Knowledge Based Systems in Distributed Design Environments

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Summary

Today's building industry not only demands more and more reduced construction time on building site, but also an advanced and mostly construction attendant design phase. Even though there is software available to support design processes in distributed environments, most applications only support simple document based exchange of information. In this paper a knowledge based system is presented to support cooperative, comprehensive design processes in distributed environments. The presented research project is financially supported by the German Research Community (DFG – Deutsche Forschungsgemeinschaft).

1 Introduction

The duration and in close dependency the total costs for design processes already were very important. Due to lower honoraria for planners the decrease of time and the resulting reduction of handling charges for design processes are becoming more and more important. Additionally the construction attendant design phase is usual practice at most projects. Therefore it is necessary to make important and cost interacting decisions in a very short time. Also the planning-participants have to consider all potential consequences of design modifications. Because of the mostly complex design processes it is nearly impossible for a planer to quickly identify all these consequences. Possible wrong decisions result and most likely they lead to higher construction costs.

Based on a computer supported cooperative design processing, the involved project planers are located on different sites (maybe worldwide). Actually the exchange of information between involved craft-planers during the realization of structural and industrial engineering already occurs at an electronic base (internet based project management – IBPM), but solely document orientated [7]. Due to this peripheral, document based data management it could be possible that the constructional processing of the separate planning participants is based on different states of design. This conventional approach is time- and cost-consuming, as well as inflexible. It can lead to considerable inconsistencies. Therefore the today's practiced document based exchange of information needs to be expanded in a suitable way. The approach presented in this paper is set up on a knowledge based system using distributed knowledge bases.

2 Structure and Functionality of the Knowledge Representation Model

The basic principle of the present research work is designated to structure *Building Information Models* as well as to formalize design standard and expert knowledge. Figure 1 shows the basic structure of the *Knowledge Representation Model.* As well as in [8], this research project pursues a knowledge based approach too. This object oriented *Knowledge Representation Model* in a distributed environment which is introduced in this work builds upon earlier models [2]; [3], especially the *OFWM* [1].

Due to the unification of notions in the scope of the DFG-SPP1103-task force “Verteilte Produktmodelle”, the notions in this paper diverge from some notions which were used in publications before (e.g.: [4]).

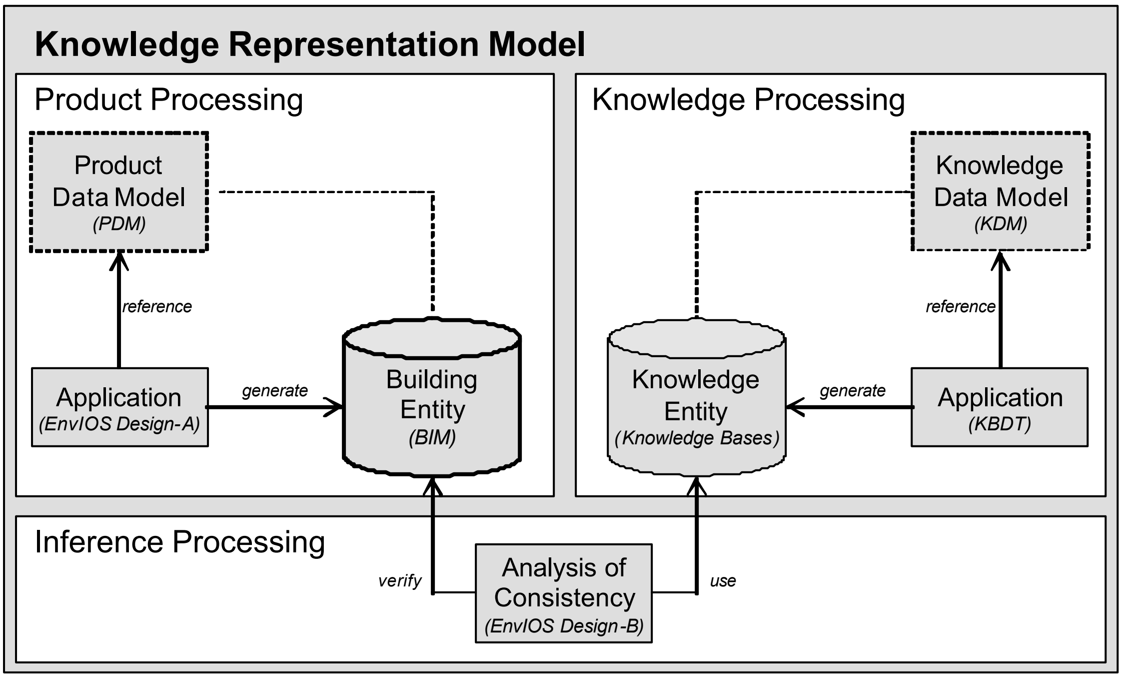

Figure 1: Structure of the *Knowledge Representation Model*

As approved in [4] and shown in Figure 1, the object oriented *Knowledge Representation Model* is split into multip le parts. The separate local knowledge bases of the different planners base on an object oriented *Knowledge Data Model (KDM)*. They operate upon a Building Information Model (BIM), which consists of instances of the *Product Data Model (PDM)*.

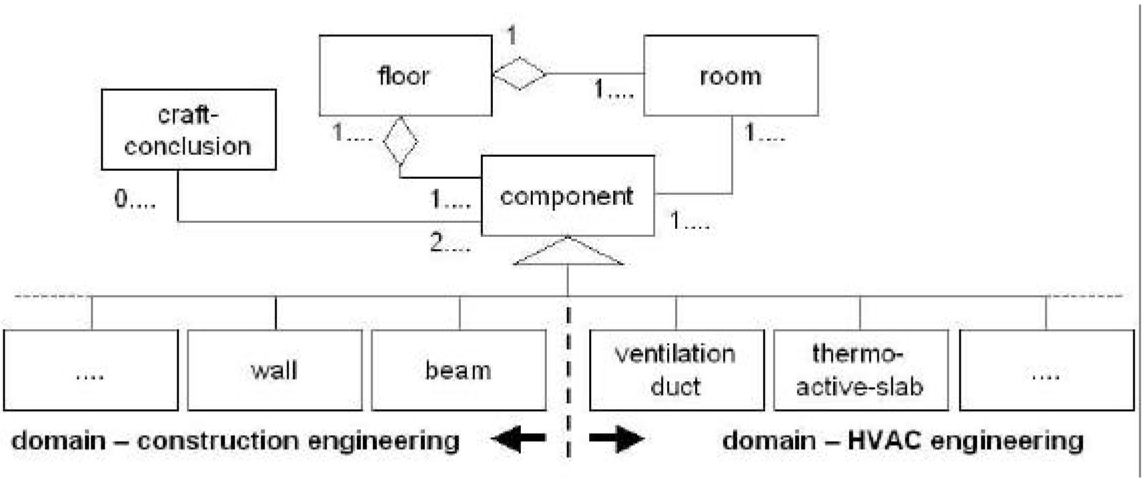

Figure 2: Simplified class diagram of the *Product Data Model (PDM)*

Regarding their use at conceptual and design-proceedings, the elements of knowledge bases are structured in a suitable way in consideration of the *Product Data Model* (*PDM* – Figure 2).

The elements of proofs are variables which are contained either in design codes or in complex engineering knowledge. These calculation elements are classified in different calculation element classes (Figure 3) according to their method of valuation.

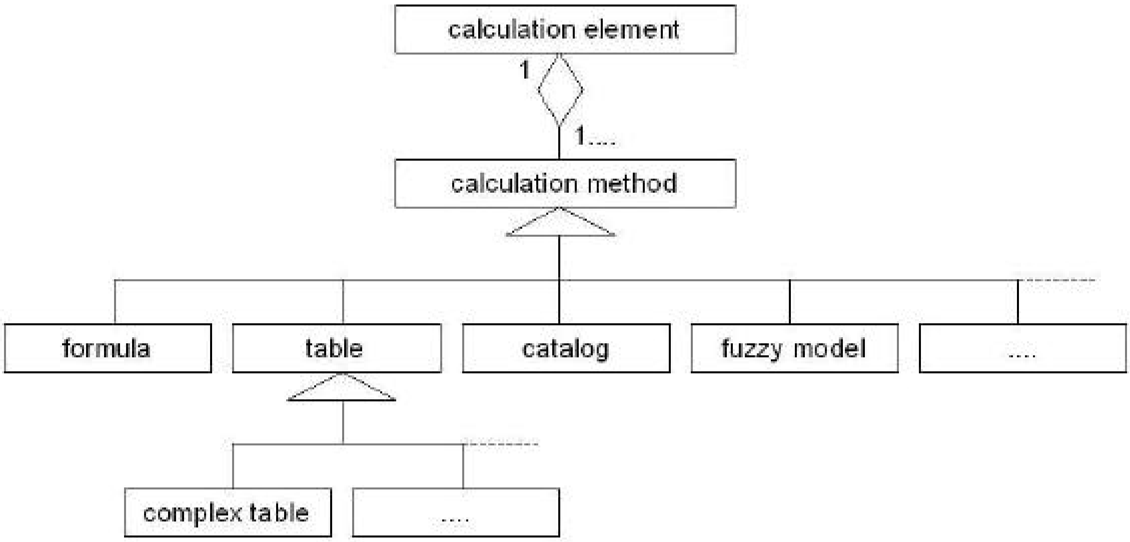

Figure 3: Simplified class diagram of the *Knowledge Data Model (KDM)*

The various craft based knowledge bases and the data base of the *BIM* are scanned for instances and their values or attributes for verification management in a recursive operation by a central inference mechanism. This proceeding permits improved comprehension of the dependencies of calculation elements and their methods. It also allows the identification of consequences of separate planning steps and ensures consistency within a distributed environment.

This presented segmentation of the multiple models enables application of the *Knowledge Representation Model* to various domains. With a different structure of categories in the *Product Data Model (PDM)* the knowledge bases could be applied to an appropriate *X-Information Model* (here: X corresponds to a *Building Information Model – BIM*). Because of the partition of *PDM* to the *Knowledge Data Model (KDM)* the system guarantees a high degree of independency to design standards. With this approach it is possible to use an edited or entirely new design method which is formalized in the *KDM* for the same planning project. Contrariwise it is also possible to use the same design standard to different kinds of construction.

Another advantage of this *Knowledge Representation Model* is the ability to deal with various *Product Data Part Models*. Because of the dynamic process the complete project passes through different phases of planning processes. In the early phases of planning processes (conceptual design) for instance the level of detail of the separate components and their attributes is very low. Therefore it is necessary to arrange an adapted *PDM* with an appropriate knowledge base including special conceptual proof selections [5].

Within the scope of this research work, knowledge bases for the two planning crafts of "HVAC-Engineering" and "Construction Engineering" are developed exemplary. More domains can be supplemented to the shown system. The content of each of these craft based knowledge bases is partitioned into two parts. The first part includes design code information with craft-specific proofs. The second part represents formalization of individual engineering knowledge. The definition, modification and processing of the knowledge bases occurs with a software tool (*Knowledge Base Definition Tool – KBDT –* Figure 4) under consideration of the schemes of the *PDM* and the *KDM.*

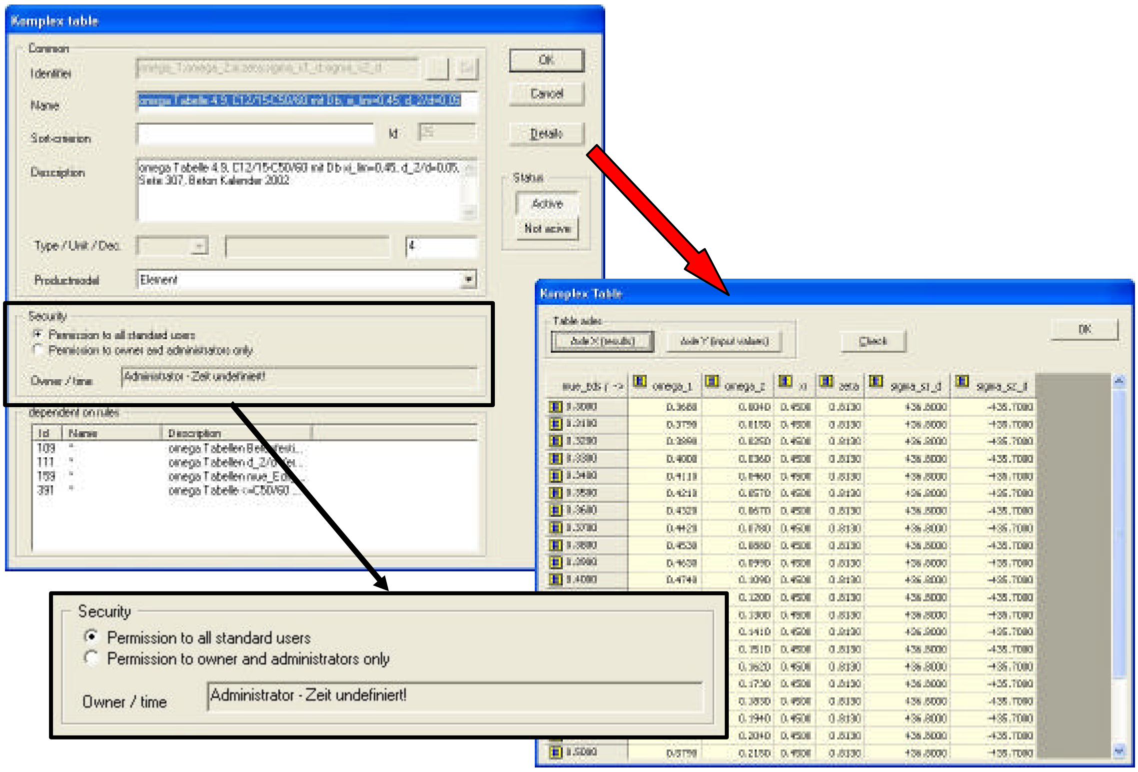

Figure 4: Cut out of a knowledge acquisition dialogue in the Application *Knowledge Base Definition Tool (KBDT)*

3 System Architecture in a Distributed Environment

Figure 5 shows the idealised structure of the architecture in a distributed environment. The various local knowledge bases are located separately at the local systems of the involved planning-participants. In contrast to the primal approach [4] the local knowledge bases are additionally replicated to the centralized server. In a series of experiments it turned out that the inference process requires an extraordinary high number of requests to the local knowledge bases, so for advanced tasks the central replicas are used. A special replication technology ensures the consistent state of the local knowledge bases and their replicas on central servers. In Figure 5 there are two respectively three craft-knowledge bases. Certainly further knowledge bases can be arranged. The replicated, server sided knowledge bases are connected to the central inference mechanism. Also a server side knowledge base for project- & planning-control is being provided. With the aid of this universal and for all participants visible knowledge base it is possible to decide progressions of planning processes for conclusion components (e.g.: openings in walls as a result of an air duct) which affect multiple planning-participants of different crafts. All these centralised knowledge bases are applied in the course of the run of the central inference mechanism during the proof management to the *Building Information Model (BIM)*.

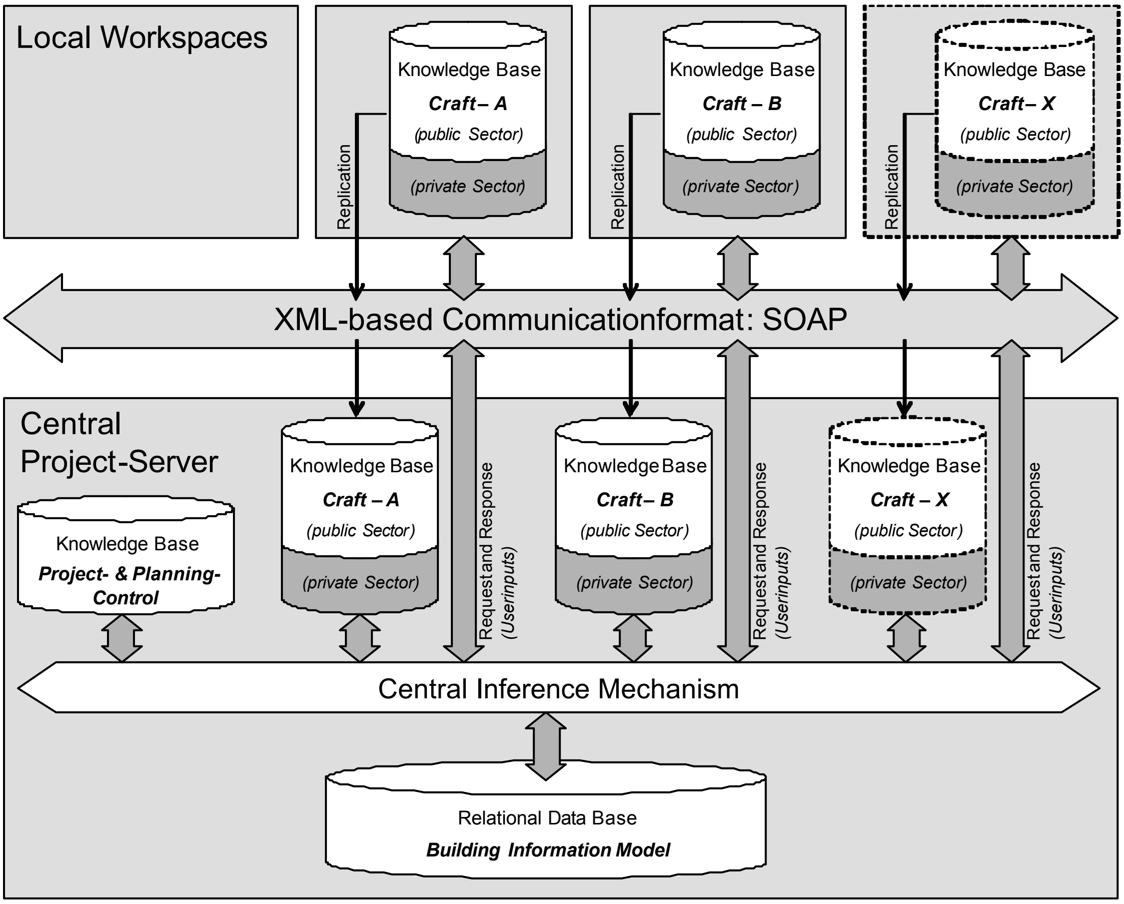

Figure 5: Architecture in a Distributed Environment

The arrangement of the distributed knowledge bases at the various systems of the craft based planning-participants is necessary for different reasons. The owners of the separate knowledge bases (planning-participants) are able to edit existing as well as to create new knowledge bases in their own workspaces. This requires the validation of the server sided knowledge base replicas before the start of each inference process.

In case of inconsistencies it is necessary to synchronise the appropriate server sided knowledge base by replication from the local ones to the central project-server. Another advantage of the distributed arrangement of the craft based knowledge bases at the local workspaces is the possibility to use a single knowledge base for several projects. Therefore the workspaces with the appropriate knowledge bases are connected to different project servers.

This kind of architecture allows tracing of the required user queries in the course of a proof process during an inference flow. This can be done by several users from their own local workspaces. The central inference mechanism sends a request to the concerned local workspace. The dedicated user handles the request (e.g.: "quality of concrete" by a civil engineer) and sends back his response.

The release and exchange of queries, commands and distributed arranged data occurs with the aid of the XML-based Client-Server-Architecture SOAP (Simple-Object-Access-Protocol – SOAP).

4 Explanation Component

One of the most important pre-condition for a comprehensive acceptance of such a system is the security of the private expert knowledge of each craft based planning-participant. As a result of every inference process users can get the conclusion of each proof in an explanation component. Also included is the derivation of each conclusion culminating in basic data items (e.g.: constants, user queries or product model queries like dimensions). Another achievment inside this system is the excellent change management. This facilitates users to track back consequenses of changes (Figure 6). An explanation component with change management capabilities guarantees a very high transparency in most situations.

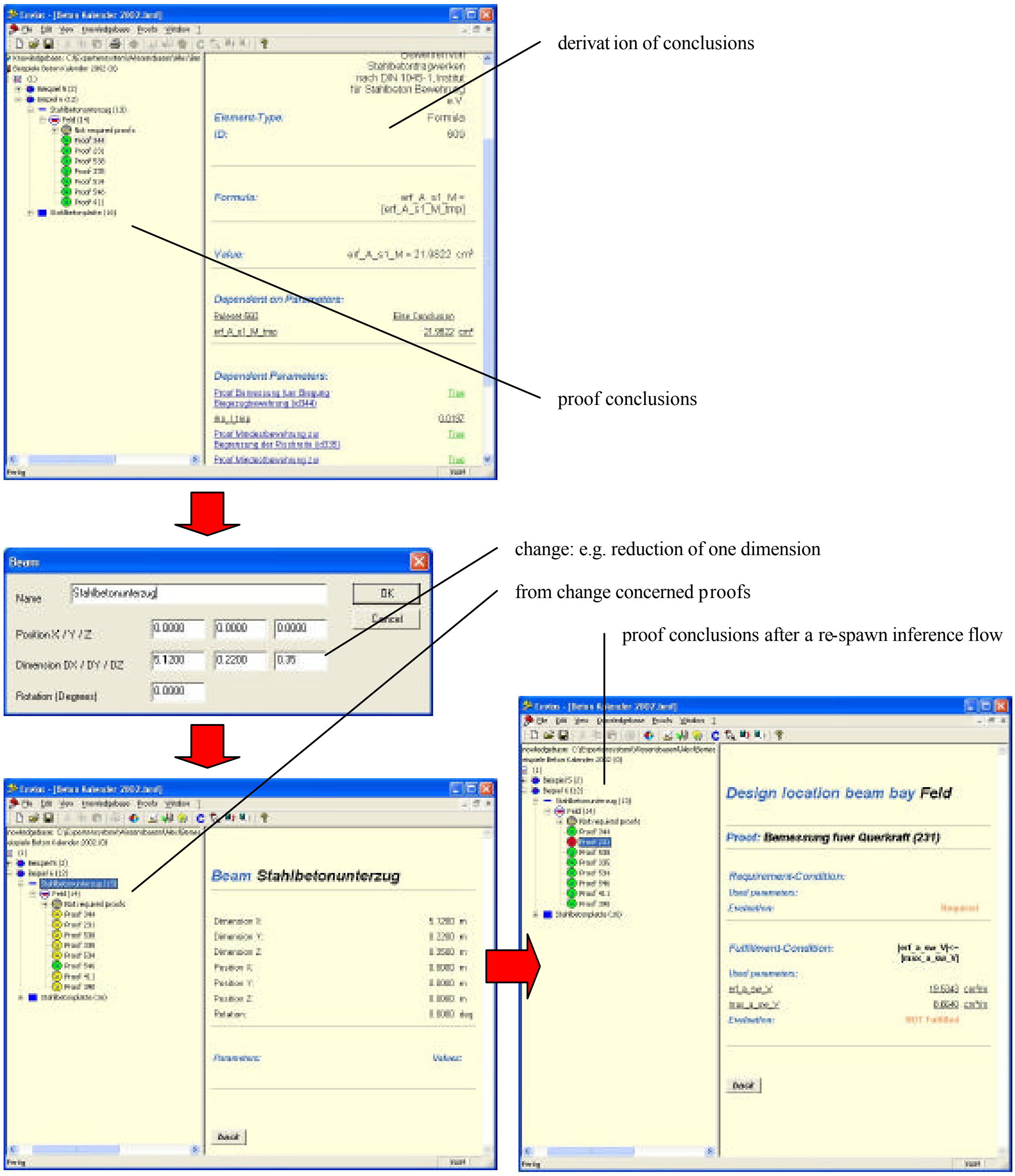

Figure 6: Exemplary illustration of the explanation component with the change management inside the application *(EnvIOS-Design-B)*

Deviant to the normal design code information it is different in case of self-acquired expert-knowledge. No planning-participant would like to divulge the own expert knowledge. Therefore the software tool (*Knowledge Base Definition Tool – KBDT* / Figure 1 & 4) for the knowledge acquisition offers an alternative to define knowledge in a private sector of the knowledge base (Figure 5). In course of a proof procedure both sectors – the private and the public – are scanned for instances and their values or attributes. In case of verifications with proofs out of the private sector, only the originator respectively the owner of the "private proof" containing knowledge base has got the privileges to get the complete derivation of such a conclusion inside the explanation component. The different planning-participants are restricted to receive only the results of the various "private proofs". All conclusions and their derivations of formalized knowledge in the public sector are visible for each planning-participant. This confinement of access in case of the explanation component is necessary to guarantee a capable use in practice.

5 Decision Support

For automated assistance of complex decisions the presented model provides parameters with diffuse limits – elements of fuzzy logic. Rule based fuzzy models assist the elementary selection of suitable components as well as the determination of suggestive dimensions [10]. Another aim is the assistance for decision support in a distributed environment. The use of diffuse limits for planning requirements and –requests in a collaborative planning environment with several planners of different crafts is highly instrumental. Therefore fuzzy methods can collect partial conformity and propose suitable compromising solutions which consider constraints and demands of all involved participants. For instance the request of an architect concerning the displacement of an axis of columns with the formulation "….the displacement should be minimum….and maximum….;….desirable would be…." is more goal oriented than a definition with crisp values.

Another part of the decision support is the assistance for deciding progressions of planning processes in case of changes. These tasks are facilitated by a server sided knowledge base for project- and planning-control (Figure 5). With the aid of this universal and for all participants visible knowledge base it is possible to decide progressions of planning processes for conclusion components (e.g.: openings in beams for installation lines) which affect multiple planning-participants of different crafts. Like in most real world situations one participant is much more affected by design changes than other ones. Initially it is up to this planner to verify the impact of the desired changes. He has to examine all consequences to his specific proofs, whereupon the other crafts verify their proofs. Normally the decision about degree of affection is being done by project controllers, mostly during project meetings. The described *Knowledge Representation Model* provides elements of fuzzy logic to simulate complex decisions of this kind. In this special case of changes concerning conclusion components which affect multiple planning-participants of different crafts it is necessary to define a procedural progression of planning processes instead of the conventional declarative procedure. Figure 7 shows exemplary a basic fuzzy model for such a decision support.

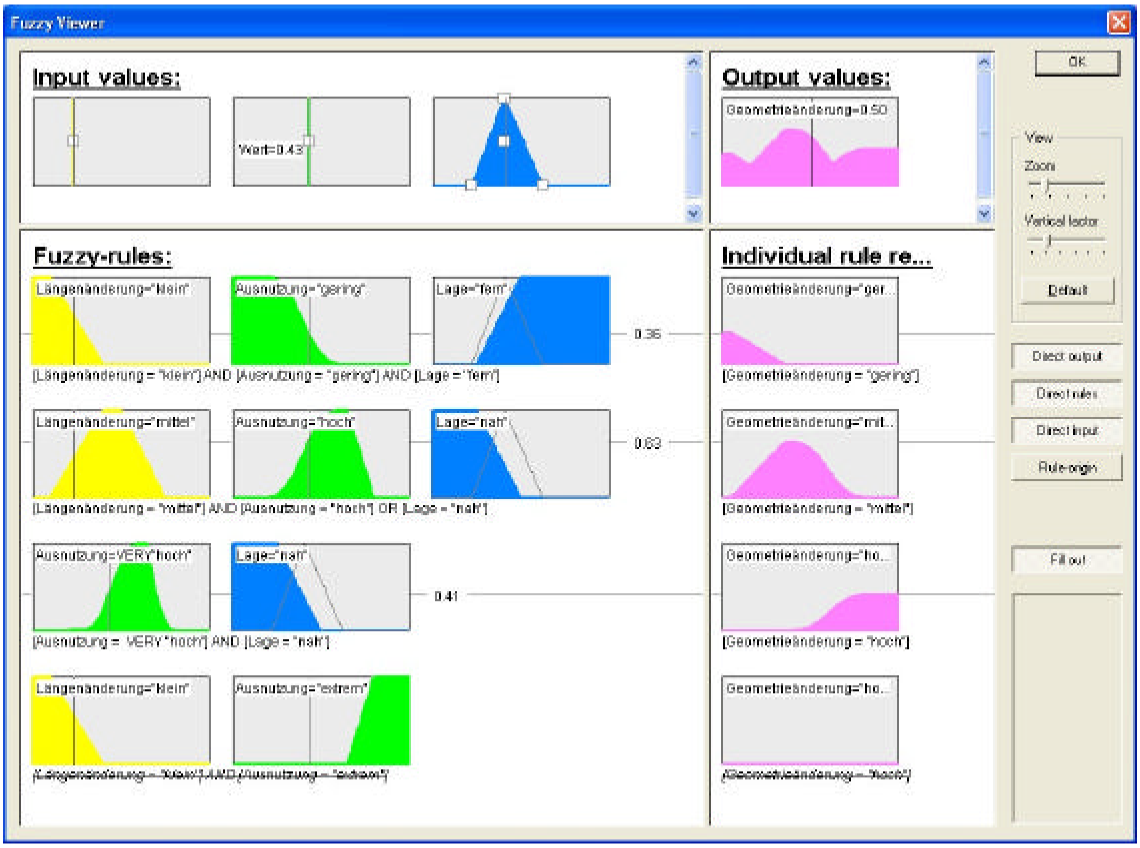

Figure 7: Illustration of a basic fuzzy model for decision support inside the application *Knowledge Base Definition Tool (KBDT)*

6 Endnotes

The aim of the presented research project is the development of concepts for computer supported cooperative design processes based on distributed knowledge bases. In consequence of the explained form of knowledge representation, the integration of heterogeneous knowledge domains is being simplified in a significant way. The different alternatives of knowledge formalization in private and public sectors guarantee a high acceptance in practice.

The advantages of this distributed knowledge based model in comparison to conventional decision processes are manifold. Individual design activities and their impact to other affected crafts are in most cases automatically identified in a complete and transparent way within a distributed, heterogeneous environment. This will be an approach to reduce communication problems, compensation duties and it will highly improve correctness, consistency of planning conditions and finally it will lead to lower planning costs.

7 Acknowledgements

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