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# OPPORTUNITIES FOR APPLICATION OF THE GENERATIVE ENGINEERING METHOD IN HEAVY MACHINE DESIGN

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**Abstract:** This paper presents a generative engineering method and the opportunities of applying it in the design of the structural components of heavy machines. The generative engineering method is a further development of the engineering methods currently used, which enables automatic generation of some parts or entire assemblies to the given requirements, thus saving time and avoiding errors during the design stages of a product life cycle. Generative engineering uses Knowledge-Based Engineering (KBE) to capture and reuse knowledge about the product and its design processes, various algorithms to create suitable geometrical models, and it enables Multi-Disciplinary Optimization (MDO) to be used effectively. The main model is based on parametric and associative geometric models created in CAD software, which are further enhanced with parametric design requirements. Discipline-specific analysis models are automatically derived from the main model, and they are used to verify if the requirements are met, or for further design optimization. The paper gives a theoretical description of a generative model and its constituent parts and it explains the differences between the engineering methods currently used and the generative engineering method, with a focus on the application of this method in the design of heavy machines' structural components. The proof-of-concept generative model is implemented in CATIA. It relies on standard modelling tools to create the initial definition model, and it uses VBA scripts to implement extended functionality required for generative model and to perform additional advanced operations on generative model.
**Keywords:** generative engineering, generative model, CATIA, heavy machine

## INTRODUCTION

The pressure to deliver ever increasingly complex and higher performing products in shorter design time is a powerful motivation for search for new design methods and their implementations. One of such methods, developed from the engineering tools and methods currently used, is generative engineering.

Generative engineering uses Knowledge-Based Engineering (KBE) to capture and reuse knowledge about the product and its design processes, various algorithms to create suitable geometrical models, and it enables Multi-Disciplinary Optimization (MDO) to be used effectively. The main model is based on parametric and associative geometric models created in CAD software, which are further enhanced with parametric design requirements. Discipline-specific analysis models are automatically derived from the main model, and they are used to verify if the requirements are met, or for further design optimization.

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## GENERATIVE ENGINEERING METHOD

Systematic studies of machine design in late 19$^{th}$ century in Germany, and later the pressure to deliver higher quality products in shorter time have resulted in formalization of engineering methods [2]. Later, deployment of sufficiently powerful computers enabled development of expert systems and Knowledge-Based Engineering (KBE) in the most progressive fields. Currently, commercial KBE tools are also available as directly integrated components of higher-end CAx systems. Modern CAx systems (e.g. CATIA) have all key components required for implementation of generative engineering method: parametric and associative models, integration of analysis tools and easily accessible automation tools.

## MOTIVATION

The reasons for development of generative engineering can be summarized as a need to create higher-level tools. This is provided by specialized tools and workflows for particular discipline and design methods that keep also the access to the underlying general principles to allow modification of generated models using standard GUI (Graphical User Interface) and commands in CAx software. This requires formalization, storage and reuse of important knowledge in those high-level tools that is connected with the underlying model, implying use of KBE approach. It also leads to better exploitation of analytical models as a fundamental design tool, because of their increased use in early design stage.

The goals of generative engineering are to get better consistency between different models (geometric, analytic) and wider use of associativity in these models where possible or desirable. This allows creating multidisciplinary models with fewer errors in shorter time that are based on proven knowledge.

## METHOD AND MODEL DESCRIPTION

The most important part of generative engineering method is the generative model describing whole product. Generative model contains not only the parametric representation of product geometry and relations between its constituent parts, but also rules and procedures used to create the product, together with design intent.

There are various possible approaches to how to store this information. One, derived from manual approach, is based on complex network of interfaces between all specialized models to ensure that the entire model is always up-to-date and changes are propagated to all affected models. Other approach is to build a more abstract high-level central model and then from this central model create or update all discipline specific models. Third possibility is a hybrid approach in which one specific model (e.g. geometric) is enhanced with information from other models and therefore serves as the main model.

The hybrid approach is presented in this work. The generative model is based on geometric CAD model. Advantages of building the generative model from geometric model are the ease of creation and no need to create fully abstract model, but only enhancing the CAD model using easily accessible tools (e.g. scripting). This approach results in some disadvantages, because it usefulness is limited to mainly structural components (because they are mostly geometry based) and not complex systems (with control algorithms). It consists of 4 parts: requirements, objects, generators and evaluators. These parts are added high-level concepts, but their data are stored in the geometric model.

Requirements are groups of parameters that represent relations between objects or assign attributes and values to them. They form part of desired product specifications, contain design intent and interfaces with other components in whole product (or machine), and define what evaluators will be used.

Objects are geometric elements or components of structure. They can be fixed and unchanging geometry used as product specification (e.g. fixed shapes of functional surfaces), auxiliary objects, or generated geometry.

Generators are sequences of commands to create or modify objects. These sequences group available CAD commands and form specialised high-level operations. Although simpler generators are in their capabilities similar to predefined parametric models, programmatic approach allows more complex models to be created and most importantly, it enables creation of all analysis models at the same time when the geometry is generated. Additionally, complex generators can incorporate rules or empirical design methods.

Evaluators are basically analysis methods to check if requirements are met by the generated model under specified conditions.

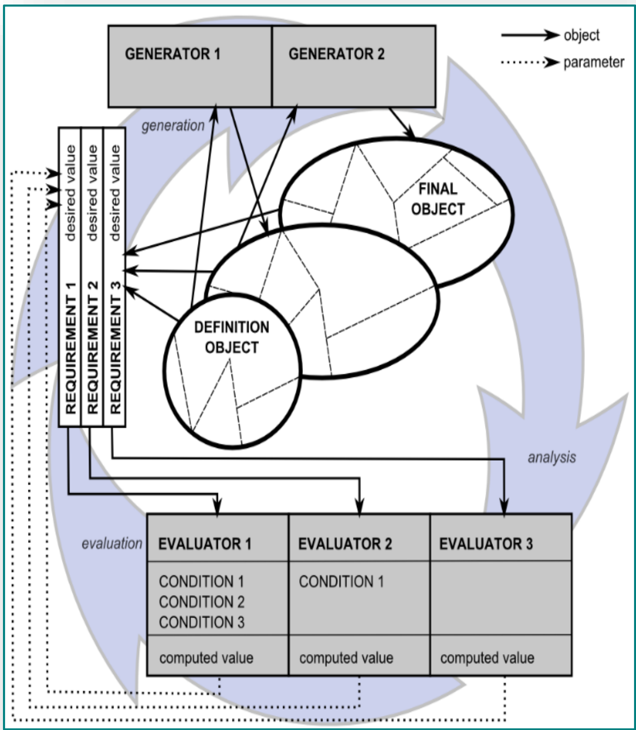


**Figure 1**: Diagram of generative engineering method

Basic generative loop is shown in Figure 1. It shows the 4 main parts (requirements, objects, generators and evaluators) and connections between them (objects and parameters). Generators and evaluators contain engineering knowledge. There are 3 main steps in the loop: generation or modification of model parts, computation of analysis results, and comparison of computed values with desired values in requirements.

## APPLICATION IN HEAVY MACHINE DESIGN

There are several works on application of KBE methods with generative properties in general engineering [4] or specific industry (automotive [1] and aerospace [3]). In heavy machine construction are various opportunities for application of generative engineering and design of structural modules (e.g. booms and arms) can be a good starting point of development of the method. These components are welded structures that are not very complex, there are many possible configurations and do not require many different analysis models.

The proof-of-concept generative model is implemented in CATIA using parametric models and VBA scripts. It has a maximum allowed displacement requirement and parts are automatically added to the assembly to meet the requirement under specified conditions. The generative model consists of an assembly (CATIA Product) that contains parts (CATIA Part). A definition part is included in assembly that aggregates all starting design specifications (requirements, fixed objects, e.g. design domain) of whole product. These are stored in tree structure of CATIA documents. Additionally, parts themselves may contain further specifications in similar structure.

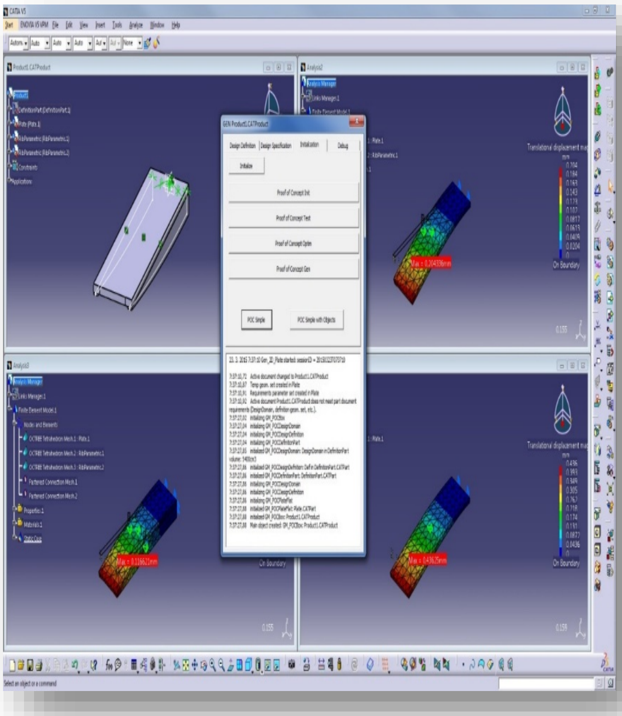

**Figure 2**: Generative model and custom GUI

The 4 parts of generative model are implemented in VBA, an object-based language that is available in CATIA. It provides automation support, and although it has limited capabilities compared to full object-oriented languages, generative model can be implemented in VBA as objects (in programming sense). All data are stored in CATIA files and can be accessed by user. A simple GUI for generative method is also created using VBA.

## CONCLUSION

This contribution describes a generative engineering method, motivation and opportunities of its application in design of heavy equipment. The presented generative model is composed of 4 parts (requirements, objects, generators and evaluators) and has a proof-of-concept implementation in CATIA using VBA scripting.

Future work will focus on further development of this method for particular heavy machine structural module with assessment of its applicability for different components.

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## Note

This paper is based on the paper presented at The 9th International Conference for Young Researchers and PhD Students (Education, Research, INnovation) - ERIN 2015, organized by the Czech Technical University in Prague, Faculty of Mechanical Engineering and the Vienna University of Technology, Faculty of Technical Chemistry, in May 4-6, 2015, Monínec, Czech Republic, referred here as [5].

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