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IMPLEMENTATION OF MATHEMATIC MODELS IN DESIGN AUTOMATION

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Abstract: In this paper will be given an example of a mathematical model implementation in the design automation process. The introductory part of the paper shows the current commercial solutions for design automation. The critical overview of this field is given all along with the good and bad sides of design automation. The practice example of design is chosen for this investigation. Before the design model is made, the design is translated to mathematics parameters and the algorithm for user communication is solved. Special attention to the user communication interface is paid to minimize errors that can happen by human mistakes. The paper concludes with mathematical model advances in design automation as well as the bad sides of this approach. Also, further research directions are pointed out.

Key words: mathematic modelling, problem formulation, design automation

1 INTRODUCTION

Nowadays, the industry is growing very fast and as a consequence of that, it is faced with a new generation of fully digitalized production companies. With development of process automation and internet of things industry started to growing even faster. With those new features the today's industry is called Industry 4.0. The digitalization and automation ensures industry and its competitive development in modern conditions. One of the most important part of industry digitalization is communication between customers and manufacturing facilities via product developers and product designers. Today, many products, especially the families of products, can be automatically designed and put to manufacturing automatically between customers and production design automation systems. In this modern systems the role of product

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developer-product designer is to make an automatic bridge between customers and company production facilities. These systems are very suitable for typical products such as: furniture, transportation systems, process equipment, workshop tools etc.

Automation in CAD design assembly process is very interesting since first CAD packages appeared. *Dinev* et. al [1] has presented in their investigation how the components of an assembly are automatically related in function of chosen assembly variant. On the other investigation *Dinev* [2] went further and showed how the FEM analyses can be automatically performed. *Tarkian* [3] in his PhD dissertation showed examples of optimization in design automation in order to gain fast and optimal solution for the problem of frame loader. A very interesting research about design automation [4] was shown by giving examples of automation of design of transport aircraft, industrial robots, and micro air vehicles. Some authors went further from design automation and tried to get fully automated design drawings, [5]. Design automation can also be based on modular blocks of the design, [6]. Some CAD packages are not parametric base yet, so the easiest automation which can be done there is commands by scripts [7]. This is mostly AutoCAD related. An interesting design automation problem is shown in paper [8], which present how the curves of the second order can be automatically designed. Special attention is given to communication between CNC machines and designer in order to create a special bridge to accelerate manufacturing. Investigation like this is shown in the paper [9], and these examples was feature based from model to manufactured part. The communication between different design users which can accelerate design automation is shown in the paper, [10]. The interesting problem is applying a configurators in the design automation, which is shown in papers, [11]. An interesting review paper shows [12] how far is field of configurators went. The latest research in this field are data driven automation which accelerates the design process in big amount, [13-15].

An example of an automated design example is shown in this paper. The aim of the paper is to show advantages and disadvantages of mathematical modelling in design automation on the simple problem.

2 MATHEMATIC MODELS AND PARAMETERS IN DESIGN AUTOMATION

Modern CAD packages offers a variety of tools and commands to increase the flexibility of geometric models. However, to utilize them in efficient way, there is a need for tool-independent, generic modeling techniques. Mastering these techniques in the most cases eases the way towards design automation, since it represents:

1. A basis for solving tasks that involving geometry design automation.
2. A helpful tool to consult when is necessary to reach fast solutions.
3. An algorithm to locate the required geometric design automation level more easily.

To achieve design automation, knowledge based engineering methods can be employed to effectively capture knowledge by storing rules, relations, and facts in a functional mathematic model. In this paper, knowledge based engineering and mathematic modeling is used to support High Level CAD modeling by creating High Level CAD templates (HLCts) i.e automated CAD design. These methods are higher abstraction geometries that can be automatically instantiated in the design of new products. In the presented paper, it has been chosen to divide geometry transformations into two categories and include them step by step. The first category will describe the morphological levels of geometric modeling while the second will reflect on how to effectively increase, reuse or replace the number of geometric objects, hence its topology. Morphological changes are transformations that occur within the same instance of a given class, i.e. it is enough to re-evaluate the instance.

Topological changes are the ones that require instances of classes to be added, replaced or removed.

2.1 Morphological transformations

During a morphological transformation, the object will change continuously in the scope of the dimensions. Different morphological levels are shown in Figure 1, with increasing modeling complexity for each step by leveling up. The higher the level, the higher the knowledge content in the method described. Morphological geometric objects can be divided into four levels:

1. Fixed Objects are essentially objects that cannot change shape. These objects are intentionally or non-intentionally static and therefore have a fixed set of geometric output. This stage has zero morphological value.
2. Parameterization is made on geometric objects of which the values can change and hence do not have a static set of output. Because of the lack of relations between the various geometric objects, it is not realistic to use models based only on parameterization other than cases of non-complex geometries.
3. An effective way to decrease the number of input parameters is to set up relations between a model's geometric objects. This can be done strictly mathematically, referred to as Equation Based Relations in Figure 1.
4. Script Based Relations are created by writing the relations using the various programming languages provided by the CAD system, described in Figure 1. Both equation and script based relations are of course rule-based, but the use of the latter allows logic reasoning to be included in a more user-friendly manner, not necessarily mathematical.

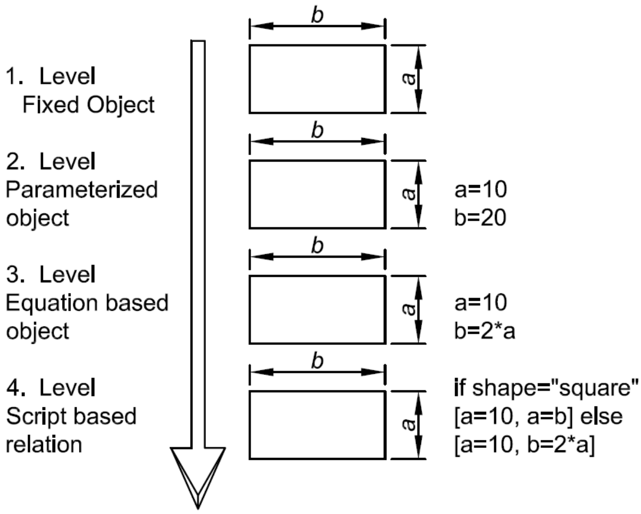

Figure 1. *Morphological transformation*

2.2 Topological transformations

As stated previously, there are three types of events that can take place during topological transformations:

- Adding an instance; an object is placed in a desired position;

- Removing an instance; an object is removed from a chosen position;
- Replacing an instance; an object is removed and one from a different class is added.

The main shortcoming of only using morphologically based models in the automatic design process is that the number of objects cannot be changed. For instance, in a structural optimization that uses morphological transformations only, the number of structure elements needs to be known in advance or alternatively the optimization must be repeated several times with different configurations. To describe the topological process the following terms are important: template, constraint and context. A template refers to an initial model to be re-instantiated; constraints are conditions which have to be satisfied by the instantiated instances; context is the geometric surroundings of an instance to which the constraints are referring to. The various levels of topological instantiation are pictured in the pyramid in Figure 2.

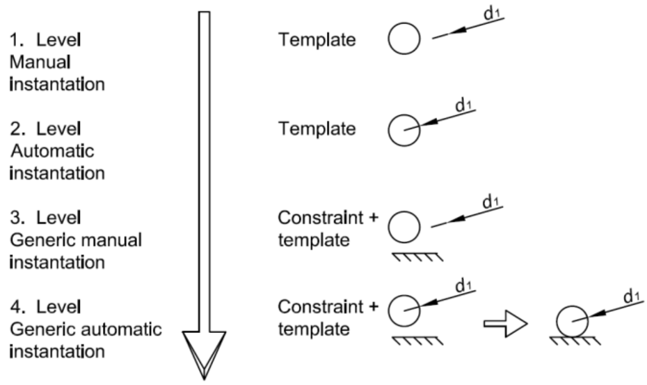

Figure 2. *Topological transformation*

The topological pyramid consists of the following stages:

1. Manual Instantiation: by performing copy and paste functions on various objects, manual instantiation is performed. However, the instances made are not context-dependent upon creation.
2. Automatic Instantiation: though only the template is defined, the instances created will follow the template model slavishly and cannot be context-dependent due to missing constraint definitions. The number of instances is parametrically modified.
3. Generic Manual Instantiation: context dependency for initiated instances is achieved by producing template and constraint manuals. These contain complete construction procedures of objects within the template and to which geometric features they are constrained. These definitions enable the template to be manually instantiated into different contexts. This increases the level of reusability in a geometric model.
4. Generic Automatic Instantiation: this stage is achieved when pre-defined functions can automatically generate or delete the instances depending on user input. The instances are both context- dependent and able to vary parametrically, hence full reuse and automation are achieved.

2.3 Dynamic top-down modeling

Traditionally, CAD design is divided into top-down and bottom up approaches. These design strategies could be associated to analysis and synthesis respectively. Top-down design requires ‘‘thinking and problem solving before integration, rather than afterwards’’. Hence, in the top-down approach, the critical information is placed on a hierarchal top level and branches down to all lower component levels in the product. When applying a dynamic top-down development process, the actual CAD models can be generated from pre-described High Level CAD templates (HLCt). The critical information on how the HLCt should be instantiated is stored in the knowledge base and used by the inference engine.

3 EXAMPLE OF MATHEMATICAL MODEL IMPLEMENTED IN DESIGN AUTOMATION

For an example of design automation using High Level CAD templates and mathematic modeling it is chosen a workshop table. Before the solution is done the following procedure is used:

1. Determination of input parameters;
2. Mathematical model of input dependent parameters is made in order to fully describe whole product;
3. The High Level CAD template is created (automated design);
4. The testing of created automated design is performed;

Input parameters for workshop table are given in Table 1.

Table 1. *Input parameters for workshop table*

Par. no.	Parameter name	Par. description	Unit
1.	Table length	Geometric	mm
2.	Table width	Geometric	mm
3.	Table height	Geometric	mm
4.	Frame section dimension	Geometric	mm
5.	Frame section wall thickness	Geometric	mm
6.	Frame color	Characteristics variable	ul
7.	Table surface paint	Characteristics variable	ul
8.	Wheels	True/False	ul

Next step in preparation for automated design is dependence definition between parameters. Dependence definition is regulated by mathematic relations, and because better overview it is shown by diagram in Figure 3.

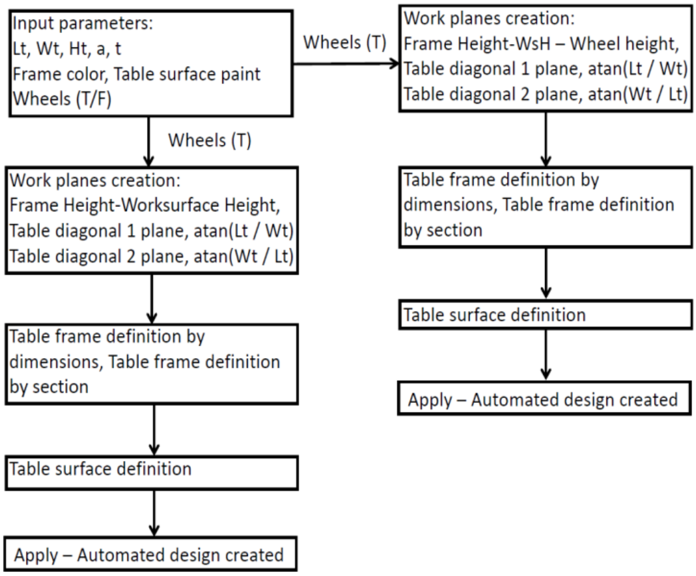

Figure 3. *Dependence between input parameters*

Before the High Level CAD template (automatic design) is created it is determined that top-down strategy is much better to be used. In this case the workplanes that will limit workshop table features must be created and parameterized. Other features will be limited to those se planes, and via future communication form the customization of workshop table will be performed.

In Figure 4 and Figure 5 are shown relation between parameters in used CAD software and model state with user communication form, respectively.

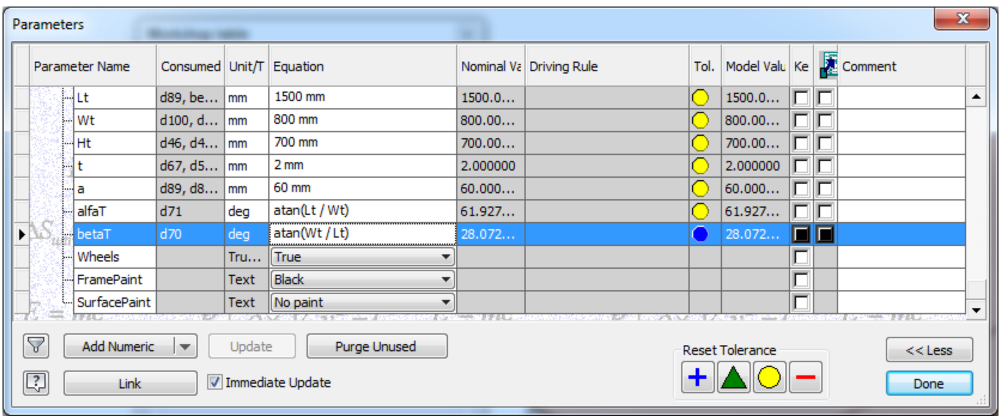

Figure 4. *Relation between parameters in CAD software*

The parameters which are previously defined by mathematic model must be defined in automated design High Level CAD template as well. All of the mathematic relations must be connected parameters to user parameters. User parameters will later appear in a communication form. Some of parameters are physical values, some are text parameters (such as table characteristics) and some of them are logical (True/False) parameters.

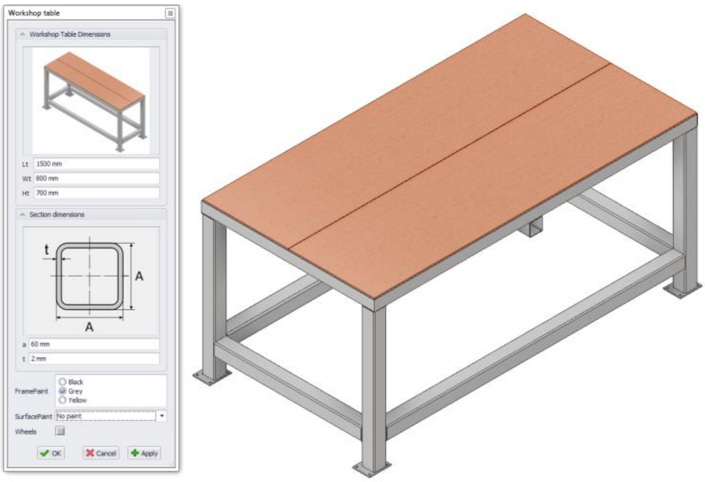

Figure 5. *Model state with user communication form*

Communication user form is a bridge between user and automated design. In the engineers scope is to limit the user form in order not to allow the user to create impossible designs.

4 CONCLUSION

The presented example of the automated design has some advantages and as well some disadvantages. Main advantages are:

- the presented model is very good for products which are manufactured as product families;
- when the system is built, the amount of necessary administrative and engineering staff can be significantly decreased, which is very positive for big companies;
- the mistakes in product design and documentation is fully avoided;
- the customer has a full control on the offered product options;
- the deals between enterprises and customers has a much easier flow etc.

However, the presented approach of automated design has a general disadvantages such as:

- the implementation of the presented approach to design automation is time consuming process;
- the design automation solutions are not suitable for small businesses because its price can be high;
- the adding of new products to the design automation system can be expensive, time consuming and potentially it can cause problems in solution working;
- the presented design automation approach is not suitable for all types of products, especially in products which is not supporting modularity.

The usage of these systems, its type choice must be based on company size, turnover, products customization level and so on. The future authors work in this field will be related to implementation of these tools into advanced CAD courses at their Institutions as a very perspective and attractive tool, which can be very successfully used in practice.

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