KNOWLEDGE BASED MODELING IN NETWORKED COOPERATIVE BUILDING DESIGN USING ELEMENTS OF FUZZY LOGIC

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ABSTRACT

In the field of Civil Engineering, particularly in planning processes involving multiple crafts, ***C**omputer **S**upported **C**ooperative **W**ork (CSCW)* is essential to fulfill the increasing demands of today's building industry. Actually the exchange of information between involved craft-planners during the realization of structural and industrial engineering occurs on an electronic base (internet based project management – IBPM), but solely document orientated. This conventional approach is time- and cost-consuming, as well as inflexible. It may lead to considerable inconsistencies. To avoid these inconsistencies, it is necessary – and one of the most important basics in distributed design environments - to completely identify all consequences of design modifications by the different participants. In this paper a knowledge based system is presented to support cooperative, comprehensive design processes in distributed environments. Furthermore this contribution shows a promising approach for representation of knowledge with imprecise assumptions by use of parameters with fuzzy limits. Possible applications are the assistance of elementary selection of suitable systems, determination of suggestive construction dimensions or sensitivity analyses of modifications.

KEY WORDS

Computing, distributed design, knowledge representation, fuzzy methods, sensitivity analysis

INTRODUCTION

Planning processes in today's building industry more and more face new challenges in terms of cooperation of different planning participants. Integration of existing software systems of different crafts is a very complex task to minimize the efforts which are necessary to synchronize the heterogeneous planning models. Many papers discussing this topic propagate different strategies to improve modeling standardization, integration of existing software and minimization of conversion loss. The model being presented in this paper does neither provide a new standardized data exchange format nor shows ways to integrate existing software.

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Existing software in most cases is exclusively designed to operate according to given instructions which are not really customizable by the user. These instructions may be design standards, they may be based on experiences with designing tasks or they just represent a proceeding the software developers decided. In any way the user is not able to trace the whole process of calculation of specific values, and he is not able to modify this calculation process to suit his specific needs. To provide the desired transparency and customization capabilities to the engineer, knowledge based systems are a promising solution. Applied to a cooperative planning environment with different crafts, special issues in terms of integration and conflict management have to be considered.

This paper introduces a complex software model which is capable to integrate a powerful knowledge based system with a comprehensive, multi objective building model. Both, the building model and the knowledge based system, are being used by different crafts in a distributed, network based environment. Furthermore, important aspects on logical fuzzy models for different purposes are discussed. A prototypic software implementation of this model is being presented, which is operational and systematical feasible to fulfill the desired functionalities of the described model.

THE MORLA MODEL

To provide a promising way of integration of knowledge based systems within a distributed planning environment, the MORLA Model has been developed by the authors. MORLA is the abbreviation for ***M**ulti-**O**bjective **R**epresentation of Know**l**edge and its **A**pplications*. With "multi-objective" the application of this model to different participants of a planning process is meant. Most of these participants will belong to different crafts and are focused on completely different aspects of the design process. Since they are finally working on the very same building, there is a high degree of interference between these crafts. This is true for the basic design, but it is highly interesting in advanced design stages where a lot of redesigning takes place, which affects the already designed parts of other crafts.

An example for craft interference of this kind is the change of a room's usage. In the first design phase a room has been a library, but later on it should be used as an office. Many crafts are affected on this change. The structural loads will decrease, but the air consumption will increase and force the HVAC craft to modify the ventilation system. The expected result may be a larger tube diameter, which also affects the structural behavior through larger openings in walls or beams.

The MORLA model is designed to provide a building information model (BIM) which enables different crafts to cooperate in a way that interferences like in the shown example can be localized quickly. Also the identification and application of necessary re-designs are supported in a way to minimize the efforts for all participants. All calculations and decision support tools are formalized using a knowledge based inference system. This system uses multiple knowledge bases for the different crafts. As mentioned before it is not the primary aim of this model to integrate existing software consequently, because it is not possible to provide the desired degree of transparency using black-boxed modules, and there are no sufficient standardized interfaces to access existing information within current software applications.

Planners often tend to create alternative or experimental designs prior to generation of final designs. The MORLA model provides the mechanism of planning scenarios. Through selective replication designers are enabled to create a copy of their current scenario, apply desired modifications and finally replicate some or all modifications back to the parent scenario. Application of knowledge based calculations to all scenarios with respect to the origin scenarios is also granted. The system does not support a separated product- and process modeling technology, like propagated in (Bretschneider, 1998). Instead, through historical logging every planning stage or milestone can be reconstructed in detail, so a kind of process modeling is virtually integrated.

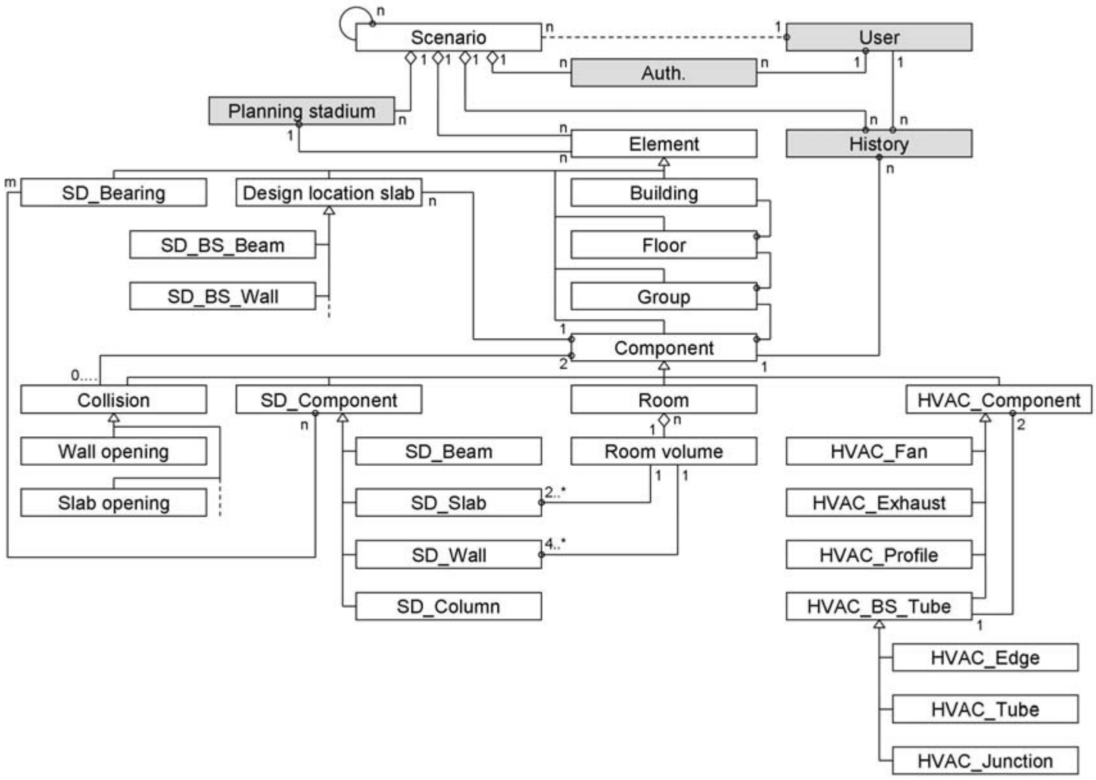

Figure 1: BIM classes of the MORLA model

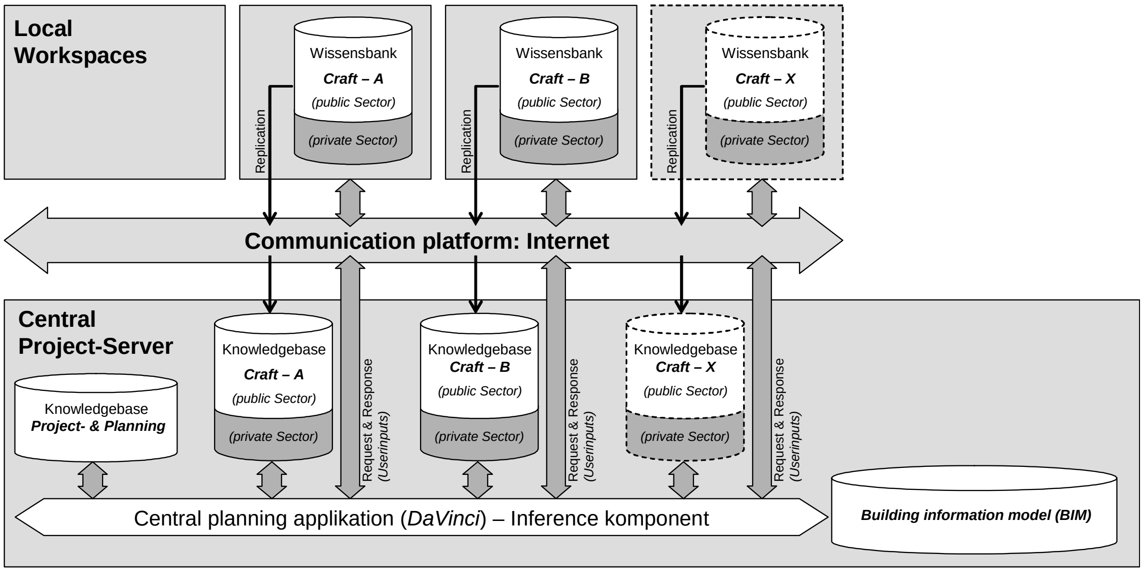

Figure 2: Distributed system architecture

KNOWLEDGE BASED SYSTEM

In contrast to traditional rule based systems, the MORLA model uses a knowledge based system which is based on the work of Garret (1992), Holéwik (1996) and Schnellenbach-Held (2003). This system is less focused on rule based decisions, but more on representation of design standard based calculations and proofs. Through combination of rule based and object oriented knowledge representation this system is called a “hybrid” knowledge based system (Schnellenbach, 1991). The knowledge based system is capable to formalize a vast variety of deterministic calculations, which allows nearly complete application of common design standards.

Due to different procedures within the engineering process a predefined order of calculations is not suitable. The inference component of the knowledge based system uses a declarative form, which assumes backwards chained knowledge representation. One of the advantages of declarative representation is an improved maintenance behavior. It is easy to remove existing knowledge elements and add new ones, without having to place them in order.

The inference process starts with the application of proof selections (resp. sensitivity selections). The inference system detects required parameters and tries to solve them. Since most of these parameters are determined by application of knowledge base elements which are dependent on other parameters, the whole process is being repeated until all required parameters are calculated.

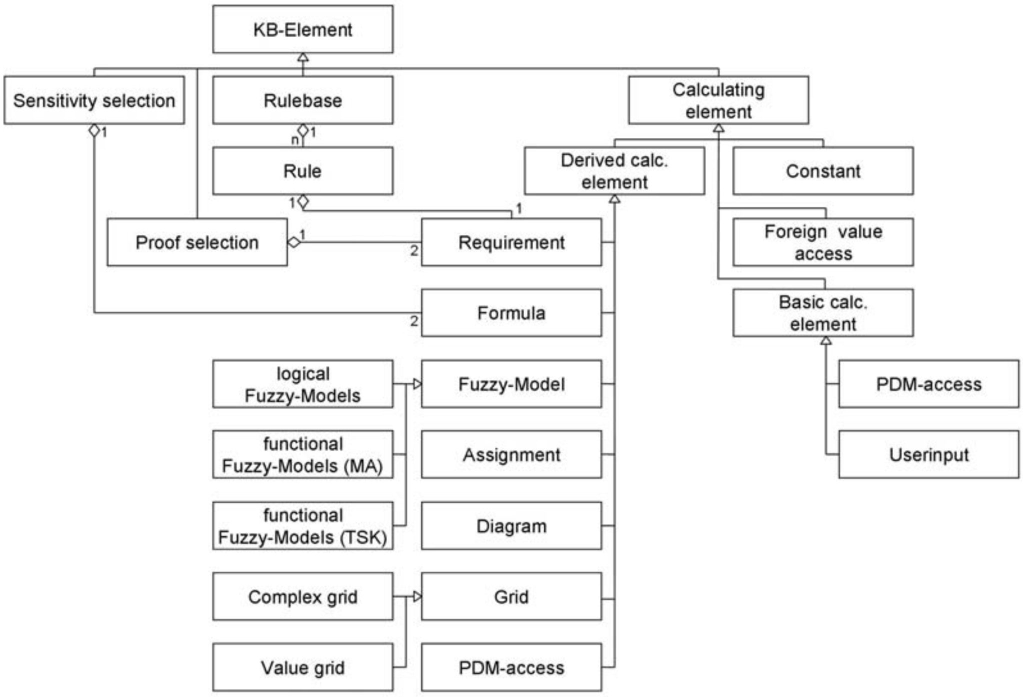

Figure 3: Knowledge base classes of the MORLA model

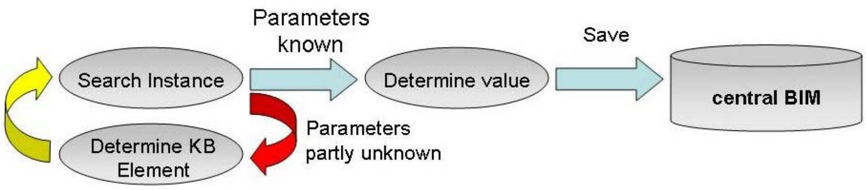

Figure 4: Inference process

The inference process explicitly does not include common search strategies like “depth search first”, “breadth first search”, etc. because of the required precision of design standard based knowledge. If a path does not lead to a feasible result, there is no way to find another suitable result.

One of the most important advantages of knowledge based systems is the transparency and traceability of all calculations. In contrast to “classical” engineering software, where the whole calculation process takes place inside a black box, knowledge based systems provide an explanation component which enables the user to retrace every detail of his model. (See also Figure 8)

APPLICATION OF LOGICAL FUZZY MODELS

Based on the work of Albert (2002), the authors analyzed the application of a set of fuzzy models in the described knowledge based system. Dependent on the kind of application and on the degree of coverage of the search space with pre-knowledge, different types of fuzzy models are used. In cases of nearly complete pre-knowledge, functional models are suitable. These are in detail Mamdani-Assilian models and Takagi-Sugeno-Kang models. The first are easier to handle for manual knowledge acquisition, where the second are the better choice for automated acquisition, for instance by use of genetic algorithms (Freischlad, 2004).

In cases of incomplete pre-knowledge, logical fuzzy models have been proven as a robust and satisfying method. The main advantage of these models is the rule independency. Each rule is representing isolated, corresponding logical information. A disadvantage of logical models is the complexity of the results. Functional models typically lead to results, which provide a numeric value (through defuzzyfication). In contrast, logical models provide the degree of possibility for every value within a search space. So with lower degree of search space coverage less rules get applied, and the result will be more undefined. Classical defuzzyfication methods, like “Center of gravity”, “Mean of maxima”, etc. are not suitable for application with logical results, because logical fuzzy models represent negative information only (Dubois 2000). Anyway, for many engineering tasks a single numerical value is required.

To solve this problem a defuzyfication method called “NMTCOG (Nearest maximum to center of gravity)” has been developed by the authors (see fig. 5). The principle of this method is an integration of MOM and COG in the way that the result in any case is within the maximum possibility values, but as close as possible to the center of Gravity. This guarantees the highest possibility rating for the proposed numerical result, while the global rating of lower possibility values is also applied in a meaningful way. The NMTCOG value is being determined as follows:

$$y_{def,NMTCOG} = \mathrm{MIN}\left(\mathrm{MAX}\left(\mu_{\tilde{A}^j \to \tilde{B}^j}(x,y)\right) - \frac{\int y \cdot \mu_{\tilde{A}^j \to \tilde{B}^j}(x,y)\,dy}{\int \mu_{\tilde{A}^j \to \tilde{B}^j}(x,y)\,dy} \right)$$

Formula 1: NMTCOG

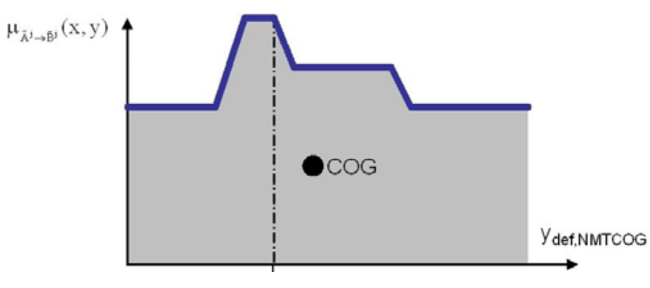

Figure 5: NMTCOG-Defuzzyfication

To give the engineer a meaningful validation of the results (Dubois 1985), an additional specifity value (PDS – Parameter for determination of specifity) is being provided. The determination method for the PDS reflects certain subjective assumptions, for instance the fact that an undefined NMTCOG area (everything is completely possible) must lead to a PDS of 0.0, and narrowing of the maximum range should increase the PDS. Many similar assumptions finally lead to the following PDS determination. The PDS consists of two parts. PDS_I regards the area parts with their distance to the COG. PDS_{II} represents the area of the functional fuzzy result.

$$PDS = \sqrt{PDS_I} \cdot PDS_{II} \qquad PDS_I = 1 - \frac{\int_0^{y_{def}} \mu_{\tilde{A}^j \to \tilde{B}^j}(x,y) \cdot \left| y - y_{NMTCOG} \right| dy}{\int_0^{y_{def}} \mu_{\tilde{A}^j \to \tilde{B}^j}(x,y)\, dy} \qquad PDS_{II} = 1 - \frac{\int_0^{y_{def}} \mu'_{\tilde{A}^j \to \tilde{B}^j}(x,y)\, dy}{y_{def}}$$

Formula 2-4: Determination of the PDS

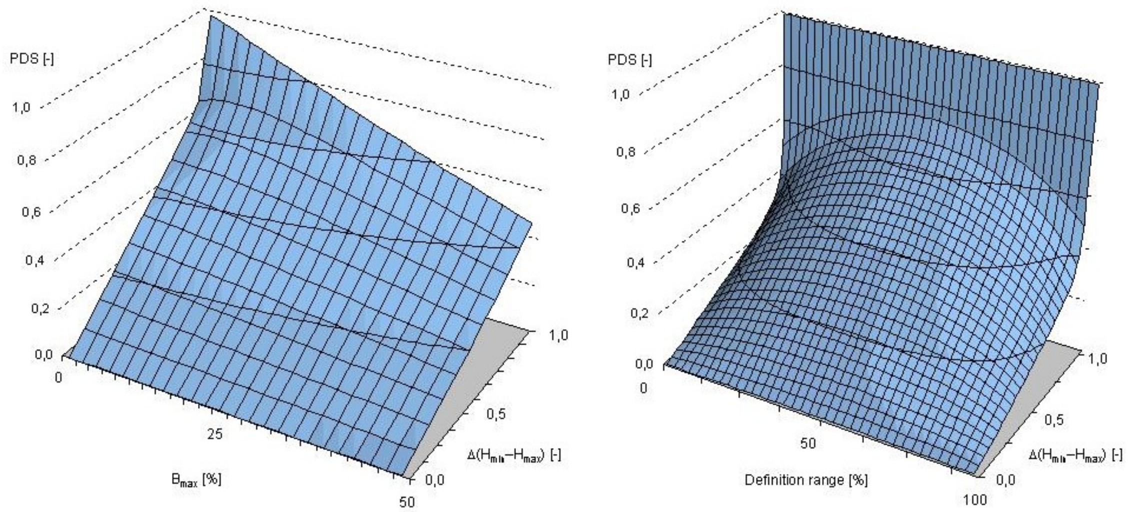

Figure 6: Specifity of NTMCOG results

Fig. 6, left diagram, shows the relation between PDS, the width of the maximum value in relation to the definition range (B_{max}) and the difference between the highest and the lowest possibility value (H_{max}-H_{min}). Fig. 6, right diagram, shows the behavior of the PDS dependent on the NTMCOG value compared to the definition range. This ensures the reduction of the PDS for NTMCOG-values close to the boundaries.

One application of the described logical fuzzy models is the separation of relevant changes from irrelevant ones. For instance the position of a column might be changed by a few centimeters. Deterministically this induces a change in the reaction force of any other column in the building, but it will usually not affect the whole design of all other columns. It is therefore important not to highlight such irrelevant changes which might distract the designer from the relevant elements. In the present research work such complex decisions are supported by the described fuzzy logic models in the scope of a sensitivity analysis in change management.

PROTOTYPICAL IMPLEMENTATION

The described concepts have been evaluated by implementation of two prototypical software applications. The application "DaVinci" (Domain augmented environment for intelligent and networked cooperative design) covers all BIM-relevant operations and the application of knowledge bases to BIM instances. DaVinci is designed to work in client / server mode to enable cooperative work. For creation and modification of knowledge bases the application "KBDT" (Knowlegde base definition tool) has been implemented.

Both applications have been used in many experimental projects covering the domains of structural engineering and HVAC. The involved engineering students were able to use these applications productively and to create knowledge bases without programming knowledge, which is a main criterion for a applicable knowledge based system.

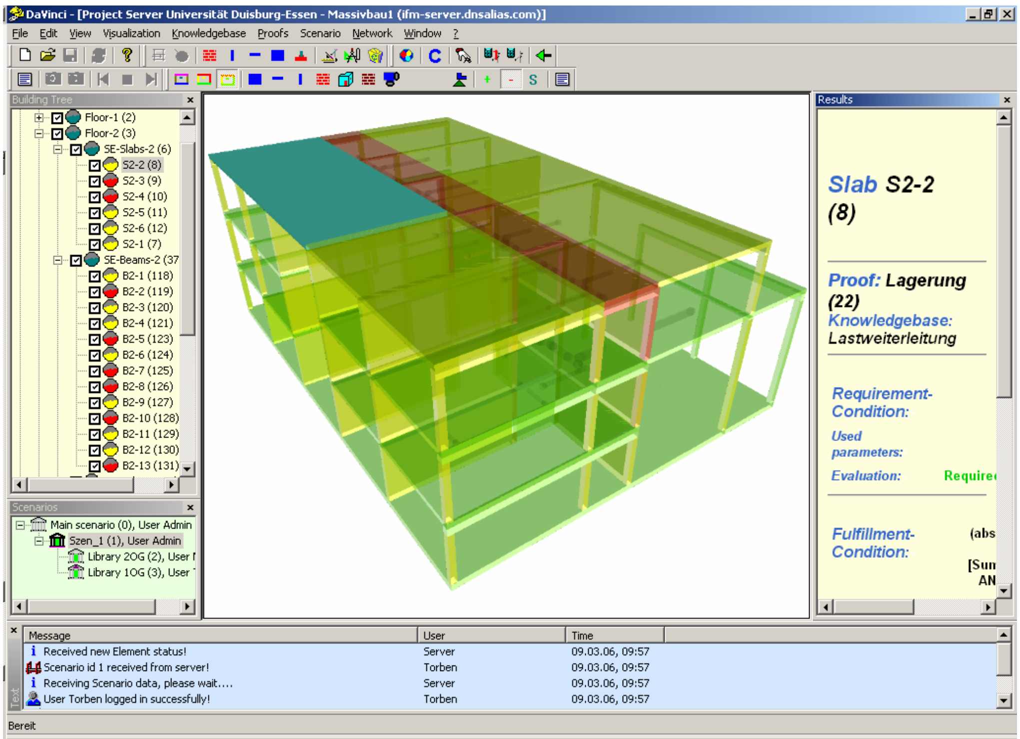

Figure 7: Application DaVinci, Sensitivity analysis mode

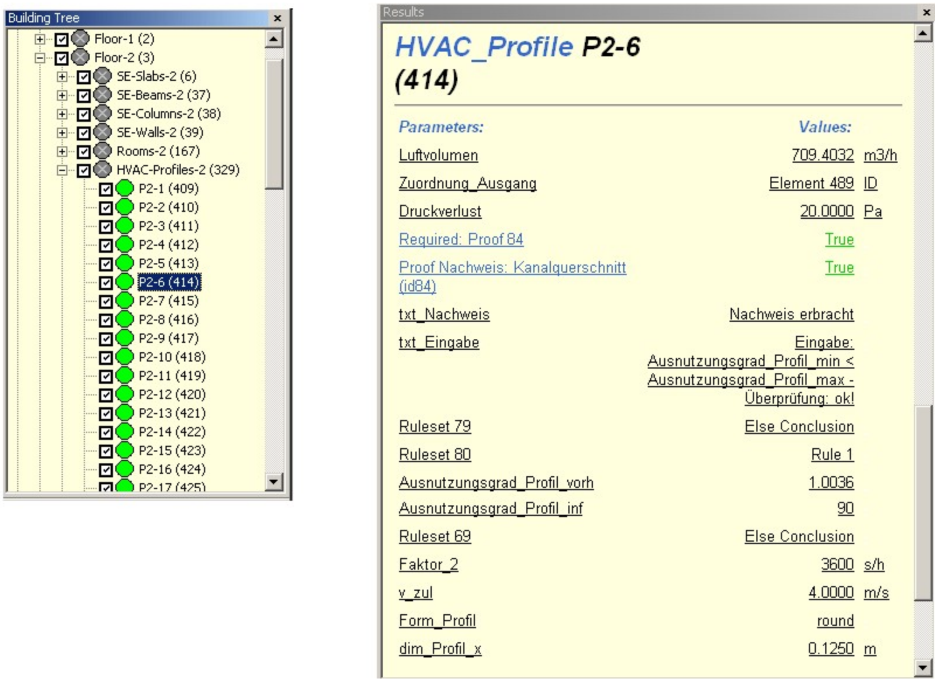

Figure 8: Explanation component of DaVinci

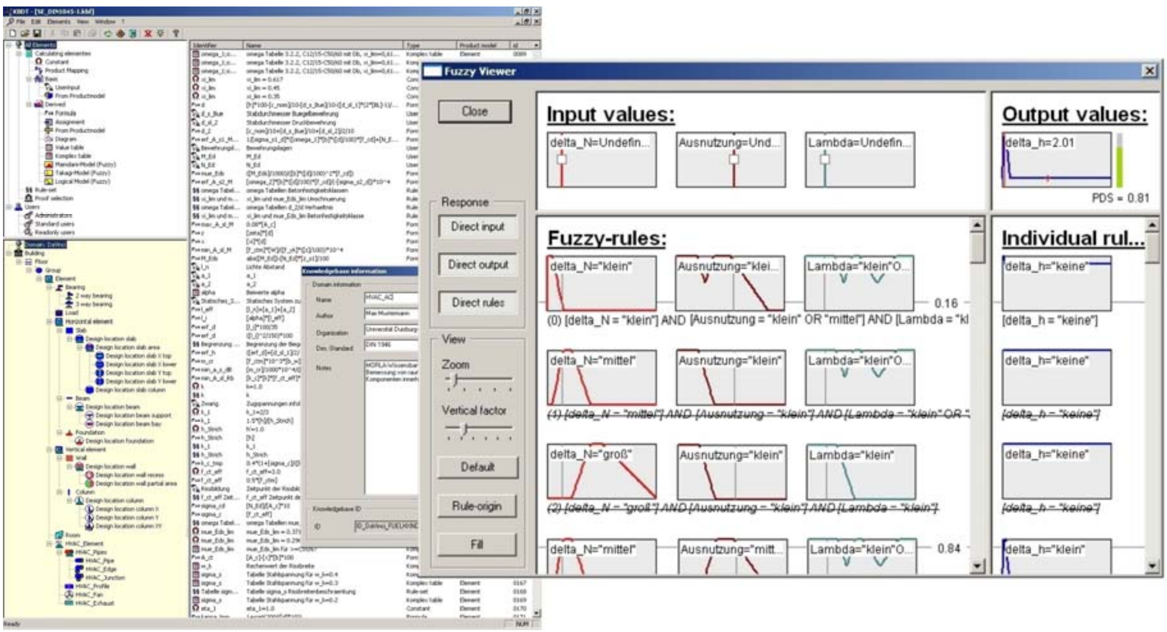

Figure 9: Application KBDT and Fuzzy Viewer showing a logical fuzzy model

CONCLUSIONS

The presented paper shows a promising concept for distributed, networked cooperative design. In contrast to existing distributed planning concepts, the provided model is able to support different crafts in conflict situations on a transparent, knowledge based way. Through application of logical fuzzy models allows handling of incomplete and fuzzy information, for instance to give craft spanning sensitivity information on proposed changes. These mechanisms can be a valuable assistance for all planning participants of a project and finally will reduce errors, planning costs and needed design time.

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