Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 91 (2020) 553–558

www.elsevier.com/locate/procedia

30th CIRP Design 2020 (CIRP Design 2020)

Development of a Design Education Platform for an Interdisciplinary Teaching Concept

Emil Heyden*, Jan Küchenhof, Erik Greve, Dieter Krause

Institute of Product Development and Mechanical Engineering Design, Denickestr. 17, Hamburg 21073, Germany
*Emil Heyden. Tel.: +49-40-42878-4257; fax: +49-40-42878-2296. E-mail address: emil.heyden@tuhh.de

Abstract

Teams of engineering students take part in a problem-based learning course, where they develop physical product variants of a robotic system and take part in a competition. Design theory and methodology are part of the teaching concept, including complexity management by platform strategy and modularization. Skills in mechanical engineering, design, numerical optimization, additive manufacturing and use of CAD, PDM and FEM software are improved. The developed robotic systems are divided into different modules, these modules are attached on the Design Education Platform. This paper shows the in-house development of this platform with regard to the requirements from the design education course and technical specifications. In this context, findings from an earlier developed product family architecture of a robotic system as reference are integrated. The product architecture is shown in a module interface graph, displaying the component variety as well as their linkages. A description of the used mechanical and electrical components and their computational as well as communication possibilities is shown. The problem-based learning course and its interdisciplinary teaching concept are presented. First findings are formulated and the resulting products of student teams of summer semester 2019 are shown. These first product variants are the starting point of a product family, with new modules and resulting product variants each semester. The influence of the Design Education Platform on the course is evaluated, with the focus on decreasing the internal work for the lecturers, while student numbers are growing. The outlook shows further possibilities of tasks to fulfill and the use of the system as a cyber-physical system for future product generations.

Peer-review under responsibility of the scientific committee of the CIRP Design Conference 2020

Keywords: Design Education; Platform strategy; Modularization; Interdisciplinary Teaching

1. Introduction

The increasing integration of digital elements into current products is changing mechanical systems to mechatronic and cyber-physical and further IoT-systems [1]. This leads to challenges for the product development, which has to handle the associated new requirements (e.g. increasing complexity due to large amounts of data, strong interdisciplinarity of activities, increasing number of variants).

One approach to support product developers is to prepare them preventively and as practically as possible for the tasks ahead [2]. To improve interdisciplinary collaboration in design education it is relevant to address the course set-up, students and instructors [3]. For this purpose, the Design Education Platform (DEP) is introduced in this work, which is intended to enable prospective product developers to understand design theory and methodology in the development of complex systems through direct application already during their studies. The DEP is a physical robotic system that combines different engineering domains such as mechanical product development, electronics and software engineering and thus requires interdisciplinary activities from the students. In order to be able to simulate different use cases for different student development teams, but at the same time to keep the internal component and process variety low, the DEP is built with a modular product family architecture [4]. The modular product family provide substantial cost and time savings while companies can still offer a variety of external product variants

Peer-review under responsibility of the scientific committee of the CIRP Design Conference 2020
10.1016/j.procir.2020.02.213

[4]. This makes it possible to use the DEP over a long time by releasing various functionalities via standardized interfaces and thus enabling students to derive a wide variety of tasks over several semesters. For acceptance of design methods from academia to industry one approach is including them in continuing education courses [5].

The objective of this work is to develop a design education platform for prospective product developers, while keeping the internal variety of the product low. For this purpose, this contribution first presents the methodological development of the DEP based on a reference system and then its first application in a real problem-based course is evaluated. The findings of this evaluation will be discussed and finally an outlook on the further use of the DEP will be given.

2. Requirements for education

Bachelor students at the Hamburg University of Technology (TUHH) can take part in the lecture “Integrated Product Development and Lightweight Design”. In addition to this lecture, the problem-based learning (PBL) course “CAE Team Project” will be conducted. About 120 students take part in this course, divided into teams of 5 students. Team members have to fulfill different tasks. Each team leaders’ main task is to plan and document the project, other students are responsible for the design and optimization.

In the PBL course each team has to develop an own product variant from idea to the whole working product, based on the given platform. Product development and the following manufacturing are part of the task. Hereby, two learning styles are combined. On one hand, the creative and conceptual learning style in product development needs to be applied to reach a working product and on the other hand the mostly operational learning style of production processes such as manufacturing is part of the task [6]

Each semester iterations of the robotic system have to fulfill new competitive tasks, e.g. a challenging parkour or finding a hidden source with help of environmental sensors. To do so, students have to define requirements for their robotic system, develop concepts and design them. In the design phase, software tools for Computer Aided Design (CAD), Product Data Management (PDM) and Finite Element Methods (FEM) are taught and applied.

Meanwhile the students use design theory and methodology in practice, which involves creative problem solving for conceptual design and a clear documentation of the progress. Conceptualization is the process of creating something previously unknown or unseen such as a new product [7]. Most parts of the robotic system are brought to existence with help of additive manufacturing, which is why the students have to consider design rules regarding additive manufacturing. Summarized, six skills are determined:

- Development from the idea to the product
- Design theory and methodology
- Usage of software tools for CAD, PDM and FEM
- Practical design with additive manufacturing
- Competition and challenging environments
- Teamwork and interdisciplinary skills

Many industries are considering platform-based product development, with modules shared across product variants within a product-family, enable better leverage investments in product design and development [8]. On the basis of industry, the educational system is platform based with a modular product architecture. In order to be able to derive different tasks over several semesters, the concept should be as future-robust as possible. This can be supported by a platform-oriented approach [9]. The system is divided into different individual modules in order to expand the variety of tasks from semester to semester. These modules are attached onto the design education platform which is explained in chapter 4 and builds the constant core of the product family, differentiation is achieved by modules attached to this platform [10]. Fig. 1 shows the four planned individual modules, for which standardized interfaces have to be provided to connect to the platform.

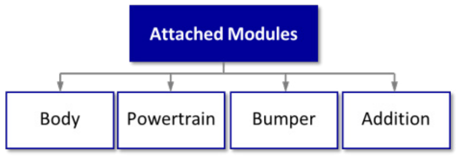

Fig. 1: Attached modules to be developed by students.

The given tasks per semester defines most of the technical requirements. Independent from the varying task, the students have to address following overall requirements for the robotic system:

- Project plan and documentation
- Requirement specifications from task
- Design of modules and components
- Stress analysis and optimization
- Requirements for additive manufacturability

3. Preceding Reference Product Family

The teaching example is based on a preceding reference. The Reference Product Family has been developed in order to support the initial product design from idea to product. The product creation process has been supported by Design for Variety (DfV) by Kipp and Blees [11, 12] which has been extended by new development tools by Küchenhof [13]. DfV connects the different domains product properties, functions, active principles and components, supported by partial product development tools for each design domain. The goal was to develop a product architecture that is easily adoptable to different use-cases. The product variants should be able to handle a variety of different applications, therefore different regions such as earth, water and air are chosen exemplary for different external influences. Modularization takes place on functional level after Stone using his three heuristics dominant flow, branching flow and conversion-transmission [14]. A one-to-one-mapping between functional elements and physical components is aspired in order to achieve and preserve the modular product architecture [15].

The resulting modular product structure on component level can be seen in the Module Interface Graph (MIG) in Fig. 2. The MIG is an appropriate tool for visualization of product components, their variety, linkages and connecting flows [16]. It enables a suitable level of abstraction for design and its simplicity provides a good basis for interdisciplinary team communication [16].

The variance relation is reached by coloring the components according to their degree of variety which can be standard (white), variant (grey) or variant specific (blue) [13]. Optional components that can be used in one product variant but not all are characterized by dashed lines. The connections presented in this MIG are mechanical and electrical power (green, solid lines) and wired and wireless information flows (yellow, dotted lines).

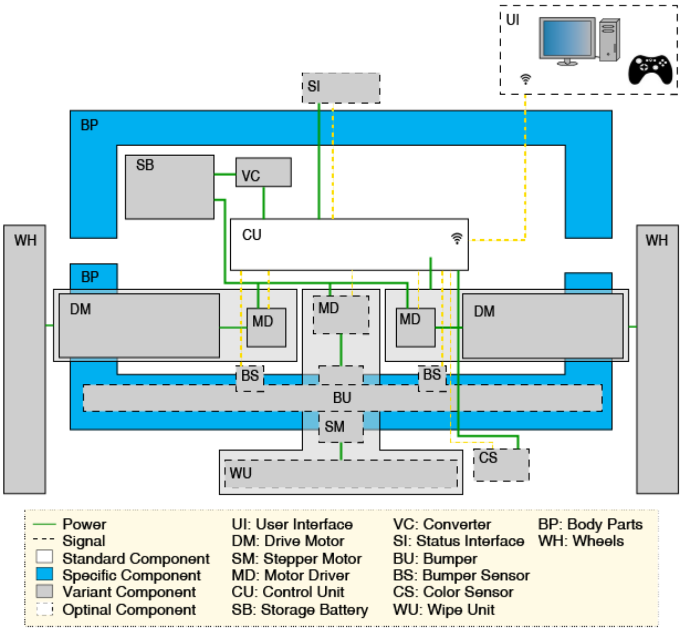

Fig. 2: Module Interface Graph of the reference product family

In addition to the mechanical design, electronic and software components have to be developed, which requires the expertise of different fields of engineering.

Three product variants are physically in use, one is shown in Fig. 3 as CAD model. This variant is characterized by its high torques and a chain drive to climb small barriers. This variant uses the optional bumper with added contact sensors, a color sensor and the wipe unit underneath (Fig. 2 and Fig. 3). All electric parts are conventionally purchased parts. The body, bumper and wheels are additive manufactured by Fused Deposition Modeling (FDM) and Stereolithography (SLA).

The control unit is already standardized as a purchasing component (raspberry pi zero). It communicates with the user interface (PC application) and is handled by a controller (Xbox One). These components are reused in the robot system for the problem-based course and the defined DEP.

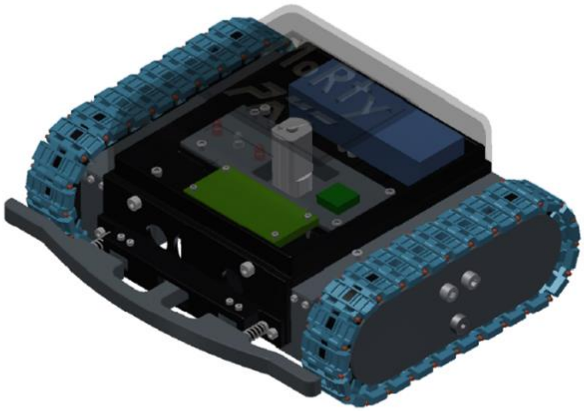

Fig. 3: CAD-model of the first Product Variant (MoRty).

As the focus for the development of the reference product family was to prepare different scenarios and use cases, the modular structure is relatively flexible for different applications. Due to the special requirements of a teaching event, the concept must be adapted accordingly. For concept creation the MIG is used as reference for further design activities.

4. Development of Design Education Platform

Starting from the reference product family (chapter 3) and resulting from the requirements for education (chapter 2), a new platform is developed - the Design Education Platform (DEP). In order to be used as a platform, standardized connections are required for attaching the modules shown in Fig. 1. Reliability, close and secure design allow the platform to be used by successive groups of students. A compact design is required to enable as much design space as possible, without resulting in huge overall systems. The technical requirements and specifications have to be fulfilled as well.

Shortly summarized, following requirements are defined:

- Standardized connections
- Reliable, close and safe design
- Compact and future robust design
- Technical requirements and specifications

Regarding the product architecture, the variant components of the MIG of the reference product family (Fig. 2) will be transformed to standard components. The main reason behind the standardization of components is to reduce the internal complexity of the product family [17]. That way the effort for lectures and student tutors decreases. Components can be chosen with more precise and purchased in higher scales. Assembling of the components, maintenance effort and error-prone decrease. All standardized components are assembled on one standardized platform – the DEP. The DEP should be robust for future courses, so that students only change the attached modules, the grey marked modules shown in the MIG in Fig. 4 can later be designed by the students. They match with the planed attached modules in Fig. 1. The variant modules are the body module, bumper module and powertrain. These modules are necessary to secure the platform from collision, for drivability and out of design aspects. The additional module on top of the system is optional, the robotic system is useable without it. It is intended for further tasks and enables the use as a cyber-physical system. The standardized connection should be able to transfer power (mechanical and electrical) and signals for sensors and actors.

Four concepts of the DEP are created, out of these the best rated was chosen by a utility analysis, by a compromise of quality and price.

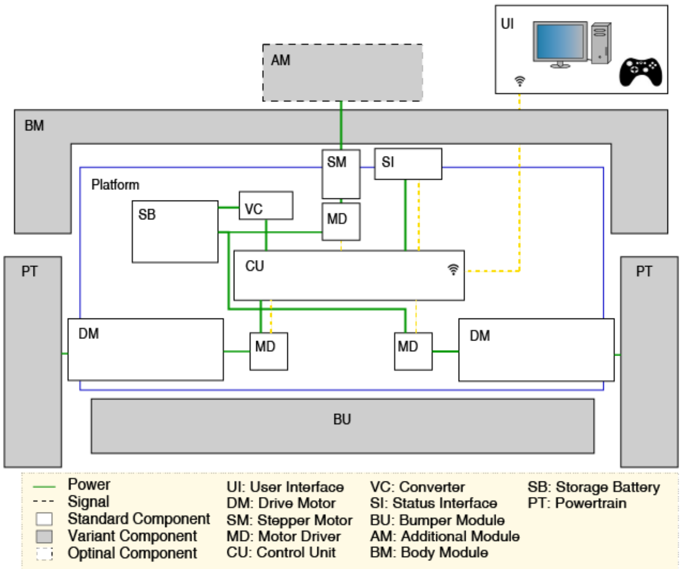

Fig. 4: Module Interface Graph of Design Education Platform (DEP).

Fig. 4 shows the MIG of the DEP, the standard platform (white color) is highlighted by blue lines. It merges the power supply, the two drive motors for moving, a stepper motor for extra applications, a status interface by LEDs, a control unit for steering and communication and the platform housing. At the platform, the storage battery with charging plugs is orientated. The battery powers the four implemented drive motors and the stepper motor of the DEP. A second power circuit with lower voltage is given to power the communication unit and transfer signals to the actors and optional sensors. For the control unit a raspberry pi zero was chosen as it is cheap, small and has enough electrical pins for further add-ons. It also provides Bluetooth and Wi-Fi which is needed for communication and control of the robotic units. The user interface is given by an PC application and controlled by Xbox controllers, which communicates by Wi-Fi with the control unit of each robot system.

The grey parts indicate variant components that can be developed flexibly by the students, these are the body module, the bumper unit, the powertrain and the additional module.

The housing of the DEP is additive manufactured by FDM with Polylactide (PLA) since this leads to less material shrinking and deformation than the more commonly used Acrylnitril-Butadien-Styrol (ABS). Axis and motor shafts are conventionally manufactured out of aluminum.

The mechanical connections to the wheel unit are given by axis and motor shafts with shaft-hub joints. The connections for the body parts and bumper are given by small bolts and clamps. For the additional module a motor shaft is given with bolt connections at the body, on top a power plug and a connection for sensors and actors is given to have a robust connection for future tasks. The multi-color LEDs give information about boot status of the control unit, battery state, Wi-Fi connection and error notifications.

Fig. 5 a) and b) show the DEP as CAD module - the base for the student projects. Fig. 5 c) shows the technical drawing of the platform to give an overview of its size. Students get a data sheet with the technical drawing to do calculations for the development.

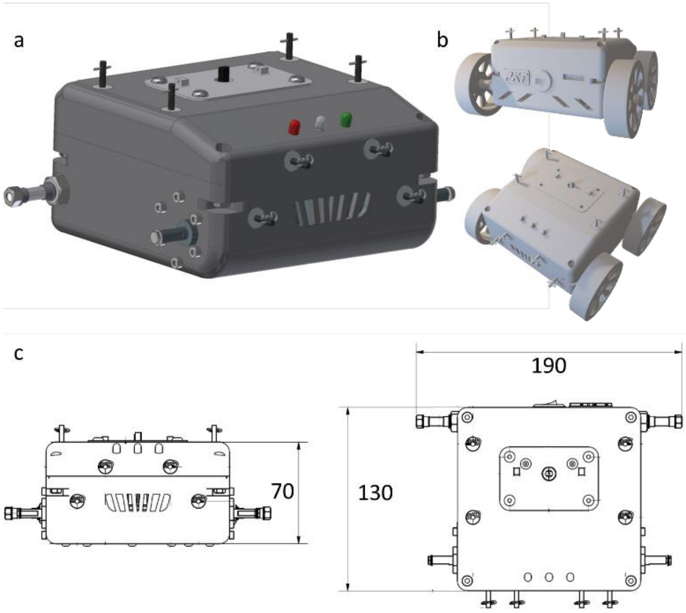

Fig. 5: (a) Design Education Platform (DEP) (b) Drivable DEP with attached wheels (c) Size of technical drawing.

5. Design course and first findings

The first revised course "CAE Team Project" was run successfully in summer semester 2019. The given task has been to master a challenging parkour with different activities and tight corners.

For the data management the PDM System "Siemens Teamcenter" and for the CAD System "Siemens NX" are used. That way the students could work simultaneously on the product, effective parallel work is possible and development time is reduced. Regarding the lightweight aspect the FEM software "Altair HyperWorks" is used for optimization.

The teams develop project plans with milestones, define their requirements, find concepts and choose one to design. Regular appointments with lecturers and student assistance help to achieve their goals (Fig. 6). The theoretical knowledge is conveyed in the lecture. At the appointments in the PBL course the student assistance present the practical work with the CAE tools and afterwards support the students individual.

Fig. 6: Regularly appointments with lecturers and student assistance.

The student teams develop virtual models with help of the CAE tools. The data is stored and exchanged via the PDM server. The PDM system “Siemens Teamcenter” can handle all kind of data with references and versioning. It helps planning and documenting the project by an internal messenger and access sharing.

A few weeks before the end of the semester the students present their design concepts and results in front of the course members, lecturers and the professor. The best product variants are chosen by giving a point (each student has one vote and may not vote for his own concept) to the favored finished product. The first three teams get the possibility to manufacture their product and compete against each other on the parkour challenge.

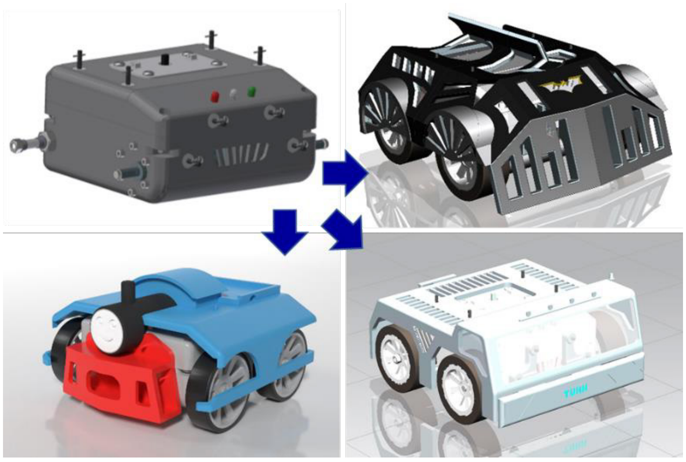

Fig. 7: Designed variants developed by student teams.

The three first placed virtual products of the design contest are shown in Fig. 7. For the parkour challenge they are manufactured by the students with help of the student assistants. The developed modules are manufactured and attached to the DEP. The modules and components are additive manufactured by FDM out of ABS.

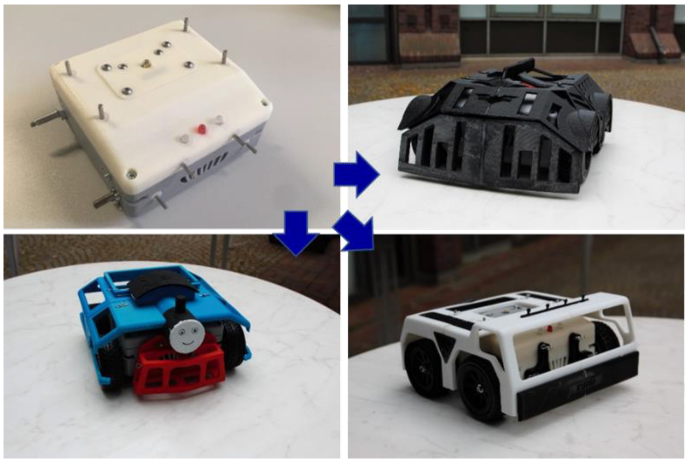

Fig. 8: Physical product variants developed, manufactured and assembled.

A few weeks after the design competition the physical competition takes part. This semester all three robot systems took part (Fig. 8), it was an exciting race day and a motivating end of the course. For the following semesters more platforms will be manufactured and more student teams will take part in the physical contest.

Fig. 9: Start and finish line at the parkour challenge.

The main positive influence of the DEP to the problem-based course “CAE Team Project” is the increasing learning experience for the students, while the effort for lectures and student tutors decreases.

With growing numbers of students, a problem-based course without setting boundary conditions is difficult to handle. The DEP as a constant core of the developed product family decreases the internal work for the lecturers, because of standardized parts. Comparing the Module Interface Graphs of the Reference Product Family in Fig. 3 with the one of the DEP in Fig. 4 shows that the amount of specific and variant parts decreases from 14 to 4, while the standard parts increase from 1 component to one platform including 8 standard components.

Secondly the number of tasks that can be implemented into the course increases compared to a conventional system with less connections. Concluding the ratio between output of creative design space for the students and the effort for the lectures increases greatly.

The current developed product variants are mechatronic systems, they integrate and interconnect fields of mechanical engineering, electrical engineering, control engineering and information technology as basis for the design of a range of products [18]. A cyber-physical system enables the physical product to be monitored, controlled and influenced adaptively and intelligently [1]. The further development to a cyber-physical system by using the additional module is planned.

The in-house developed DEP increases the adaptability and knowledge of this product. The well understanding makes optimization better and future generations easier to develop. The increase in knowledge of this product is shared in a small team of lectures and student assistants. This is problematic since knowledge has to be spread internal and external. Manufacturing drawings, used software, program codes, instructions and the development process are documented and described. Papers are used to spread the knowledge in the scientific community.

6. Conclusion and Outlook

The objective to increase the learning experience for prospective product developers is addressed by a wide variety of tasks over several semesters, by designing different attached modules. The reduction of variant components compared to the Reference Product Family addresses the announced objective to develop a design education platform, while keeping the internal variety of the product low. The reduction of the internal variety is reached by decreasing the amount of variant parts while increasing the amount of standard parts. The decreasing effort for lectures and student tutors can not be evaluated jet because of the high initial effort for the first implementation, evaluation of future courses will be done.

The whole concept of the event will be continued given the success of the first run. These first product variants are the starting point of a new product family, with new product variants and growing functionally each semester. Students of the summer semester 2019 were the first ones taking part at the revised course “CAE Team Project”. the renovated teaching concept, platform and software were a new experience for lectures and student assistants. Therefore, next semesters students will be confronted with new more challenging tasks. This semester the modules body and bumper were designed, the powertrain was given and the addition module unused. Following semesters students will design a different selection of modules fulfilling another competition. A little robot arm can be put on top to lift things, intelligent bumper or other innovation course themes are possible. With new tasks new module variants are created, that can be implemented into the product family and increase the external product variants.

Going further from the jet developed mechatronic system to a cyber-physical system the additional module and the control unit grow in importance. The standardized connection for the additional module has mechanical connections, power plugs and connections to exchange information with sensors and actors. The computational possibilities with the raspberry pi zero as the control unit of each robot system make cyber physical systems and swarm tasks possible. With a growing amount of robot units and the ability of each to communicate, the focus can also be the further development of the digital parts of the product. More integration of sensors and control theory can make the products communicate with each other. A possibility is to replace the X-Box-Controller with autonomous, swarm-like behavioral control.

Acknowledgements

Special thanks to our student assistants for their valuable support during the development of the DEP, as well as the student assistants who helped the student teams with their projects at regular appointments.

References

[1] Hehenberger P, Vogel-Heuser B, Bradley D et al. Design, modelling, simulation and integration of cyber physical systems: Methods and applications. Computers in Industry 82; 2016. p. 273–289.

[2] Jänsch J, Birkhofer H. The Gap Between Learning and Applying Design Methods. International Design Conference – DESIGN; 2004.

[3] Fixcon, SK, Teaching Innovation through Interdisciplinary Courses and Programmes in Product Design and Development: An Analysis at 16 US Schools, Creativity and Innovation Management, 2009

[4] Otto K, Hölttä-Otto K, Simpson TW et al. Global Views on Modular Design Research: Linking Alternative Methods to Support Modular Product Family Concept Development. Journal of Mechanical Design 138; 2016, art. 071101.

[5] Üreten S, Beckmann G, Schwenke E, Krause D, Cao S: Continuing Education and Personalization of Design Methods to Improve their Acceptance in Practice – An Explorative Study. Procedia CIRP, 2017, p. 524–529.

[6] Smulders FE. Co-operation in NPD: Coping with Different Learning Styles. Creativity and Innovation Management; 2004.

[7] Andreasen MM, Hansen CT. Cash, P. Conceptual Design: Interpretations, Mindset and Models, Springer International Publishing, Cham; 2015.

[8] Krishnan V, Gupta S. Appropriateness and Impact of Platform-Based Product Development. Management Science 47, 2001. p. 52–68.

[9] Greve E, Krause D. An Assessment of Methods to Support the Design of Future Robust Modular Product Architectures. International Design Conference – DESIGN, Dubrovnik, Croatia; 2018.

[10] Bauer W, Elezi F, Maurer M. An Approach for Cycle-Robust Platform Design. 19th International Conference on Engineering Design (ICED13). Seoul; 2013.

[11] Blees C, Kipp T, Beckmann G et al. Development of Modular Product Families: Integration of Design for Variety and Modularization. NordDesign; 2010, p. 159–168.

[12] Kipp T, Krause D. Design for Variety – Efficient Support for Design Engineers. International Design Conference – DESIGN; 2008. p. 425–432.

[13] Küchenhof J, Schwede LN, Hanna M, Krause D. From Visualizations to Matrices – Methodical support for New Development of Modular Product Families. 21st International Dependency and Structure Modeling Conference; 2019.

[14] Stone RB. Towards a Theory of Modular Design. Dissertation, 1997.

[15] Ulrich K. The role of product architecture in the manufacturing firm. Research Policy 24; 1995. p. 419–440.

[16] Gebhardt N, Bahns T, Krause D. An Example of Visually Supported Design of Modular Product Families. Procedia CIRP; 2014, p. 75–80.

[17] Krause, D.; Gebhardt, N. Methodische Entwicklung modularer Produktfamilien, Springer, Berlin Heidelberg, 2018.

[18] Harashima F, Tomizuka M, Fukuda T. Mechatronics – “What Is It, Why, and How?” An editorial. IEEE/ASME Transactions on Mechatronics 1; 1996, p. 1–4.