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APPLICATION OF MODEL BASED SYSTEMS-ENGINEERING IN AUSTRIAN VOCATIONAL SCHOOLS

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ABSTRACT

Due to the rapid growth of technical complexity in modern products and shortened product life cycles, product development has become increasingly complex. More and more people with different backgrounds and skills are involved in the process to develop a system catalysing each different domain involved. Model-Based Systems Engineering (MBSE) is a method to overcome the difficulty of such a complex process. Yet, because of the lack of practice of such a new method, this research aims to induce young technical students to use MBSE tools and approaches to generate a functional product model on an abstract level following the stated customer needs, before starting concrete mechanical, electrical or software engineering activities. It is divided in three points. First, research is leveraging knowledge about MBSE to the four involved Austrian vocational schools participating in the project. Furthermore, research focuses on installing and connecting the different Austrian partner schools with a software solution in order to enhance a collaborative working experience. The last point of this research is to analyse the application of MBSE in those five partner schools. At the end of the project, interviews will be conducted with the students in order to analyse the acceptance of the MBSE methods and its usage. In order to do so, specific interviews will be developed. Furthermore, feedback from the young students and also their teachers during the practical workshops reveals difficulties with the handling of MBSE methods and tools and gives the chance to adapt teaching materials for easier understanding.

Keywords: MBSE, Systems Engineering, Product Development, Complexity, V model.

1 INTRODUCTION

Modern products are characterized by an increasing complexity. The mobile phone is one of the best examples to show the rapid advancement of mechatronic products especially. A modern smartphone is capable of doing what a computer in the 80s was not able to. Mechanical engineers are not necessarily the main actors in the process anymore. Nowadays, 80% of innovations within mechatronic products are made thanks to embedded systems and software [1]. Software, electronic and mechanical parts have to complement each other and form a large complex system. Model-Based Systems Engineering (MBSE) is a method to overcome the difficulties of such a complex product development process. Because of the smart product revolution, young technical students get in touch with mechatronic design issues quite early in their technical education. It is important that they get familiar with systems engineering methods to handle complex multi-disciplinary product development problems. Therefore, this research, which has been carried out as a project funded within the Sparkling Science program, a program of the Austrian federal ministry of Science, Research and Economy, focuses on three points. First, research is leveraging knowledge about MBSE to the four involved Austrian vocational schools participating in the project. Furthermore, research focuses on installing and connecting the different Austrian partner schools with a software solution in order to enhance a collaborative working experience. The last point of this research is to analyse the application of MBSE in those four partner schools.

2 MODEL-BASED SYSTEMS ENGINEERING

Systems engineering integrates all disciplines and describes a structured development process, from concept to production to operation phase and finally to putting the system out of operation. It looks at both technical and economic aspects to develop a system that meets the users' needs [2]. In other words, systems engineering coordinates all development efforts in conjunction with complex products considering all life cycle phases of the product. MBSE is a special approach of the systems engineering concept using one or more domain specific models (e.g. CAD models, functional models…) to describe all relevant aspects of a complex system. The basic approach for developing a complex mechatronic product is described in the VDI 2206 guideline [3]. It contains the well-known V model as an iterative macro-cycle for product development (see Figure 1). The development normally starts at predefined product requirements. These requirements reflect the customer needs, which have to be satisfied with the new product. First, the system design phase starts and a macroscopic system design is developed. After sketching the overall system and its important sub-systems the domain-specific design is done by experts. The functionality of single modules and sub-systems is tested separately first, followed by the system integration. The components of the system are assembled and the interoperability is tested. Verification tests assure the operational reliability of the specified properties. The result of the macro-cycle is ideally a product that meets all input requirements. If the validation of the product identifies deficits in fulfilling the requirements, another pass of the macro-cycle can be performed.

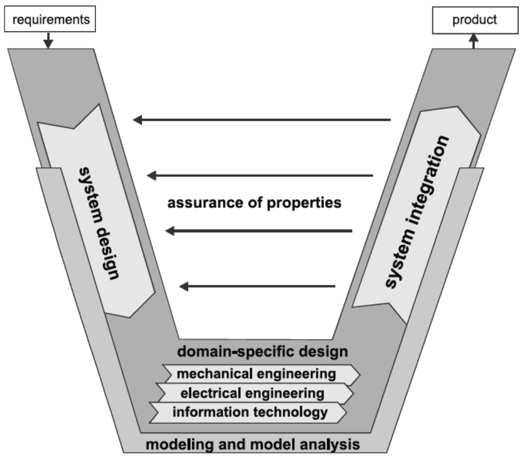

Figure 1. V model as macro-cycle

3 COLLABORATIVE MBSE PROJECT IN AUSTRIAN VOCATIONAL SCHOOLS

3.1 Project approach

The approach consists of two parallel works. On one hand, the project is conducted with four Austrian vocational schools in order to design a 3D printer using the basic Model Based Systems-Engineering approach following the V model presented above. On the other hand, several students are working for their own research on a 3D Printer at TU Wien using MBSE methods in combination with PTC ATEGO as well, along with additional software tools like EPLAN, PTC Creo and DS CATIA v5.

Considering the fact that no project participant of the partner schools has had prior experience with MBSE, the first activities of the research aimed to bring basic understanding about Model-Based Systems-Engineering to the students and teachers at Linz, Ried, Graz and Zeltweg. In order to do so first-step workshops were conducted in March and April 2015 in Graz and Linz with each time two schools together. During those workshops the basics of product development especially focusing on mechatronic products (e.g. the RFLP approach (Requirements, Function, Logic, Physical)) and the reasons for using MBSE supporting the product development process were formulated as well as the potential of developing a product with all abstraction layers connected was detailed. The links between requirements, behaviour and structure were explained as well as the roles of designers and project managers.

To enable the project members building descriptive models already in the early product development stages, the System Modelling Language (SysML) was detailed. The different diagram types and modelling artefacts were explained. The requirement's diagram is used for modelling the requirements, with all the links among each other, e.g. aggregation, composition, generalization, association and dependencies. Structure diagrams are used to show the functional structure of the system and the relationships and interfaces between the parts, subsystems, and also requirements. For instance, if a part is fulfilling a requirement it can be showed in the requirements diagram with a "satisfies" relationship established between the involved artefacts. This interlinking of different abstraction levels of product development is one goal of Systems Engineering. For the same purpose, activity diagrams, state machine diagrams and use case diagrams, which are specialized diagram types to describe the system behaviour, were detailed, see Figure 2.

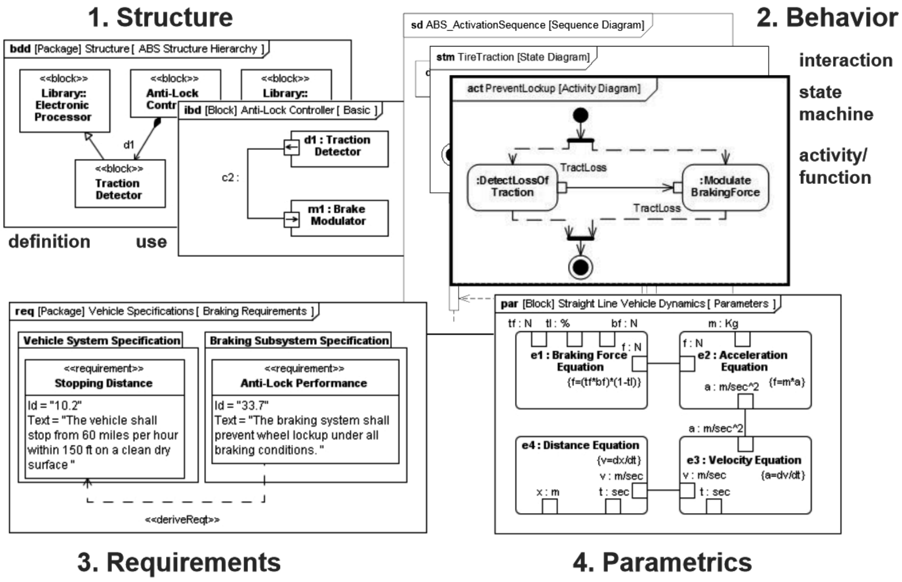

Figure 2, Pillars of SysML with the ABS example, source: INCOSE [7]

The software, that the students were going to use, PTC Windchill and PTC ATEGO, were also generally presented in order to facilitate the next steps of the project.
The chosen educational concept of teaching the students the complex topic of systems engineering is "Learning by Doing". After receiving and discussing new information during the workshops the students shall be able to apply the knowledge immediately in practical exercises. Where needed, collective brain storming sessions can be held and generate new ideas and potential improvements on both perspectives, lecturers and learners. In order to support the students during their development and modelling work outside the workshops, a couple of tutorials, especially for using the SysML modelling tool ATEGO, were prepared. To allow easy access to all project data and learning material a collaborative platform consisting of an already existing product data management (PDM) system and a new installed ATEGO server with a central model data repository is used. Some details concerning the IT infrastructure can be found in section 4.

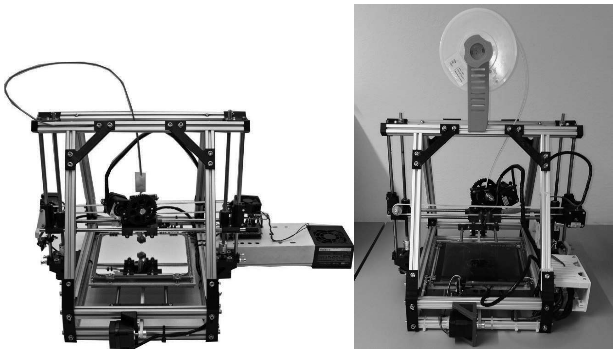

Figure 3. Left: Original MendelMax Right: MendelMax with Adaptions

With this background, the students started the development of their 3D Printer. The example of a 3D Printer was chosen because of the need for a complex system as well as the interest it gives to the students. At the end of the research project they will indeed be able to transform their design into a physical product and print whatever they want.

3.2 University approach with the example of the 3D printer

To provide a sample solution for the purpose of comparison, a SysML model of a MendelMax 3D printer is developed with students at TU Wien. After having the printer assembled optimizations and changes of some parts were made to improve the printer's performance. For example, a holder for the filament was added in order to not have it simply lying on the table. Figure 2 illustrates the original MendelMax (left picture) and the adapted MendelMax (right picture). More information is given in section 5 of this paper.

4 SOFTWARE TOOLS USED IN THE PROJECT

Within the project, there are mainly two software tools used. These are PTC Windchill 10.2 as product data management (PDM) platform and PTC ATEGO 8 as a supporting software tool for model based systems engineering. PTC Windchill was already implemented and used in a previous project [4]. Implementation and use of the PDM system for educational purposes in design lectures within the mentioned project showed that a PDM system is an essential tool to overcome well-known problems of data handling without a data management system, e.g. overwriting existing files or transferring large amounts of data [6]. Although teaching of the PDM basics to teachers and students needed more time at the beginning of the project, it was rated quite positively by the participants. For the students, it is an essential opportunity to be able to access project data and work with project data via web as well as the possibility to use PDM functionality within collaboration projects. As already introduced in the previous section all created documents like meeting minutes, slides and training documents of the current project "Systems Engineering" are stored within the PDM system in project structure and the participants are able to use the general functional areas of a PDM system. These are, for example, Model and Document Management, Parts and Product Structure Management, Approval and Release Management, Workflow and Process Management etc. [4][5]

ATEGO, formerly known as Artisan Studio, provides various modelling tools, including SysML modelling capabilities. It is quite new for all project participants and therefore it is explained and practiced step by step during the workshops with a real sample product 3D Printer. ATEGO brings together Requirement Management, Functional Analysis, Logical Architecture Design, Physical Design and Systems Behaviour Modelling. The aim is especially to provide the support for development of complex systems with software, electronic and also mechanic parts. The participants are able to import the customer requirements and system requirements as well as specifications. Moreover, they design the system, boundaries, and model-based architecture with subsystems as well as behaviour models and specify test and use cases. Finally, they will experience change and variant management using ATEGO.

5 FIRST REPORT OF THE PROJECT ACTIVITIES

5.1 MBSE with the four Austrian vocational schools

The project is still in progress and the involved vocational schools will continue the work in order to analyze the whole product and its interdependencies. After defining and arranging the 3D printer requirements in the requirements diagram, the students from the 4 technical vocational schools were developing the structure of their 3D printer in a block definition diagram, an example from one school is shown in Figure 4. The parts were being connected among each other and counted. Within each part, the students can see all the other parts connected to it. Furthermore, the requirements of the Requirements diagram were related with the structure defining parts in the block definition diagram.

As for now, the requirements and the structure are modelled with ATEGO. Before the next project meeting, those 2 diagrams along with a state machine diagram, a use case diagram and a behaviour diagram, which shows how the product logically reacts to commands, will be finalized. With all of those diagrams connected the last challenge will be to analyze if a change in a requirement is correctly transferred to the other diagrams so the designer easily knows which parts are affected of the change. By connecting every partial model, the students will hopefully get a good overview of the complexity of the product and are able to better understand it. This will be evaluated with the last workshop where interviews and surveys will be conducted.

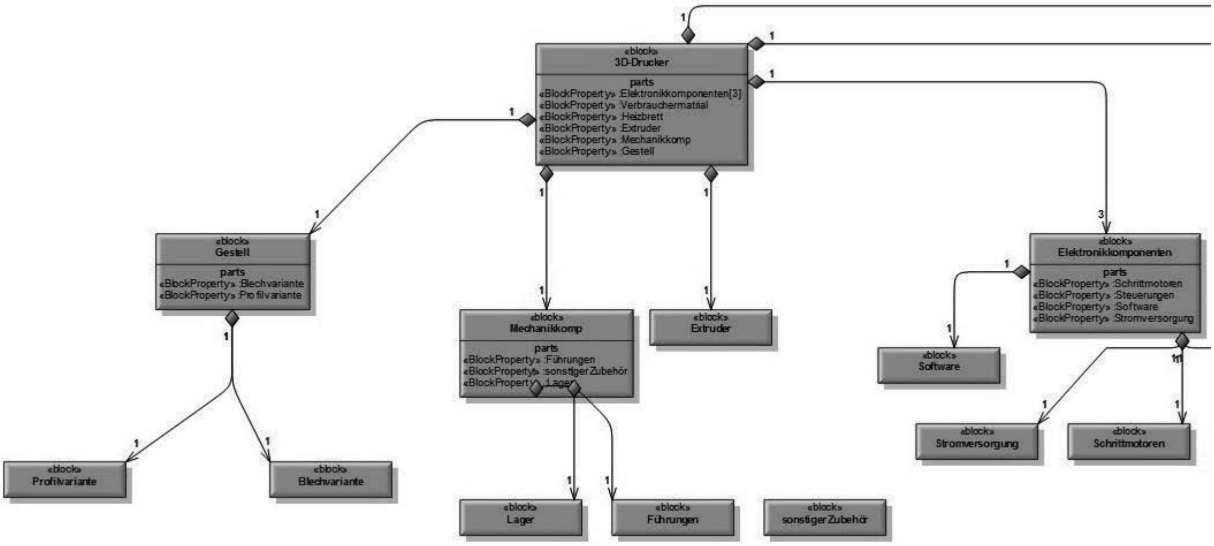

Figure 4. Section of a SysML block definition diagram in ATEGO

5.2 MBSE at TU Wien

During the project runtime students from the TU Wien also are modelling the 3D printer. The aim is to create one solution that could be discussed at the end of the project along with the solutions from the vocational schools. This could reward the students that thought about something different and went on successfully with their idea. It could also show other developing aspects created by different requirements hence underlining their importance in the product development process as known in the industry. In the course of several bachelor theses and a project work, the university students developed a CAD model including the mentioned improvements, an electrical circuit diagram and a SysML model of the MendelMax 3D printer. The SysML model consists out of requirement, structure and behaviour diagrams. Figure 5 shows a section of a requirement diagram of the created SysML model in ATEGO. The red boxes called “blocks” are structural elements that are connected with a “satisfy” relationship to the proper requirement elements (green framed).

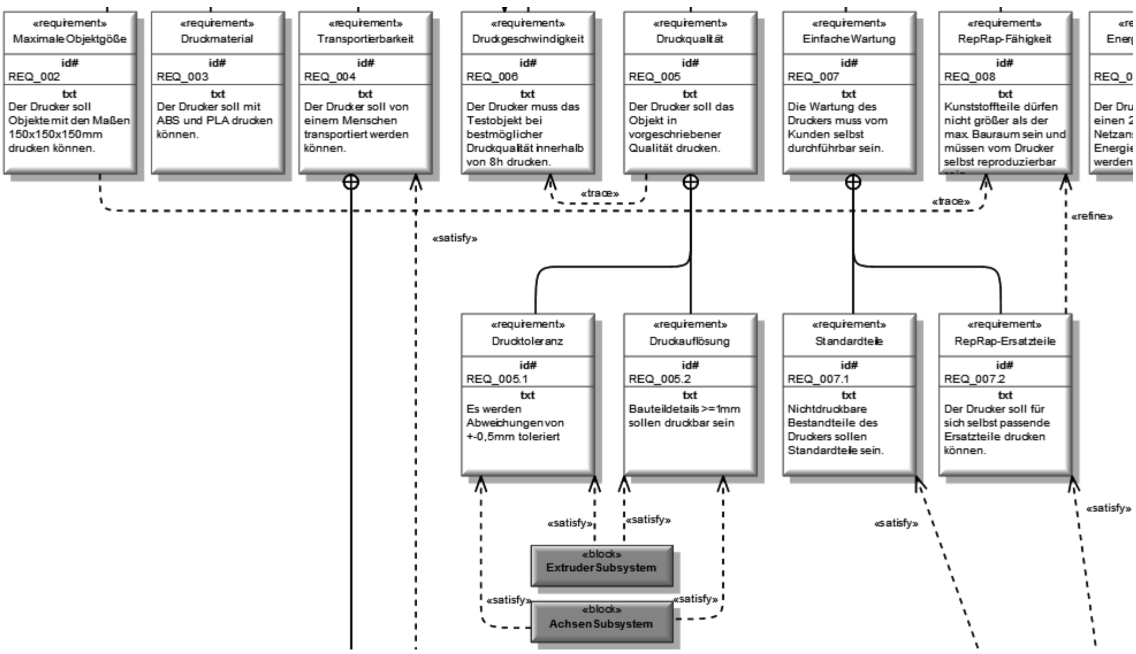

Figure 5. Section of a SysML requirement diagram in ATEGO

5.3 First experiences of learning and applying MBSE

Although the final results cannot be presented yet, some experiences and lessons learned can already be mentioned before the concluding evaluation is done:

As experienced in the first 2 workshops it is hard to stay concentrated for teachers and students following the theory of product development, MBSE and SysML with just some little practical examples for applicability. A step by step execution of a practical product development cycle together with all participants would make it easier to understand the whole process and why it is beneficial to proceed this way. The first example must be an easy one, every teacher and student should be familiar with it, just to point out the problems appearing during the product development process and which tools can be used to handle them. While the first example demonstrates the basic approach of MBSE and the used tools, a more complex one should follow to get in touch with the problems arise out of product complexity. Furthermore, the strengths and benefits of MBSE, for instance traceability and requirement-orientation, are entirely revealed only in the context of a sufficient complex system. In this study, the second example is as already mentioned a 3D printer. Another important point is that everybody in the workshop has to participate actively in finding proper requirements, building the system boundaries in the concept phase and using adequate software tools to build the model. Doing all these steps on their own helps teachers and students a lot in understanding and using MBSE advantageous in their further engineering activities.

Summarized the most important observations are:

- Product development and MBSE theory should be taught/ learned along with a practical example right from the beginning.
- Start with an easy example, followed by a complex one
- Highlight the benefits of MBSE during the learning process to ensure attention and acceptance
- Learning by doing is the only way to really understand MBSE and its benefits

6 CONCLUSION AND OUTLOOK

The "Systems Engineering" project addresses the right and actual questions about the complexity of product development and the interdisciplinary work in a design team. Thanks to MBSE, students can instantly know what they have to change in the design after other changes occurred. Although the concept of MBSE was a bit difficult to comprehend at the beginning, the students as well as the teachers are actually getting along with the concept and directly practicing it. At the end of the project, it is expected that the students have grasp the complexity of mechatronic product development and know how all the complexity of it could be managed with the right tools. At the end of the project, interviews and surveys will be conducted in order to prove that assumption.

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