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THE HANOVER KNOWLEDGE-BASED-DESIGN-LAB: A PROJECT-ORIENTED CAPSTONE COURSE IN ENGINEERING DESIGN

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ABSTRACT

Knowledge based design (KBD) and engineering (KBE) as solutions for design automation and product configuration are discussed for more than 20 years already. Nevertheless, only little application in industry is documented and existing approaches are limited to niche design activities like computer aided fixture design or to automotive and aviation engineering. Since process models for the creation of KBE applications and KBD functionalities in computer-aided-design (CAD) systems exist, the authors' hypothesis is that this situation results from deficiencies in education. To bridge this gap, the Knowledge-Based-Design-Lab was founded. The Lab is conceived as project-based learning environment that incorporates problem-based and case-based elements. Meant as capstone course, it places knowledge from design projects and design theory from the first four semesters in engineering design at the Leibniz University of Hanover in a higher context in order to create configurable virtual prototypes. In the following article the authors present details about the course of action in the Knowledge-Based-Design-Lab and the teaching concept. Afterwards, an example of student projects is introduced followed by an evaluation of the Knowledge-Based-Design-Lab 2017.

Keywords: Solution Space Development, CAD-Configuration, Project-Based Learning

1 INTRODUCTION

For more than 20 years, the use of computer-aided design (CAD) and engineering (CAE) raised competitiveness and innovativeness of companies in engineering. In particular, parametric design systems offer great potential regarding adaptive and variant design tasks [1]. The possibility to define constraints between parameters in a CAD system allows the implementation of explicit knowledge in digital prototypes. So, beside the shape, the designer has to define the control and configuration concept for his artefacts as well [2]. Knowledge-based design (KBD) and knowledge-based engineering (KBE) go a step further in order to adapt a designed artefact even more easily to new functional or design requirements. Here, the automation of routine design tasks as well as knowledge capture and reuse are targeted by implementing design rules, manufacturing restrictions or reasoning [3]. The resulting reduction of time and costs in product development is especially beneficial in business models that rely on tailoring products to a customer's needs, like mass customisation [4].

In spite of the potentials, KBE and KBD have not achieved a remarkable breakthrough aside from single niche design activities like fixture design or applications in aviation or automotive engineering [5]. From the authors' point of view this does not originate from missing KBD functionalities in contemporary CAD-systems because the technologies are at hand (refer e.g. to [6]). Also, process models for creating KBE-applications and prior to that acquiring the necessary knowledge to be implemented are available (e.g. [7, 8]). But most authors do not present concrete modelling principles or detailed application examples to learn from. No scientific books can be found that are dedicated to CAD-KBD. Additionally, most engineering curricula do not offer lectures on setup, structured exploration and management of (geometry-based) design solution spaces for configuration and optimization [9]. So, the authors' hypothesis is that the little application of KBD results from deficiencies in education.

In the following paper the authors want to narrow this gap and document their experience with the Knowledge-Based-Design-Lab which is held at the Leibniz University of Hanover for five years. Section 2 provides a brief overview of the field of knowledge based engineering and design. Section 3 contains a review of problem-, project and case-based learning in engineering design. Section 4 then presents the current approach of the *Hanover Knowledge-Based-Design-Lab*, giving details about educational objectives, learning sequence and examples. Afterwards in section 5, the Knowledge-Based-Design-Lab 2017 is evaluated and reflected. Closing the paper, section 6 contains a brief summary and outlook.

2 BACKGROUND OF KNOWLEDGE-BASED-ENGINEERING AND DESIGN

According to Chapman et al, ‘KBE represents an evolutionary step in computer-aided-engineering (CAE) and is an engineering method that represents a merging of object-oriented programming (OOP), artificial intelligence (AI) and computer-aided-design (CAD) technologies, giving benefit to customized or variant design automation solutions’ [10].

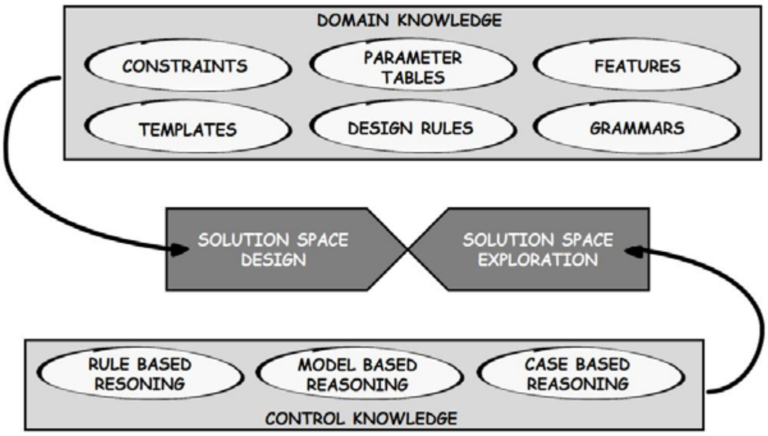


Figure 1. Knowledge Modelling in KBE and KBD

According to Hirz, ‘knowledge-based design supports design processes by reusing predefined methods, algorithms or results, and it is integrated into specific tasks or workflows that are involved in the design processes’ [3]. In detail, two different kinds of knowledge have to be considered (Figure 1): On the one hand, domain knowledge sets up a solution space in which a solution for a design problem may be found [11]. This domain knowledge may be formulated e.g. by constraints between parameters that reflect dimensioning formulae. Another way of expressing domain knowledge is templates that have to be understood as reusable, updatable building blocks in a virtual prototype [3]. On the other hand, control knowledge determines the way a solution space is explored. A possible yet simple way to do this is rule-based reasoning. Rules are if-then-else-statements that are fired procedurally. Although its one directional nature, complex rule bases may be implemented by instantiation and loops where rules activate sub-ordinate rules or exclude them from further processing [5]. For a detailed overview of knowledge modelling techniques in contemporary CAD-systems refer to [6].

3 A REVIEW OF PROBLEM-, PROJECT- AND CASE-BASED LEARNING

Beside theoretical knowledge about modelling principles and the functional implementation in CAD, knowledge engineering and the set-up of KBE systems require a certain amount of experience and students taking responsibility for a project. From the authors’ point of view, deductive lectures and the *chalk-and-talk*-approach are not suitable for teaching knowledge-based design. Especially acquiring the relevant knowledge from human and non-human resources and working together in a team of future knowledge engineers has to be an educational objective that only can be dealt with by doing.

The point of origin for inductive teaching methods that transfer responsibility for learning and content to the students may be stated as real-world problems, case study or experimental data [12]. While the course instructor supervises the learning process and provides necessary impulses where needed, the students identify needs and discover relevant knowledge (guiding principles, rules of thumb, standard procedures) by themselves. In engineering education, basically problem-, project- and case-based learning approaches are used [13].

Problem-based learning was first implemented in medicine and dates back to the 1960ies. The core concept is a three-stages learning process: In the first stage, the student is confronted with the problem and then develops necessary reasoning skills guided by a tutor. In the second stage, the student performs a self-directed study in order to acquire the knowledge relevant for the solution on his own. In the third stage, this knowledge is applied to the initial problem in the presence of the tutor again. The stage is closed by a reflection if the learning process [12]. Ideally, the problem statement should be designed authentically, open-ended and ill-structured. The major focus of problem-based learning is on knowledge acquisition [14]. Compared to the aforementioned, project-based learning has many similar aspects but a project is of wider scope, may contain multiple problems and leads to a kind of end product (a design, a simulation, etc.). To complete the project the students have to apply knowledge that is either previously acquired or taught in accompanying courses [15]. Case-based learning is different. A case mirrors a real-world problem and the complexity encountered by engineers today. Compared to problems in problem-based learning, a case is usually well-structured, involves a rich contextual background and is used to drive students to apply already existing knowledge. The typical setup of a case analysis may be described as a seven step process consisting of case review, problem statement, gathering information, development of alternatives, examination and argumentation of identified alternatives, choice of possible solutions and finally evaluation [13].

4 THE HANOVER KNOWLEDGE-BASED-DESIGN-LAB

The Knowledge-Based-Design-Lab is conceived as project-based learning environment that also incorporates problem-based and case-based elements. Students may take the course from the fifth bachelor semester on. Since it is meant as capstone course in computer-aided design, mandatory preconditions are the completion of the design projects I and II, where the students experience technical drafting, computer-aided design and design methodology while designing devices and gears and the completion of the advanced CAD tutorials. Depending on the amount of instructors, 20 to 30 students are accepted for one class, which are divided into groups of four to six people. Each group is guided by one instructor, who also takes the role of a project manager for this group. Taking into account that the instructors contribute to the design project as well, the design automation task covers approximately 800 to 1200 man hours in total. The following is an excerpt of the course and module catalogue of the faculty of engineering at the Leibniz University of Hanover:

The Knowledge-Based-Design-Lab provides skills for knowledge-based design of products within Autodesk Inventor. The knowledge from the design projects and the design theory are thus placed in a higher context and used for design automation. Our students model parametric parts and sub-assemblies, learn the iLogic programming language and implement design rules into parts and assemblies, use equations for constraining parameters, create simple product configurators and finally apply the acquired knowledge to a design task within teams and reflect the group work.

4.1 Course of Action

The tutorial is organized in 10 appointments of ninety minutes of presence time each. The same amount of time is recommended as preparation and wrap-up for each group outside class. The appointments have the following content:

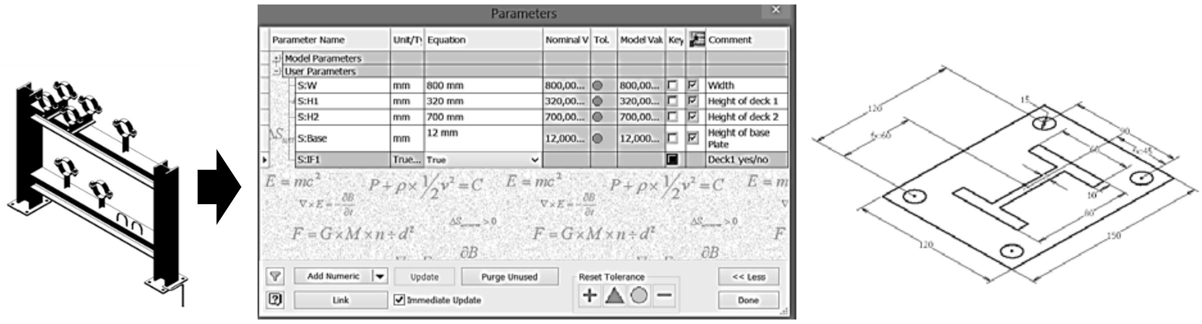
1. Get-together and iPart parametric part families
2. Parameter constraining, equations and skeleton techniques
3. Spreadsheet-driven design and iLogic
4. Group formation, presentation of the design project and initial information gathering
5. Sub-project assignment and impulse for knowledge-based systems development (usually MOKA)
6. Group work and reporting: Parameter planning
7. Class discussion: Agreement on design interfaces and the global configuration concept
8. Group work and reporting: Dynamic assembly concept
9. Group work and reporting: Sub-assembly Modelling
10. Final assembly, testing and review of the learning process

In the first two appointments, the amount of deductive teaching is high because of the simple structure of the content where the students get a set of tools that are necessary for the project that is initiated in appointment four. The following subsection contains an overview about the content of the second appointment that is dedicated, amongst others, to skeleton techniques.

4.2 Example Unit: Skeleton Techniques

One of the educational objectives in unit two is the creation of intelligent templates using a parametric model, constraints and skeleton techniques. In the first 15 minutes of the appointment, the students are taught about creating user defined parameters, parameter constraining and the implementation of dimensioning formulae in a CAD model. For another 15 minutes, the students implement the calculation of a bolt diameter into a bearing support.

Afterwards the course instructor introduces a skeleton technique that is based upon derived components. The basic idea behind is to create a part that consists of conceptual geometry and parameters only. Afterwards single elements of such a skeleton part may be imported into the single parts of an assembly. A change in the skeleton part is then propagated into the derived components.



Parameter Name	Unit/Ty	Equation	Nominal V	Tol.	Model Valu	Key		Comment
Model Parameters								
User Parameters								
S:W	mm	800 mm	800,00...	●	800,00...	☐	☑	Width
S:H1	mm	320 mm	320,00...	●	320,00...	☐	☑	Height of deck 1
S:H2	mm	700 mm	700,00...	●	700,00...	☐	☑	Height of deck 2
S:Base	mm	12 mm	12,000...	●	12,000...	☐	☑	Height of base Plate
S:IF1	True...	True				■		Deck1 yes/no

☑ Immediate Update

Figure 2. Pipe Support and skeletal Parameters plus Geometry

The example assembly is a pipe support whose skeleton contains the four basic configuration parameters height over ground of both decks, the width of the rack and the thickness of the flange plates. Additionally the cross section for the used beams and the layout of the flange plate are defined as sketches (Figure 2). Via the derive component command within Autodesk Inventor the skeleton is imported into the corresponding part documents for the beams and the flange plate. Afterwards the extrusion for the first beam is set up. Therefore, the length dimension is calculated from the imported parameters. The procedure is similar for the second beam and the flange plate. Afterwards, the parts are traditionally placed and constrained to each other in an assembly document. This takes about 20 minutes. For the rest of this appointment, the students have the task to implement such a skeleton for a base frame (Figure 3). Therefore, all standard parts and the later configuration parameters are given to the students as well as the front cover and different forklift pads that also have to be linked to the skeleton. The beams and the plates have to be modelled correspondingly to the pipe support. Especially the front cover contains some surprises for the students since it is not modelled accurately for change propagation and so has to be modified and re-parameterized to a greater degree.

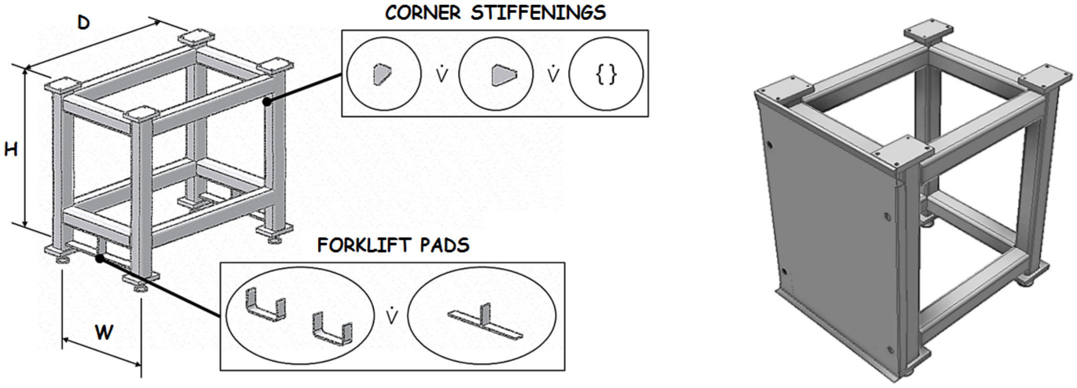


Figure 3. Base Frame

4.3 Project Result 2014 – Configurable Caravan

In 2014, 22 students and 4 instructors worked on a configurable caravan (Figure 4). The model consists of trailer, floor assembly, body with door and windows, kitchen, bathroom and furniture. Key features are as follows:

- The body's shape is adjustable via sketches
- Body trims the back of the furniture so that no collisions occur
- Outer shape of the upper shelves is modifiable by a cross-section configurator
- Kitchen and bathroom have multiple options
- Trailer reasons about weight and centre of gravity of the whole caravan and adjusts the position of the axle for an optimal hitch load.

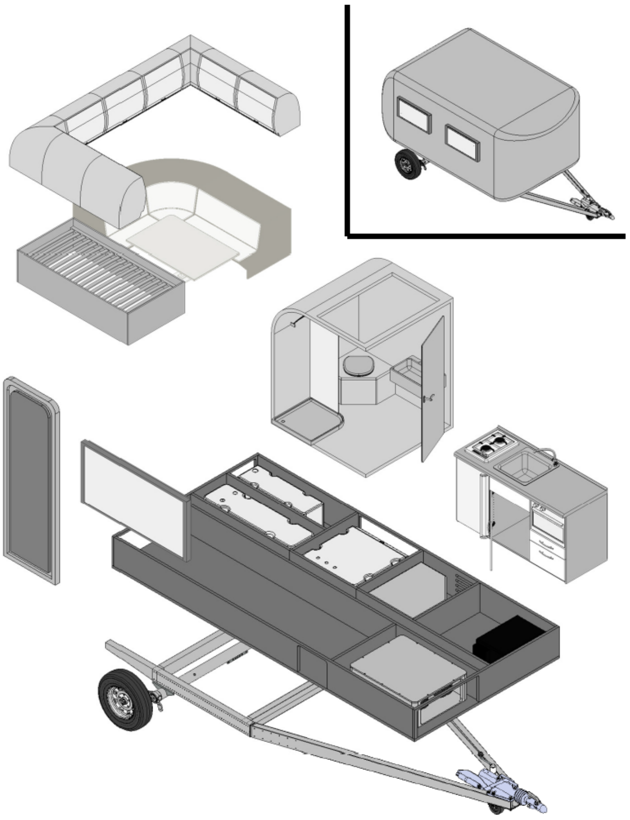


Figure 4. Configurable Caravan (Exploded View)

5 EVALUATION OF THE KNOWLEDGE-BASED-DESIGN-LAB 2017

The Knowledge-Based-Design-Lab 2017 was conducted with 24 students and 5 instructors. The design challenge was a configurable trash rack cleaner. At the beginning and at the end we asked our students in a self-assessment test about their abilities and experience in computer-aided design, knowledge retrieval and collaborative work.

In the initial assessment, the students estimated their CAD-abilities in average on 2.4 on a 1 to 5 scale. This was tested by the instructors in the first appointment during a working period by observation of the students dealing with a standardized modelling task. Taking into account the time in which the students finalized the task and the quality of the designed artefact, the value was downgraded only to a minor degree on 2.2 on a 1 to 5 scale. In the final assessment, the student rated their advancements in average on 4.0 on a 1 to 5 scale. This was basically confirmed in a second CAD-test. The improvements in knowledge retrieval and collaborative work were smaller compared to the aforementioned; the students estimated their improvements corresponding to one point on the 1 to 5 scale. We also asked if and to what degree the students improved in engineering design in general. Although the students argued their answers, the result of 3.2 on a 1 to 5 scale is questionable and remains subjective. The instructors observed an increase in searching for and working with engineering standards, design rules of thumb and specific design guidelines, but we did no concept test in order to confirm this neither at the beginning of the course nor at its end.

Another question was if a closer guidance of the instructors would have been beneficial. In average the students negated this, indeed the autonomy was helpful for the students to organize within their groups and match their individual contributions to the project. So, our learning objectives have been totally fulfilled.

6 SUMMARY AND OUTLOOK

The Hanover Knowledge-Based-Design-Lab was founded in order to educate students in KBD. In this capstone course of computer-aided design, the students extend the parametric modelling they are taught in the first semesters of their bachelor studies in engineering. Parameter planning, constraining, building parametric part and assembly models and the implementation of design rules as well as simple configurators are some of the techniques the students use to widely automate a product design within a project-based learning environment.

The results form the past five years are encouraging. On the one hand, the results of the lab itself show a wide applicability of KBD in today's product development and the creativity and the potential of engineering students at the end of their studies. On the other hand, the engagement of the graduates to convey this knowledge to their future employers offers the possibility of directly transferring this topic into a wide application in industry.

Our next steps will be to design a case base and a collection of exercises for different tasks in order to virtualize the preparation and flip the classroom concept at the first three appointments. This will be accompanied by single video tutorials that the students can use during the course as a virtual manual for knowledge-based design with Autodesk Inventor.

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