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USING KNOWLEDGE-BASED ENGINEERING METHODS IN DESIGNING WITH MODULAR COMPONENTS OF ASSEMBLY SYSTEMS

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1. Introduction

Modular construction based on modular components of fast assembly [BoschRexroth 2009], [ITEM 2009] are more and more often used in many technological branches as their usage shortens significantly the time of designing, implementation and launching of a designed object. Such systems are used for repetitive objects of given constructional forms such as filling in office and industrial spaces, warehouse shelf racks and working tops, elements of production lines (Fig. 1) (conveyors, robots, drives etc.) A great number of suggested elements of assembly system enables construction of optimal and elastic solution and what is more the use of ready made elements and subassemblies reduces the time considerably.

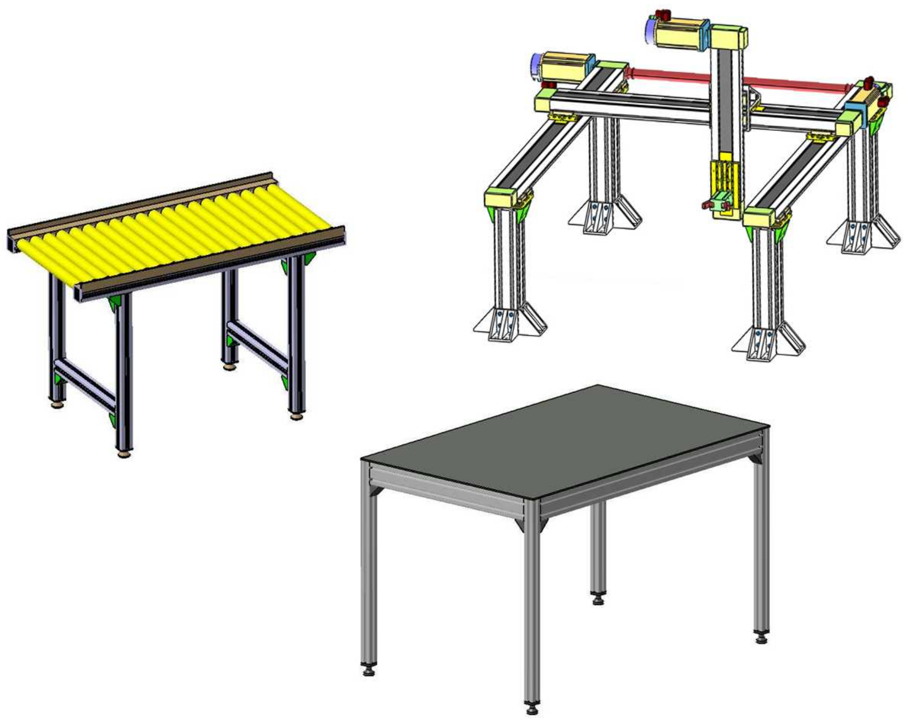

Figure 1. Examples of various products constructed from components of assembly systems

Designing a product from assembly system components is not an easy task and despite the limited number of components and resulting from this fact finite number of designing solutions there is a lack

of advanced aiding tools for a designer. The number of system components is very big and new components are being offered constantly. Nevertheless, designers are aided first of all by catalogues of ready made parametric components as well as detailed guidelines for the selection of some components. These catalogues accelerate the very modeling of design in CAD (Computer Aided Design) system and detailed guidelines on selection of particular complex components which are available in catalogues simplify routine activities of designing process.
Common usage of such systems of fast assembly allows application of more advanced aided designing methods of objects consisting of such components. For that purpose of designing products consisting of assembly system components methods based on KBE (Knowledge-Based Engineering) have been suggested. The use of knowledge-based methods is possible when designing any object but due to high time-consuming factor connected with formal identification of designing processes and designing knowledge space it is profitable mainly while designing repetitive products [Hopgood 2001].
It is particularly useful when [Skarka 2009]:

- routine designing procedures are used,
- target form of a designer product is well known,
- given class of objects constitutes the subject of designing,
- it is possible to identify and record knowledge concerning designing process.

Among the methods based on knowledge the application of generative models [Sandberg 2003], [Skarka 2009] is worth mentioning, which allows the use of CAD environment and directly CAD model for knowledge integration from designing process. Therefore, generative model is not only an extension of parametric CAD model but it forms a knowledge base relying on construction features represented by CAD model features. So far the designer basing on his knowledge which was derived from the outside and additional computer tools e.g. CAE (Computer Aided Engineering), determined designed product features in CAD model. However, in generative model this knowledge integrated to the very CAD model independently manages design features by its own. Generative model is a record of a given class of product which was created on the basis of identified knowledge space as opposed to a record of single product instance.
Since generative model is to reflect detailed relations between design features and functional features which up till now have been identified on the basis of designing procedures, it is necessary to record these procedures formally and identify these relations as well as redefine the way of integration in CAD model, basing on given scenarios regarding the degree of advanced level and scope of generative model operation.

2. Scenarios of generative models usage for design with assembly system components

For assembly system components two scenarios (Fig. 2) of generative models usage have been distinguished and two corresponding ranges of generative model creation concerning:

- parts (assembly system components),
- assemblies.

The first one covers the application of models for single elements of assembly system. Because particular elements of assembly system are not designed while their form and a set of design features values are known, then during generative models preparation geometric form is prepared and alternative values of construction features are introduced as for a regular parametric model. As opposed to regular parametric CAD model, relations are identified between other system elements (Fig.3).
For a beam and a beam fastener connector (Fig. 3) there is a relation between size index i.e. it is possible to join elements of congruent size indexes and what is more connector is fastened only in given position i.e. set surfaces of a beam groove and connector are adjacent. Identification of these relations (in each part with relation to another part) is a time consuming task although taking them into consideration is relatively easy thanks to the usage of knowledge templates (CATIA system) [Skarka 2009]. How do we use such pre-prepared generative models of a beam and a key connector. Assumingly a connector is added by inserting it and identifying features with which there is a

connection of two elements. It is similar to Lego blocks when they connect only in a given position with their tips fit to other block, here by pointing to features on the basis of which automatic connections are built on predefined relations, results in automatically adjustment to the size of a key connector to the beam size as well as its correct location (Fig. 3). Furthermore, such connection is constantly monitored and when there is a change of one element feature e.g. its size or configuration, the connected element reacts intelligently by adapting to another part.

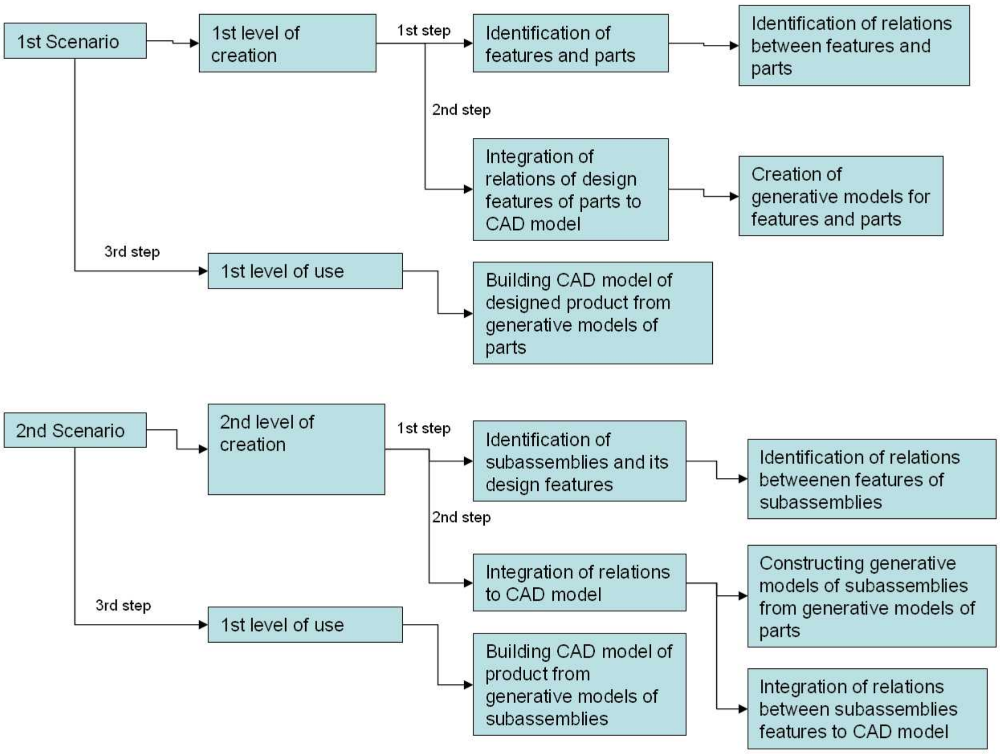

Figure 2. Scenarios of creation and use of generative models

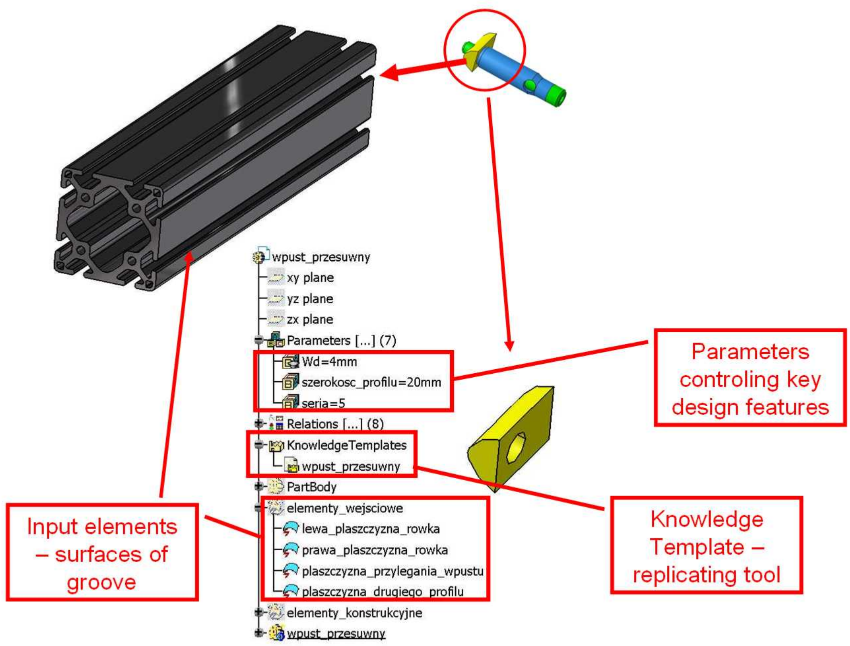

Figure 3. Example of part (key) generative model with integrated relation to another part (beam)

The second scenario covers the use of generative models at the level of assembly which do not directly exist in catalogues of components. Such assemblies, at the first approach, are built based on generative models of assembly system components. As an example of such subassembly a roller conveyor can be given, which is often used in process lines. Putting such a conveyor together from ready made generative models enables quick reaction of model to changes in single elements but do not reflect tasks of designing process of it such as e.g. choice of form or size of frame or rollers depending on a transported object. In the next phase of generative model preparation for a given class of design (e.g. roller conveyor) detailed designing procedures, alternative forms of design, principles of design are defined and then integrated at the level of these subassemblies. For a straight line fragment of roller conveyor, prepared generative model introduced to process line construction, requires determination of parameters of transported object such as size and weight and on that basis a model of a fragment is generated automatically.

Distinctive feature of the process of generative model system construction is its general form. In no way is it connected with the subject of designing and can be used in designing other objects of assembly system such as exhaust system of cars [Skarka 2007], subassemblies of general machine design [Skarka 2009] characterized by high degree of routine works and thus high time consumption. The whole process of generative models construction has been worked out on the basis of KADM (Knowledge Aided Design Methodology) methodology [Skarka 2007], covering the whole range of processes from identification and recording of designing knowledge to its integration in a form of generative models. The main phases of the process have been described below.

3. Knowledge acquisition for creation of generative models of assembly system components

Since generative modeling is a modeling which relies in knowledge integration to CAD model, the quality of generative modeling depends on the quality of acquired knowledge. Thus, particular attention should be paid to the processes of acquisition, maintenance and up-dating of knowledge [Shadbolt et al. 1999] and specifically to the right choice of methods and tools as well as selection of the correct form of knowledge record. Often incorrect assumptions are taken since this knowledge exists it is possible to integrate it to the models [Young et al. 2003]. However, proper choice of identification methods and knowledge record enables its easy processing and analysis. For knowledge acquisition and processing in product designing based on assembly system, guidelines of KADM methodology [Skarka 2007] have been used which are partly derived from known MOKA (**M**ethodology and Tools **O**riented to **K**nowledge-Based Engineering **A**pplications) methodology [Stokes 2001] and PCPACK5 [PCPACK 2009] has been employed as aiding software.

Ontology which has been elaborated especially for that task has been used for knowledge record. Ontology can have different forms but it must have a glossary and specification of the meanings as well as mutual relations between terms. The whole forms constraints of possible interpretations of terms [Uschold et al. 1999]

The created application which aids the process of knowledge acquisition has been implemented on a server of team work and is of a character of a designer's assistant [Pokojski 2003]. It has been assumed that knowledge will be acquired directly from designers and they will have remote access to knowledge base. The following forms of knowledge record are used:

- Activity diagrams,
- Class diagrams,
- Matrixes,
- Taxonomies,
- ICARE (**I**llustrations, **C**onstraints, **A**ctivities, **R**ules, **E**ntities) forms

The above mentioned forms of record allow not only creation of knowledge bases but also constitute some kind of specialized views on knowledge included in knowledge base and showing only these elements and relations (or kinds of them) which in a given moment a user wants to see (Fig. 4). It enables good command over complex knowledge base.

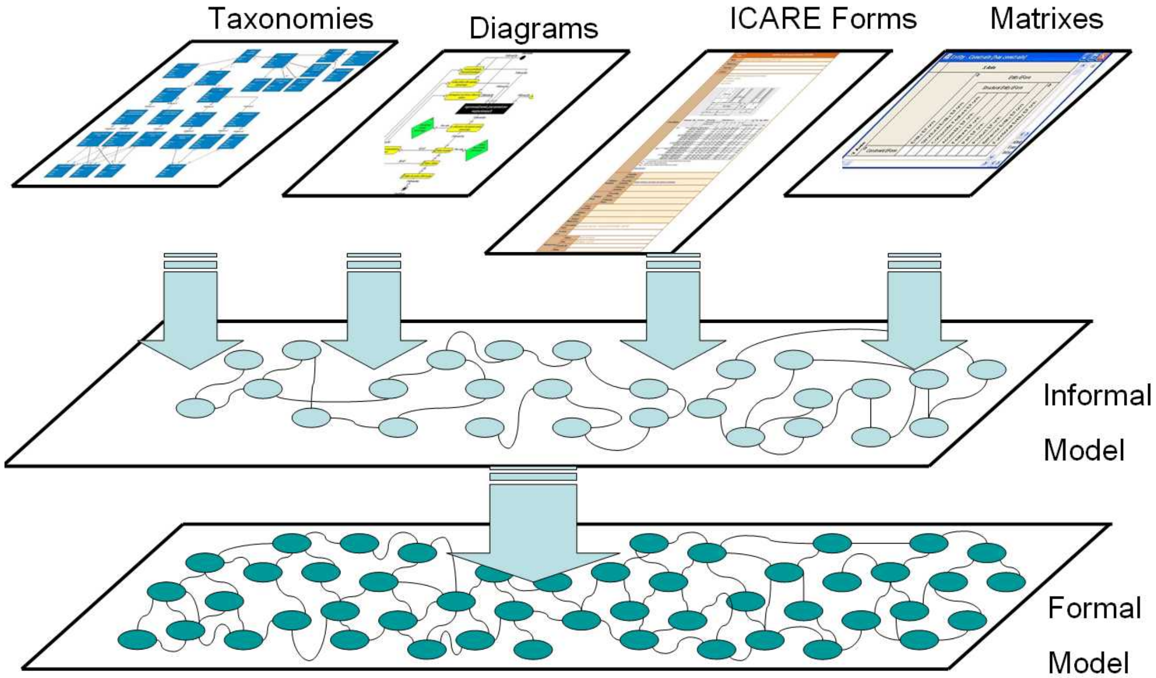

Figure 4. General structure of knowledge base ontology

The whole ontology is divided into two basic models (Fig. 4): formal and informal. Informal model is oriented on designing process record and the structure of designed product, whereas formal one is oriented on record of generative model structure and the processes of generative model creation.
In other words, informal model is independent from CAD tools way of recording knowledge, referring to designing process and structure of a designed product. Formal model forms however, the same knowledge recorded in forms of record available in a given CAD tool and therefore is oriented to a specified CAD tool (e.g. CATIA, Inventor etc).
Knowledge is recorded first of all in a user friendly form of diagrams. Diagrams used in knowledge management in PCPACK are based on UML (Unified Modeling Language) [OMG – UML 2009] language. For designing procedures activity diagrams are used (Fig. 4) whereas for product structure diagrams class diagrams are used. One is able to define also relations between knowledge base elements on these diagrams. Additionally, for defining relations matrixes have been intended while taxonomies are designed to order hierarchically the resources of knowledge base. However, they are ICARE (**I**llustrations, **C**onstraints, **A**ctivities, **R**ules, **E**ntities) forms which record the most detailed entries.
Example of such Activity diagram and ICARE Form relating to one of the rules is shown in figure 5. Presented Activity diagram describes generally the following steps in process of selection of gate robot drive. Diagrams have multilevel construction. Action of each activity can be controlled by Rule. Each activity or Rule can be described by ICARE Form. In ICARE Rule Form which is presented in figure 5 details concerning rules of drive VKK selection for gate robot are presented. Each Activity can be described by another activity diagram describing in more details analyzed process step by step.
The form of ICARE forms derives directly from MOKA methodology. There are five types of these forms: Illustration, Constraints, Activity, Rule, Entity. Each of them is a record template of main diagrams and taxonomies mentioned before. Some fields in the table are automatically filled and reflects information already recorded in graphic form e.g. in diagrams,but some are edited directly by a user.
Both Entity and Constrains forms belong to structural diagrams.
Entity form is for recording information concerning structure entities e.g. product its subassemblies, elements and features or generative model structure.
Constrains forms are for recording limitations put on elements of entity type.

Both Activity and Rule forms belong to activity diagrams and so
Activity is for recording detailed information referring to designing activities whereas
Rule is dedicated to record general rules managing particular designing activities.
Illustration form is designed to record additional nonclassified information.

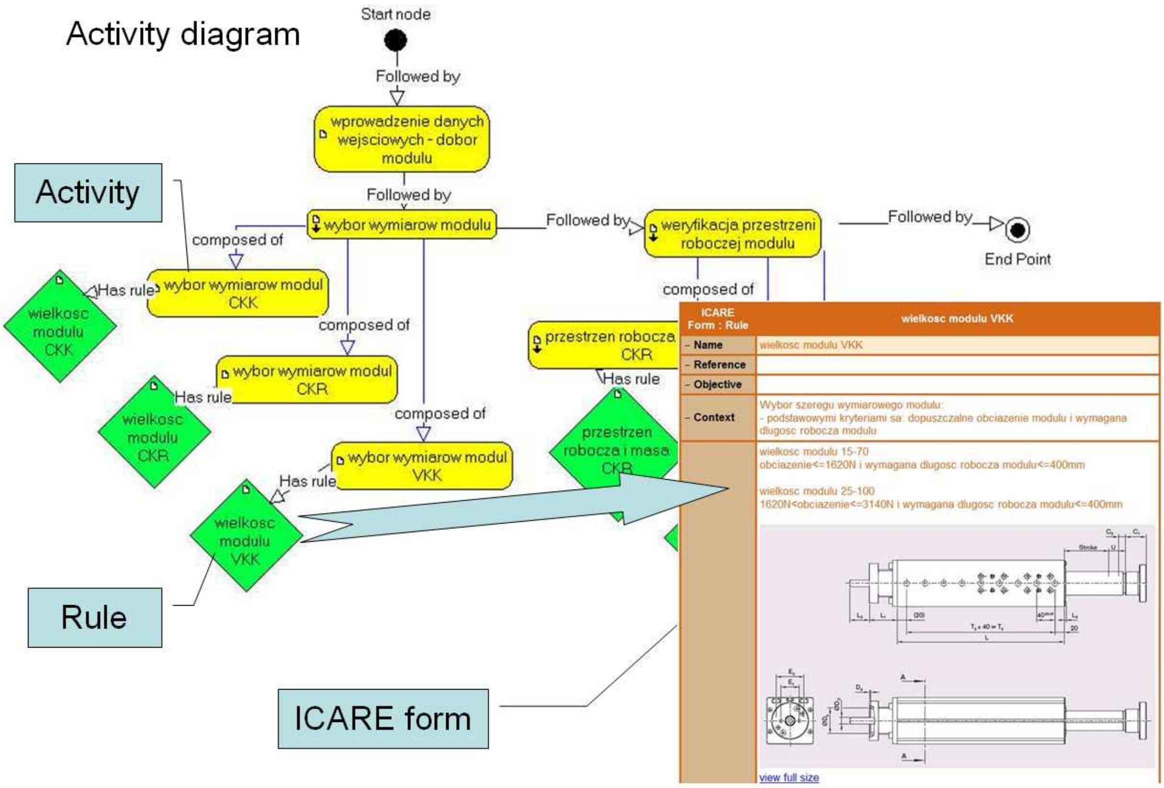

Figure 5. Example of Activity Diagram connected with ICARE Form for gate robot knowledge base

4. Creation of generative models of assembly system components

Creation of knowledge base and its detailed analysis aims at full identification and description of principles of choice of particular components of assembly system, discovering dependencies between design features in a component as well as between components. Full identification of the structure of design features constitutes basis for correct defining of generative models. Design features which are described in knowledge base are reflected in a model and relations between these features are reflected in a form of relations in generative model.
At the level of single components of assembly system vast majority of them refers to simple issues.
As shown on figure 6 previously mentioned beam connectors are selected suitably to the profile size. In the generative model of a connector it has been planned that parameter of size index is set on the basis of the size of beam index. Nevertheless, the location of coupler in a profile is determined by the surfaces of collaboration of both elements. In other words, generative model of connector ‘knows’ which input parameters should be determined for generating an instant of connector, and while inserting it into a model it orders a designer to determine parameters. Determination of input parameters is carried not via giving them directly by a designer but via pointing to parameters/design features in an already existing model with which it is to be connected. For an inserted connector there are indexes of the profile size and surface of connector mounting. A relation created in this way is durable i.e. in case of profile change , its location or size, connector automatically adjusts to the profile. The whole design model in CAD environment can be quickly put together and updated; geometric and meritoric connection of features of particular elements ensures instant adaptation to the model changes.

The key issue in the creation of generative model for components of assembly system is the fact that integrated knowledge is a direct reflection of, previously recorded in knowledge base, process of components selection (as for beam connector from figure 6 and associated active diagram)

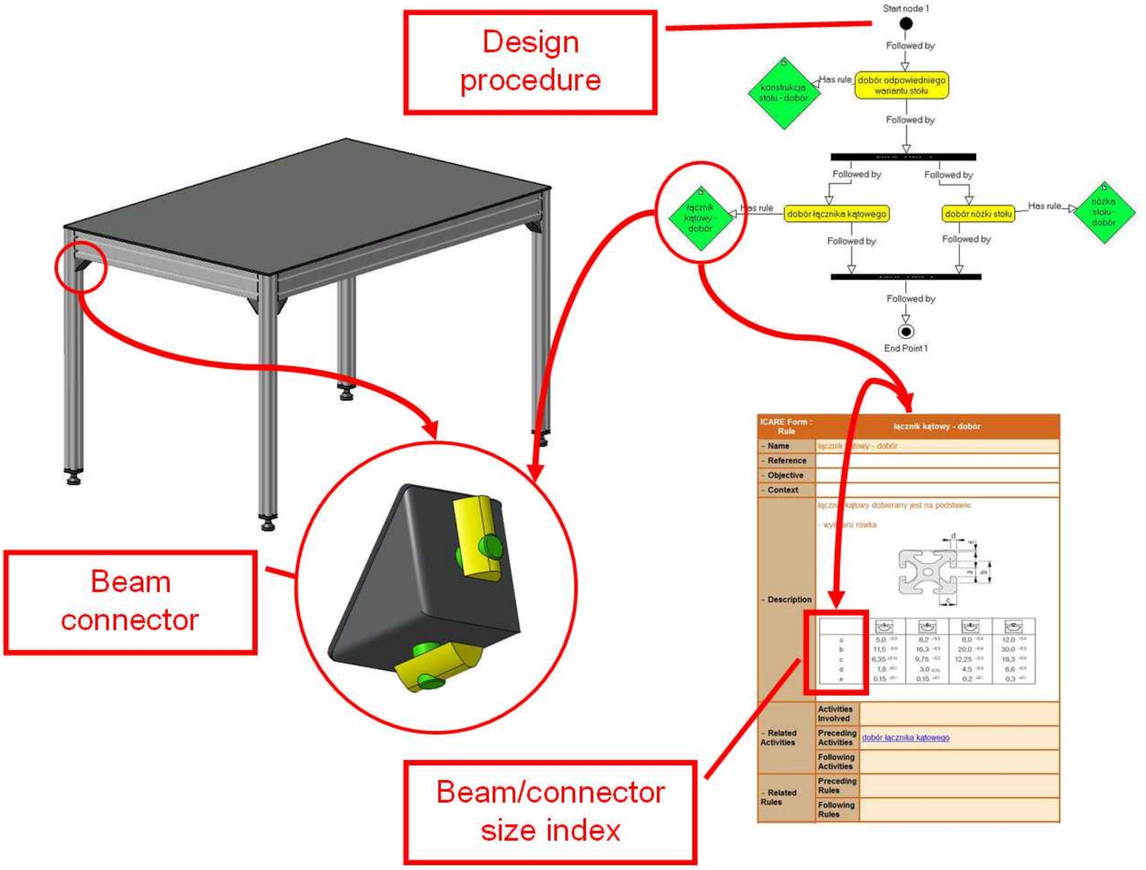

Figure 6. Relations between features of components of assembly system from knowledge base are reflected in generative model

5. Creation of generative models for a given class of assembly system object

Creation of generative models for a given class of objects or subassembly made from ready components of assembly system differs significantly from creation of generative models for particular components. Relations which are identified in the process of knowledge acquisition are of a very complex character. They refer to dependencies at the level of assemblies and design features and functional features of assemblies or the whole product. As far as design matters are concerned, relations are more important and they reflect more essential knowledge for a designer of design, functional and technological character referring to determination of values of design features of a given class of product. As examples of such relations one can mention the choice of the thickness of the deck of workshop table depending on the load, base and the character of support (Fig. 7). Since relations often link many design features and mutual dependencies cover a few or dozens of features managed by different rules therefore it is very difficult to separate these relations into consecutive designing task which would be represented in CAD model by means of e.g. a rule or optimization task. Hence, the division of nets of identified mutual relations between construction features of different character constitutes the most important task in the creation of generative models in a given class of product. The whole model is built in such a way that on the basis of a set of functional features, the values of construction features are determined.

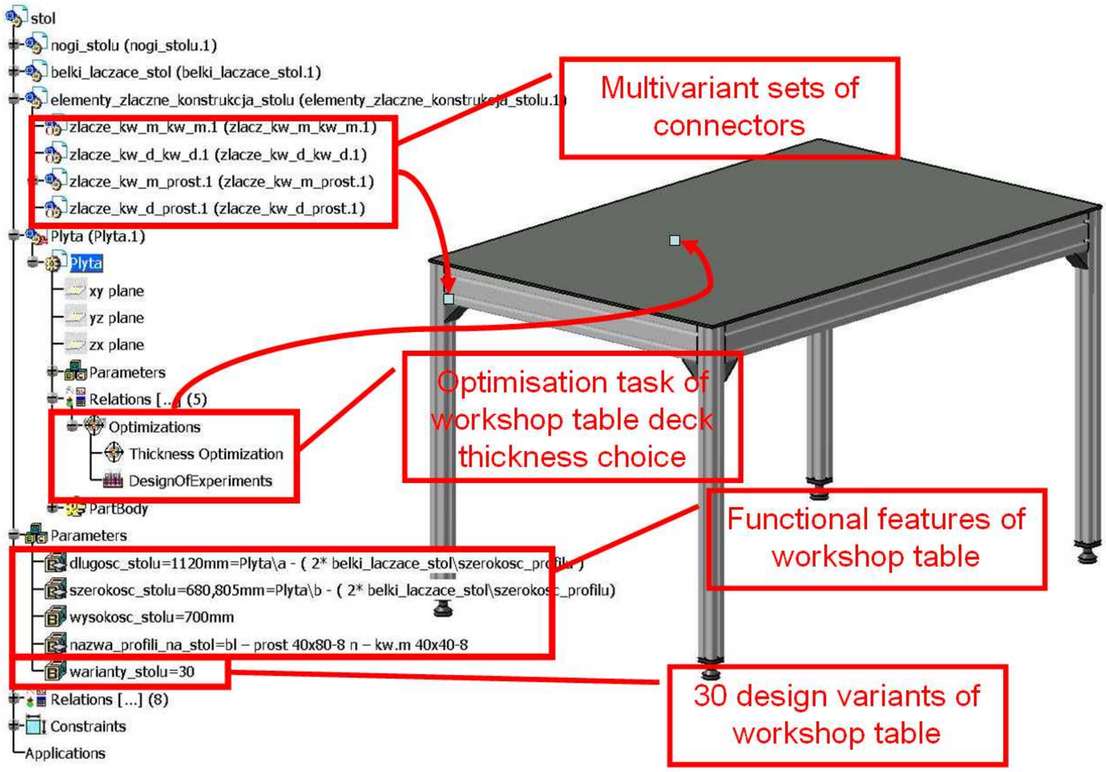

Figure 7. Example of integrating optimization task in workshop table generative model

Figure 7 shows example of generative model of workshop table made from components of assembly system. Design features, parameters, relations and activities in structure tree of workshop table model are derived directly from knowledge base. Inputs to the model are formed by a set of functional features like assumed dimensions and loads of table design features of table are calculated from mutual relations, rules and constraints described in knowledge base. Depending on these relations, rules and constraints not only design features but also variants of table are recognized. Example of such task is optimization task. It is integrated in the table and solved with alternative methods (optimization algorithm or design of experiment). On the basis of this optimization task some values of design features are calculated.

Relations and particular activities of designing process are most often integrated by the following functions of CAD system:

- design tables,
- formulas,
- rules,
- checks,
- knowledge templates
- optimization tasks
- or in a program way e.g. by macros or using API (Application Programming Interface) of CAD system,

6. Conclusions

Designing with the use of assembly system components is an excellent subject for aiding with Knowledge-Based Engineering method and in particular with Generative Modeling. It is due to the specific construction features and namely such as:

- precisely determined form of assembly system components
- accurately determined set of forms in the scope of single class of design created by means of assembly system components

- vast participation of repetitive and routine activities in the designing process of a given construction class

Verification of the usage of Generative Modeling method has been done for assembly systems of two independent producers of systems [BoschRexroth 2009, ITEM 2009] and in the range of three construction classes- gate robots [Jastrzębski 2009], roller conveyors and working tables [Borusiński, 2009]. It has covered components which are part of these three classes of products.
Although preparation of generative models is a time consuming process, during its creation apart from the generative models other numerous advantages are achieved. Ordering and analysis of up till then design activities are carried. Additionally knowledge base is created where knowledge used in designing is recorded. Moreover, contradictions of designing process are eliminated as well as steps of this process are simplified and verified.
The fact that activities of knowledge acquisition and its integration to generative model are time consuming is compensated in the usage of generative models. In the first scenario at the stage of modeling, designing time is only slightly decreased whereas in the stage of design changes introduction in CAD model, due to the existence of defined relations in generative model restructuring of the model and consideration of many different versions is significantly shortened. In the second scenario there is a considerable time shortening of designing and modeling in CAD system.
Great time consumption of the process of knowledge base integration to generative model obliges to undertake research on automotive integration of knowledge base to generative model. Therefore, it is necessary to expand ontology in the scope of formal model. Initial steps taken in this direction gave positive results but the degree of complexity of construction representation in different CAD systems hinder the development of ontology in that respect.

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