyword or full-text based search used in search engines on the internet, without a limited and predefined vocabulary the quality of results is poor. Also, for knowledge based applications the meaning of the relations and relation types need to be known.

With the OWL standard so called ontology based vocabularies are used. Applied to knowledge modeling with semantic web techniques an ontology defines a basis of permissible relations and types of relations. Roles can be restricted to apply e. g. only for certain relation types; cardinality constraints can be given. Additional knowledge is encoded in the ontology model with basic logical operators like AND, OR or IS NOT.

For ship design an ontology defined for a specific problem domain can be used to represent knowledge about this domain as structured knowledge. For example a basic ontology that defines the knowledge about brackets, stiffeners and cutouts can be used to define a set of permissible combinations. With an extended ontology it is also possible to describe the context valid for a certain part.

Reasoning With RDF, topic maps and OWL a static yet extensible encoding of domain specific knowledge can be achieved. On this basis the process of reasoning uses first order description logic to infer additional knowledge from the knowledge base or to apply the knowledge base to a specific given problem.

While first order description logic provides the means to validate a given knowledge model and to compare a given set of information with this model it does not give a machine interpretable representation of the meaning of constructs like relationship types, documents or other data objects. Therefore, the meaning of the different concepts defined in a base ontology need to be implemented as part of the application software applied. For a complex problem domain this can be a significant task to complete.

4 Ship design & Semantic Web Techniques

Knowledge modeling and semantic web techniques offer the possibilities to apply the concept of knowledge based engineering to the process of ship design, Krüger (2003).

As part of the research project KonSenS an application server is developed, see. Fig. 3. The system offers an information server that provides information about design procedures, standard 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 into the system KonSenS. A stand-alone client can be used to access the application server directly.

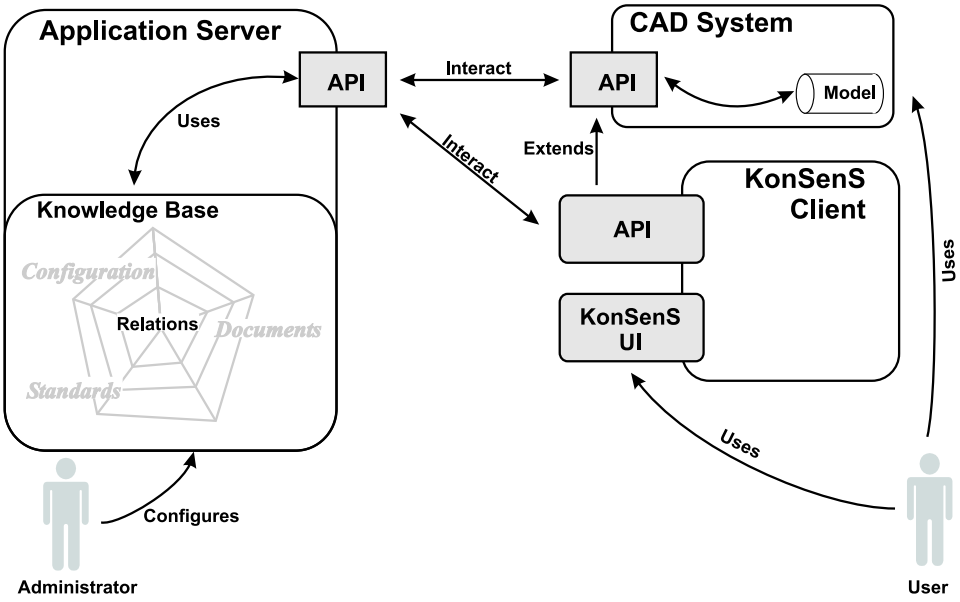

Figure 3: Conceptual model of the application server and the client-server interaction

In the following an overview over advantages gained through these techniques is given. An overview over possible use cases is given in chapter 5.

Interoperability & Integration With a diverse software landscape as present in today's shipbuilding industry integration and interoperability are important issues.

Here, interoperability guarantees that data can be exchanged with other applications. In most cases a file based exchange using import and export functionality is chosen. While such a solution is helpful to reuse data in other applications the issue of multiple data storage persists. Merging issues and synchronization problems arise. Similar to STEP physical files the XML based standards offer the means for file based data exchange. The format of the exchange files can be described with the help of so called schema's. Checks for syntactical correctness are possible.

One objective of the project KonSenS is increased integration, i. e. the concurrent access of diverse applications to one or multiple unified data repositories. This enables the user to work

with up-to-date data and removes the need for synchronization. For a seamless integration of applications an ontology based information model can be applied. With such an ontology not only the syntax but also the semantic and logic of the data can be defined.

Because of the network centric orientation of the committee developing the XML based standards distributed storage and retrieval can easily be implemented. Platform independence, a large user base and the availability of the appropriate tools ease the transition to these standards.

Flexibility With STEP the information model for data storage and exchange is fixed upon system design. This means that custom extensions to the capabilities of the data model can only be achieved in cooperation with the software developers. Customization and extension of a data model at runtime is not an option.

With semantic web techniques the knowledge encoded in topic maps or RDF structures an increase in flexibility is given allowing for a yard specific configuration of applications. As long as the underlying ontology is sufficient the information model can be extended without loosing the power of automatic computer-based interpretation. Still, limits are present if the base ontology does not offer sufficient means for the description of upcoming requirements.

Due to the integration capabilities offered by the network centric design the flexible combination of different services available into one homogeneous information model is possible. Multiple applications can be integrated.

5 Use Cases

For the maritime industry or, more specific, in ship design the application of semantic web techniques can be used to ease the passage to knowledge based applications and to knowledge based engineering. In this chapter possible use cases are shown.

5.1 Knowledge Modeling

For an organization operating in the maritime industry knowledge is an important asset for the successful acquisition of and work on contracts. In the last years the importance of this role has increased so that corporations actively seek to extend the benefits from all the knowledge available. With the knowledge types as defined in chapter 2, the objective of corporations is to make information available to the employee as needed, Nieuwenhuis (2004). In ship design explicit knowledge is available in the form of standards, that i. e. regulate the use of parts etc, or as other documentation, mostly available as text.

Documentation As part of the application server a documentation component offers the means to store documentation that hereby is made available to all employees. These documents are linked to a topic map or RDF representation founded on a base ontology of topics and topic types. This allows for a consistent classification and reduces the ambiguity of freely defined keywords.

The search capabilities offered by semantic web techniques do not restrict information retrieval to full text and keyword search, but also enables an application or user to search by context or with even more complex logical operations. This leads to a reduced time needed for information retrieval.

Also, for new employees or people not familiar with certain specifics a consistent knowledge model provides these people with a tool that enables them to research and learn the procedures

common in a company. The problem of different work techniques or solution strategies can be minimized.

Standards In this paper, as mentioned above, in standards predefined solutions or parts are defined. A standards component is integrated into the server. This component enables the administrator to store standard parts and combinations of part. For constraints, context information and requirements a knowledge model is used. While no internal shape representation is implemented, the relevant dimensions are stored so that they can be exported to different CAD systems.

The standard catalog is linked into the base ontology for ship structural parts. While a paper based catalog only provides a single, mostly shape-oriented view onto the standard parts, with an ontology-supported relational representation of e. g. a parts catalog additional views can be derived. These can be views with respect to areas of application, strength or manufacturing. With these views additional support for a decision is given at the hand of the engineer.

Knowledge & the CAD Model In the maritime industry the CAD model of e. g. a ship comprises the result of the application of the engineers' knowledge on the shipyard or network.

If life cycle aspects, modifications or rebuilds of a design are taken into account the search for the reason a certain solution was developed in a given way and which standards were used becomes a serious obstacle. Media breaks play an important role in this issue. With an electronical representation of knowledge the knowledge used for certain decision can be documented. This allows an engineer to reproduce and validate the design if needed.

Also, the project KonSenS strives for a tight integration of electronically encoded knowledge - this might be standards or other documentation - and the CAD model. With the help of ontology modeling techniques, for a specific problem the corresponding documentation and standards can be presented to the engineer within the CAD system where appropriate. With such an approach the system provides decision support.

5.2 Context Sensitive Design

Standards like parts catalogs or listings of preferred solutions are stored in the application server. Here, with relational modeling based on an ontology these parts can not only be linked with documentation items but also can be put into relationship to other parts. A classification of the type of relationship is possible; constraints can be imposed. This allows to define possible solutions, e. g. a certain combination of parts. In the knowledge model such a solution can then be linked to context information. This can be seen in Fig. 2, see chapter 3.

With qualified links from a solution to the context the definition of a permissible domain for this solution can be achieved. I. e. it is possible to specify the requirements a design solution needs to fulfill. 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 further 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 to e. g. deny 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 designers in ship structural

design. For each task the work-flow, i. e. the order of necessary action to reach a solution, from the problem to a solution is defined; information needed as part of the solution process is identified.

Similar to a design process based on conventional CAD system a knowledge enabled CAD system offers the engineer an interface to select the action to perform. With an analysis of the context additional 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. This leads to a significant reduction of the amount of information that needs to be entered by the end user. Hence, a reduction of design time can be achieved.

In the future an additional assessment of the solutions provided by the application with respect to manufacturability, cost, strength and other factors is planed.

5.3 Standardization, Quality Control & Automatization

The definition of an electronic standards catalog can guarantee that only correct and unequivocal standards are published. For this purpose first order description logic can be used to validate an information model and to warn about ambiguities or contradictions. As a result a concise set of standards avoids differing interpretations of a standard that may lead to design errors.

With standards defined in such a way the engineers are not only supported in their decisions but also the validity of existing solutions can be tested for. The validation of the CAD model can detect errors at an early stage in the design process. This shows the ability to improve the process of quality control and to guarantee that only applicable solutions are used. An improved overall quality of the final product can be achieved.

In ship structural design series effects play an important role with respect to manufacturing costs. The definition of standard solutions can help to reduce the diversity of parts used and to increase the number of parts needed of certain types. This allows to explore cost saving series effects.

With an extended version of the system the knowledge model available might help to improve automatization and reduce the design time needed. As possible scenarios for application the fully automatic creation of e. g. holes or of notches could be achieved, if the context is fully defined.

Also, the definition of additional task groups can be applied to describe the definition of complex parts like bulkheads or girder. Here, the design process is split into individual tasks; for a given part the order these tasks are executed is defined. As an example Fig. 4 shows the tasks as they might be applied to a girder.

5.4 Design Agents

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

With the system, as mentioned in chapter 4, the access to documentation and standards can be granted, see Fig. 5. 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

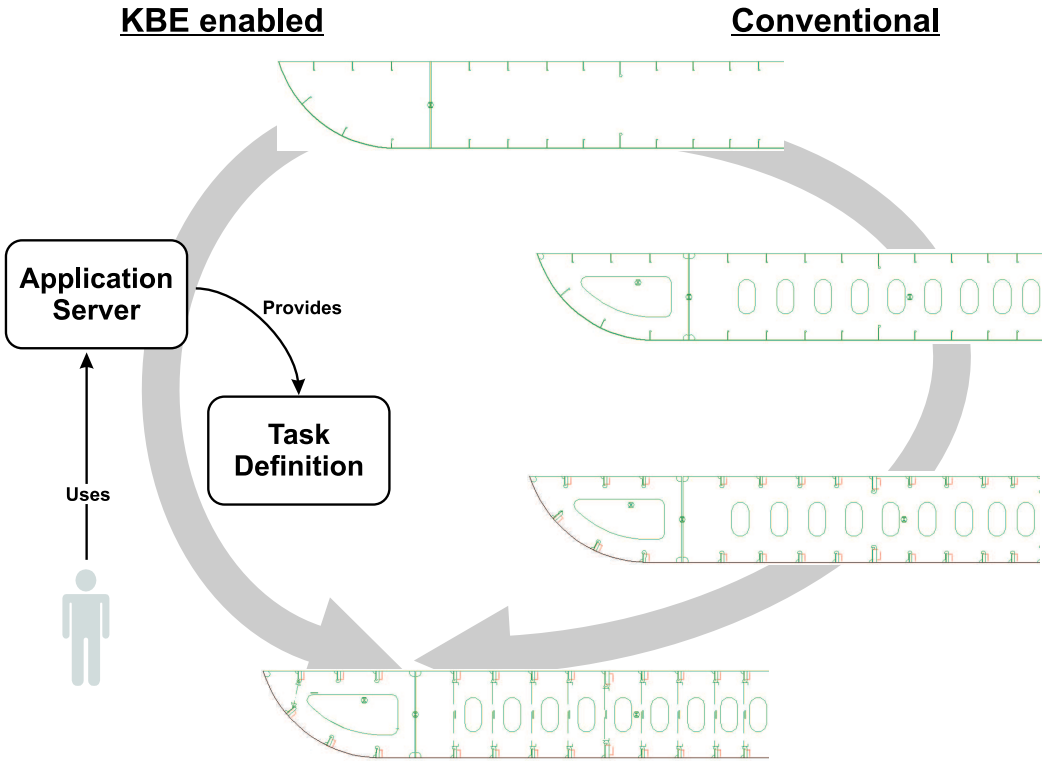

Figure 4: Task based design process

environment.

Because standard catalogs are stored platform and system independently in the knowledge 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. to the requirements of the shipyard. For this purpose the information server is able to export the configuration to 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 on the shipyard can be given to the design agent. The decision support provided enables the design agent to build according to the standards of the shipyard. The time needed to get familiar with the specifics of a shipyard is reduced.

6 Summary and Conclusion

With semantic web techniques standards for the creation, management and use of machine interpretable knowledge models are available. Such models are comprised of individual facts linked by qualified relations; constraints can be used to capture additional information.

With knowledge modeling and semantic web techniques 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. An ontology base allows for an unequivocal classification of facts with respect to the problem domain.

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

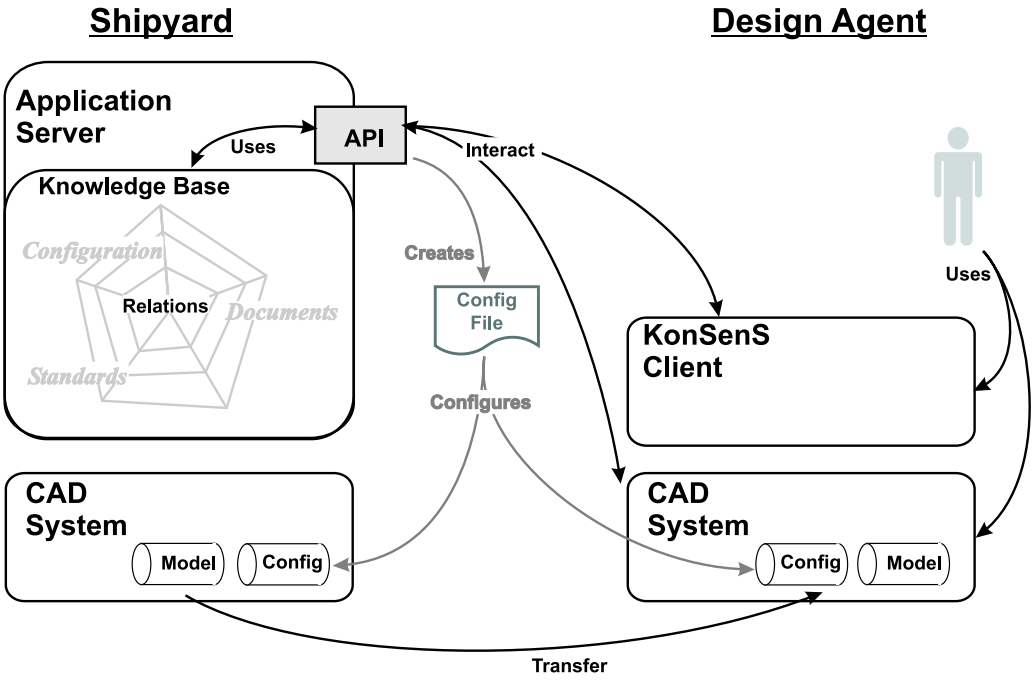

Figure 5: CAD system configuration and knowledge base access

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 on 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. Finally, the development of a suitable base ontology that captures the relevant concepts for ship structural design is a significant task not completed yet.

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