Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 119 (2023) 41–46

www.elsevier.com/locate/procedia

33rd CIRP Design Conference

Live-Lab GSD – Generational Sheet Metal Development: a validation environment for methodological design support in sheet metal development

Nikola Bursac*, Artur Krause, Mona Batora, Katharina Ritzer

Hamburg University of Technology (TUHH), ISEM – Institute for Smart Engineering and Machine Elements, Am Schwarzberg-Campus 4, 21073 Hamburg, Germany

* Corresponding author. Tel.: +49-40-42878-4002. *E-mail address:* Nikola.Bursac@tuhh.de

Abstract

This paper describes the development of a Live-Lab for generational sheet metal development, which can be used to validate methods, processes, and tools. For this purpose, requirements regarding the design task, development process, participants, equipment, and data collection for a Live-Lab are derived based on a literature review and expert interviews. Subsequently, a Live-Lab is developed and presented in which the test subjects develop and manufacture a gas grill over six months. Based on the concept of the Live-Lab, which was implemented and carried out in three years, the validation of three different approaches for methodological design support is described. These approaches address (1) engineering generations and variation types, (2) sheet metal design concerning sustainability, and (3) decision heuristics in agile development.

Keywords: Live-Lab; design support; validation environment; sheet metal development; PGE – Product Generation Engineering

1. Introduction

YouTube was developed in 2005 as a dating website. Users were to have the opportunity to introduce themselves with the help of videos. However, the founders quickly realized from early user feedback that their product was not meeting user needs. They used this realization to further develop their product and open it up to any type of video. The very next year, YouTube was purchased by Google for over $1 billion. There is broad, scientific consensus that iteration and early validation of products support the knowledge work of product development [1]. Increasingly more available iterative and agile approaches are helping to generate knowledge and develop appropriate products for each market through early and continuous validation [2]. However, the development, of design support, is still often done sequentially, with validation, only at the end of the research activity [3]. One reason for this is the lack of suitable validation environments in which, on the one hand, the subjects behave as authentically as possible, like developers in companies, and, on the other hand, the validation environment can be easily manipulated by the researchers [4]. For example, A/B tests in a test group-control group design with realistic tasks can provide insights through early validation opportunities [5]. An alternative to enabling this is the concept of Live-Labs. These can be classified between laboratory and field study and allow the combination of respective advantages [5]. In this paper, the newly developed Live-Lab GSD - Generational Sheet-Metal Development is presented.

2. State of research

2.1. The Model of PGE – Product Generation Engineering

The PGE - Product Generation Engineering is a model for the description of the planning and control of entrepreneurial product development and is used as a basis for the research and development of method, tool, and process development [6]. To keep a product as attractive as possible for the customer over

10.1016/j.procir.2023.03.082

its entire product lifecycle, new enthusiasm attributes must be offered on the market with the introduction of new product generations [7]. The development of a subsequent product generation is always based on at least one existing product, which is declared as a reference product [8]. Based on a reference system, which consists of reference system elements, product development is carried out according to the PGE model using the three variation activities: Carryover Variation (CV), Embodiment Variation (EV), and Principle Variation (PV) [9]. In turn, the reference system elements come from a partial solution of previous generations, related series, or variants of the company under consideration, as well as from the external environment, such as from products of other companies or research [8]. The PGE model can be used to analyze relationships between variation types and development challenges [10]. For example, it can be observed that embodiment and principle variation entail increased development risks due to technical novelty.

2.2. Realistic validation of methodological design support in Live-Labs

The application of methods, processes, and tools often shows challenges in development practice and thus provides less support for a company's R&D than expected. This results from the fact that methods, processes, and tools are mostly designed in an academic environment and evaluation only takes place in pure laboratory studies or individual companies. In this context, laboratory studies have a high internal validity with reduced complexity, whereas studies in the field represent a better reflection of reality, but often only represent the results specifically for individual study environments [11,12]. Live-Labs offer the possibility to minimize the discrepancy between laboratory and field studies [4]. A Live-Lab is to be understood as a research environment in which the use of methods, processes, and tools can be investigated based on development processes that are as realistic as possible while offering a high degree of control and design of the boundary conditions [5]. Within a Live-Lab, the participants do not associate themselves with the role of a subject, rather they adopt the role of a developer. In this way, various aspects such as quality, acceptance, applicability, and the combination of different methods for design challenges can be examined [4]. Previous studies have investigated, e.g., how creativity methods can be transferred into a virtual space and which technical requirements are necessary for a successful application [13].

2.3. Development challenges in sheet metal development

The design and manufacture of sheet metal components take on an important role in almost all areas of modern mechanical and plant engineering. Modern manufacturing technologies enable sheet metal components of any complexity to be manufactured rapidly, precisely, and cost-effective. With the use of modern laser and machine tools, sheet metal development can be realized comparably cost-effective due to flexible processing, even for low quantities. Through bending, cut sheet metal components can be manufactured into 3-dimensional elements. According to Doellken, Lorin et al. [14], when developing geometries and the components and products to be manufactured of them, special requirements such as constraints due to the manufacturing process and detailed features, the complexity of the design or even the material properties have to be met to ensure the manufacturability of the products. Due to these requirements, errors often occur in the development of sheet metal designs with a high proportion of principle and embodiment variation, which can hamper or even make subsequent production impossible [14]. Approaches such as design for manufacturing focus on reducing complexity and thus enable a reduction in manufacturing costs and need to occur early in the design process. Herein, principles such as the manufacturing process, product and construction design, material properties as well as environmental aspects are examined. In this context, it is important to identify and eliminate any construction and design errors early on in the product development process [15].

Real development environments within R&D departments of industrial companies pose challenges to the exploration of methodological design support for sheet metal processing due to, e.g., the dynamics of the environment and the complex interactions of the processing capabilities [5]. Among other things, this significantly complicates the ability to control the research environment and evaluate the research data. For this reason, an environment is required that represents development processes realistically, yet at the same time offers researchers the possibility to control the research design.

3. Research methodology and objectives

Although iterative and agile approaches are already used in product generation engineering, in particular methodological design support, such as processes, methods, and tools of product generation engineering, are validated sequentially and thus only at an advanced point in time due to non-existent or inadequate validation environments [3]. A sequential approach and the associated late validation lead to late findings, which in turn can have a negative impact on the further development of support. This ultimately leads to negative effects in development practice, e.g., in the form of waste due to missed successes through support in the research and development phase. For this reason, iterative validation offers the potential to enable changes in the methodological support of product generation engineering at an early stage and thus to sustainably increase quality in iterative steps, while minimizing resources such as time and costs. Especially in sheet metal development, the need for methodological design support is evident, for example, due to the complex interplay of processing options. For the iterative and agile investigation of the support for sheet metal development in the context of product generation engineering, a validation environment is therefore needed in which the development process of sheet metal development can be represented realistically while enabling researchers to control the research design. Therefore, the objective of this paper is to develop the Live-Lab GSD - Generational Sheet

Metal Development for iterative and agile validation of methodology design support for sheet metal development in product generation engineering. This is operationalized by the following research questions:

- What are the requirements for a Live-Lab for sheet metal development in product generation engineering?
- How must a Live-Lab for sheet metal development in product generation engineering be designed based on the requirements?
- What are the research opportunities for iterative and agile validation of methodology design support when conducting the Live-Lab for sheet metal development in product generation engineering?

This research follows the Design Research Methodology (DRM) according to Blessing and Chakrabarti [16]. In the descriptive study 1, requirements for a Live-Lab are first identified based on a literature review and an empirical collection of data from referenced Live-Labs using expert interviews. In addition, requirements for the use case of sheet metal development in product generation engineering are supplemented with the support of further expert interviews. In the prescriptive study, a first concept of the Live-Lab for sheet metal development in product generation engineering will be derived from the previously identified requirements, which will be validated and further developed in future studies. Based on the concept, an analysis will be conducted to determine which further research opportunities and potentials are presented through the developed Live-Lab.

4. Requirements on a Live-Lab for generational metal sheet development

A literature review was conducted to define requirements for a Live-Lab for methodological design support in generational metal sheet development. Based on publications between 2015 and 2022, requirements from the description of existing Live-Lab environments and conducted Live-Lab studies were derived. The query „Live Lab OR (Live-Lab) AND (product development) OR (product design)“ was used in SCOPUS to search the title, keywords, or abstract. Out of 58 documents, 16 gave information on requirements for a Live-Lab. This was followed by interviewing two former project managers of Live-Labs (E1 and E2) based on the lead questions:

- What are the general requirements for a Live-Lab to investigate methodological design support?
- What did you learn from the implementation of the Live-Labs for the development of further Live-Labs?

The collected requirements were supplemented by the specifics of sheet metal development by two experts from the sheet metal development use case (E3 and E4). The identified requirements were finally unified and clustered into 22 requirements within 6 clusters (cf. Table 1).

Table 1. Requirements on a Live-Lab for generational metal sheet development

No.	Cluster	Requirement	Origin
1	Design task	Requires interdisciplinary collaboration	Literature
2	Design task	Existence of reference product	Literature
3	Design task	Solvable by sheet metal development	E3
4	Design task	Integrated constraints of sheet metal development	E4
5	Development process	Milestones with customers	Literature
6	Development process	Adequate duration of iterations	E2
7	Development process	Adequate degree of reality	Literature
8	Development process	Possibility to realize the constructive part	E4
9	Participants	Technical experience	Literature
10	Participants	Technical knowledge	Literature
11	Participants	Sufficient available time of participants	E1
12	Equipment	Access to infrastructure	Literature
13	Equipment	Access to manufacturing machines	E3
14	Equipment	Access to tools and programs	Literature
15	Data collection	Access to data collection tools and software	Literature
16	Data collection	Access to data about developed increments	E4
17	Data collection	Useful data format	Literature
18	Data collection	Appropriate cost-benefit ratio in data generation and analysis	Literature
19	Research object	Appropriate cost-benefit ratio of the implementation of additionally required activities	E1
20	Research object	Connection to design task	E2
21	Research object	Connection to development process	E4
22	Research object	Connection to support of metal sheet development activities	E4

5. Concept of the Live-Labs GSD – Generational Sheet Development

The Live-Lab GSD builds on the course GSD - Generational Sheet Metal Development at ISEM. During the course, students acquire all the necessary knowledge of manufacturing sheet metal development through generational engineering using the example of top-heat grills. During the course, an advanced knowledge level in product design, requirements of manufacturability of sheet-metal components as well as a broad range of soft skills necessary in R&D environments are gained.

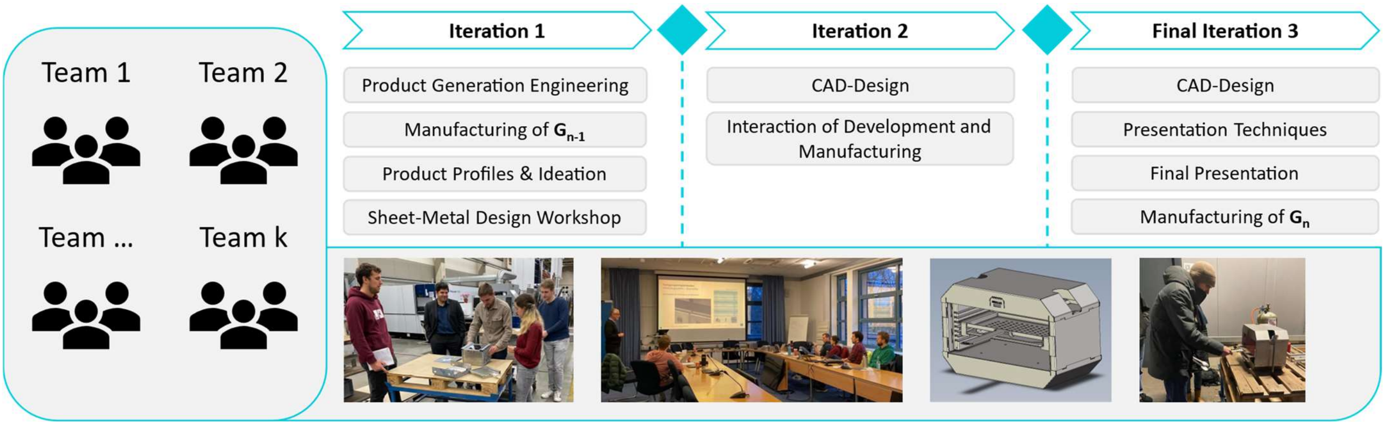

Fig. 1. Structure of the course GSD - Generational Sheet Metal Development

The product design measures to be taken ensure the development and design of the grill components are in line with manufacturing requirements and enable the sheet metal components to be manufactured as easily as possible, thus minimizing manufacturing costs and times and ensuring compliance with production-dependent quality characteristics (cf. Design for Manufacturing, DFM).

The cyclically recurring course (Fig. 1) is suitable as a Live-Lab for validating methodological design support, as the students further develop the top-heat grill in generations as part of a competition. Here, the students receive all available results regarding previous product generations and continue to develop the next generation of the grill over three months. The given grill generation G_{n-1} as part of the reference system offers a baseline situation as it exists in the development practice of the industry. The cross-generation development of the top-heat grill represents a real development process. The development of the new generation (G_n) is carried out in three iterations in which the respective development increments are reviewed and the decision-making process is supported regarding further necessary development steps. Within the reviews, the designs are analyzed regarding their manufacturability and necessary product design measures are derived for the subsequent iteration. The available resources for the CAD design as well as the manufacturing of the new product generation in a cooperating company remain identical for all teams and thus offer ideal comparability. In the end, a jury consisting of customers, company partners, and teachers selects a winning grill which is subsequently manufactured and put into operation.

In the Live-Lab, teams of five students compete against each other (see Fig. 1). The students all have a technical background with individual thematic focuses and take on the role of product developers in an interdisciplinary team. To support the generational development of the top heat grill, all necessary theoretical knowledge of PGE as well as sheet metal design is taught in the course. In addition to the necessary knowledge of design, knowledge of product profiles is also conveyed, and subsequently, the product development activities are carried out. Based on the respective experience and knowledge, the participation of the individual students in the different tasks within the development process shifts and enhances the realistic character of the Live-Lab. Due to the given framework conditions within the Live-Lab, such as the review with stakeholders as well as the association with the role of a product developer, the project success is in the foreground.

The development in iterations offers a suitable form of data collection in which the work results can be evaluated based on current development progress through CAD data and video recordings of the reviews. In this way, it is possible to comprehend how the types of variation in the individual development generations occurred. The competitive character helps the students to focus primarily on the development of the next development generation. Thus, only methods are used that help the students realistically in the development of the top-heat grill. In this way, various methods for agile development, sheet metal design, and engineering in product generation can be validated and further developed within the Live-Lab GSD. By regularly gathering feedback from the participants, the methods used for methodological design support can also be examined in terms of their acceptance and challenges in their implementation. This enables an analysis of the realistic development process and generational engineering while ensuring the controllability of the study environment.

6. Research possibilities of methodological design support in the Live-Lab GSD

For the implementation of the developed Live-Lab GSD, a wide variety of research possibilities for the iterative and agile validation of methodological design support arises. The research issues to be investigated in the Live-Lab arise from current industry research needs. Three examples are presented in the following.

6.1. Reducing the validation time using the example of generational engineering and variation types

Within the Live-Lab, it can be comprehended how the variation types of the individual engineering generations can be analyzed. Therefore, the course of the development process and the product development activities undertaken therein must be documented. This is achieved by utilizing the CAD data within the respective development stages as well as the documentation

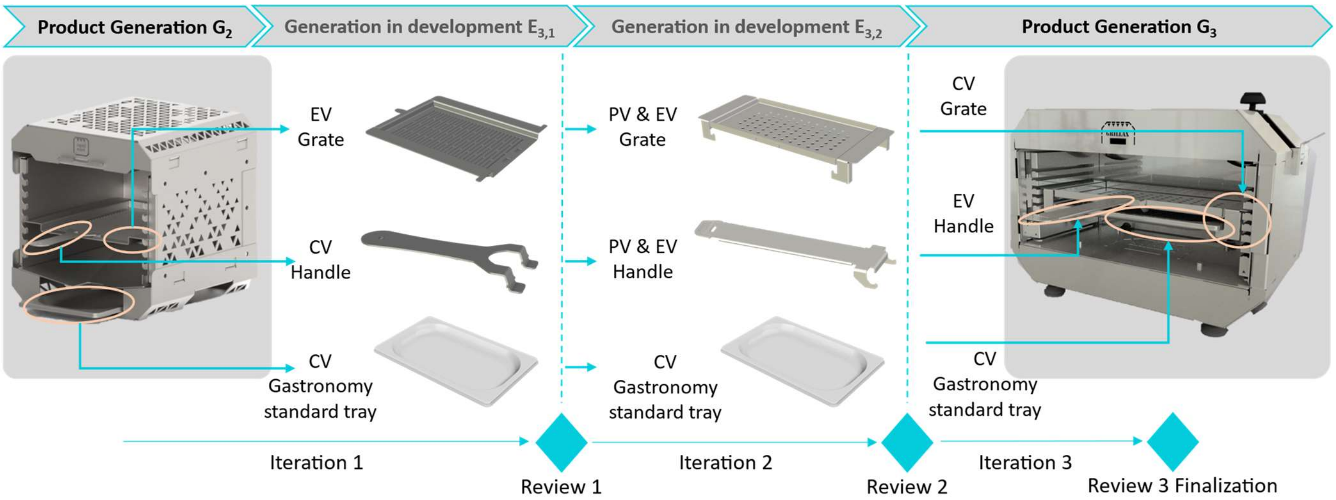

Fig. 2. Product Development in the Live-Lab GSD - Generational Sheet-Metal Development

of the reviews and the background described therein, which initiate and influence the product design changes.

Fig. 2 shows the product development process and the types of variation between the existing G_2 and the newly developed G_3. Between G_2 and G_3, all types of variation can be observed with varying degrees of expression in all sheet metal components. Both the grill grate and the handle show changes over time in the variation types. Within the first iteration, a high share of CV can be seen by the changes made in the grate area. Also, a complete adoption of a reference system element (standardized gastronomy tray) with 100% CV takes place. During the iterations, it is also possible to trace the decision changes in the product design activities. By analyzing the product design actions and the background of why these actions were undertaken, conclusions can be drawn about synergies in the product development process and methodological design support.

6.2. Impact of design cues on sustainability in sheet metal development

Doellken, Lorin et al. [14] show possibilities to support developers with the help of design cues in sheet metal development. For example, design catalogs can be used to avoid collisions between the workpiece and the tool at an early stage. Further potentials are shown by early feedback for developers regarding the CO_2 consumption caused by the respective design. The application of life cycle analysis (LCA) through eco-design strategies enables the respective sheet metal design to be adapted at an early stage. This involves a systematic analysis of the potential environmental impacts and the energy balance of products throughout their entire life cycle. However, these investigations have primarily been conducted on simple examples in laboratory environments. Through the Live-Lab, developers can now incorporate early feedback into their decisions regarding product sustainability during sheet metal development in a controllable research environment. For the researchers, this creates more realistic feedback, as the developers in the Live-Lab have the primary goal of developing the product generation of the grill.

6.3. Decision heuristics in the agile development of mechatronic systems

Nudging approaches are already used in politics and society [17], for example in the form of product placements (e.g., placing healthy snacks within easy reach in cafeterias or Nutri-Score for healthier lifestyles) and laws (e.g., objection rules regarding organ donation) to influence individual decisions and steer them in a positive direction (for society). However, nudging approaches have so far not been applied in product generation engineering, therefore decision heuristics and their steering potentials toward optimal decisions have not been investigated much in this field. Previous laboratory studies have shown that different decision heuristics are present in typical development situations, such as the selection of a product concept from different alternative solutions [18]. These decisions can be influenced in desired ways through various approaches to nudging. For example, Bursac, Tanaiutchawoot et al. [19] concluded in their study that revealing personas has a significant impact on the expression of subsequent decisions regarding product design. However, these investigations in the context of product engineering have, so far, taken place exclusively under laboratory conditions. A transfer into development practice is not yet possible, since the methodological design support by nudging has not yet reached a sufficient degree of maturity. The Live-Lab GSD now offers the possibility to validate this support in a more realistic environment to represent additional influencing factors more accurately, such as the number of conflicting goals, lack of time and complexity of the system. Furthermore, it is possible to realistically investigate the extent to which nudging has an impact on decision success within a development organization.

7. Discussion and outlook

This contribution presents the Live-Lab GSD that enables iterative and agile validation of methodological design support for sheet metal development in the context of product generation engineering. The Live-Lab enables the validation in a realistic environment while enabling researchers to control the research environment. The development task in the Live-Lab is the iterative development of a gas grill based on existing reference products. The Live-Lab allows a wide variety of studies for validating methodological design support for sheet metal development, including the reduction of validation time using the example of generational engineering and variation types, metal design concerning sustainability, and decision heuristics in agile development. Nevertheless, the requirements on which the Live-Lab GSD is developed are based on existing literature and expert interviews. Furthermore, the use of a controlled research environment carries the risk that important influencing factors that occur in reality and affect the results are not covered, thus limiting the validity and transfer of the results into practice. However, for the development of new methods and tools, a Live-Lab is very well suited to accelerate the development process of methodological design supports.

Subsequent research activities address the design of an engineering simulator based on the task of the Live-Lab GSD. Compared to the Live-Lab, the engineering simulator further shortens the duration of the validation studies to around two days and therefore tackles the challenge of the length of time until research results can be generated. In addition, an improvement in the replicability of the validation results and the controllability of the measurable variables can be achieved (cf. [20]). Furthermore, another contribution can show how GSD in the context of design education research contributes to the students' competence regarding (1) sheet metal design, (2) development in product generations, and (3) agile development.

References

[1] Matthiesen S, Meboldt M, Lohmeyer Q. The dilemma of managing iterations in time-to-market development processes. In: Heisig P, Clarkson PJ, editors. MMEP 2012 - 2nd International Workshop on Modelling and Management of Engineering Processes. Cambridge, United Kingdom. Zürich: Eidgenössische Technische Hochschule Zürich; 2012, https://doi.10.3929/ethz-a-009774163.

[2] Atzberger A, Nicklas SJ, Schrof J, Weiss S, Paetzold K. Agile Entwicklung physischer Produkte. 10th ed. Neubiberg, Deutschland; 2020.

[3] Duehr K, Kopp D, Rapp S, Albers A. Validating a Design Method to Support Collaboration in Distributed Product Design – What Needs to be Considered? In: Proceedings of NordDesign 2022. Lyngby, Denmark, 16.-19.08.2022; 2022, https://doi.org/10.35199/NORDDESIGN2022.9.

[4] Albers A, Bursac N, Eckert CM, Walter B, Wilmsen M, Heimicke J. AGILE METHOD DEVELOPMENT: A LIVE-LAB CASE STUDY ON PRODUCT PROPERTIES FOR PROCESS PLANNING. In: Marjanović D, Storga M, Skec S, Bojcetic N, Pavkovic N, editors. DS92: Proceedings of the DESIGN 2018 15th International Design Conference. Dubrovnik, Croatia, 21.-24.05.2018. Glasgow: The Design Society; 2018, 713–724. https://doi.10.21278/idc.2018.0341.

[5] Albers A, Walter B, Wilmsen M, Bursac N. Live-Labs as real-world validation environments for design methods. In: Marjanović D, Storga M, Skec S, Bojcetic N, Pavkovic N, editors. DS92: Proceedings of the DESIGN 2018 15th International Design Conference. Dubrovnik, Croatia, 21.-24.05.2018. Glasgow: The Design Society; 2018, 13–24. https://doi.org/10.21278/idc.2018.0303.

[6] Albers A, Rapp S, Birk C, Bursac N. Die Frühe Phase der PGE – Produktgenerationsentwicklung. In: Binz H, Bertsche B, Bauer W, Spath D, Roth D, editors. Stuttgarter Symposium für Produktentwicklung SSP 2017. Stuttgart, Germany, 29.06.2017. Stuttgart: Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO; 2017.

[7] Bailom F, Hinterhuber HH, Matzler K, Sauerwein E. Das Kano-Modell der Kundenzufriedenheit. Marketing: Zeitschrift für Forschung und Praxis 1996:117–26.

[8] Albers A, Rapp S, Spadinger M, Richter T, Birk C, Marthaler F et al. The reference system in the model of PGE: proposing a generalized description of reference products and their interrelations. In: The Design Society, editor. Proceedings of the 22nd International Conference on Engineering Design (ICED19). Delft, The Netherlands, 05.-08.08.2019. Cambridge: Cambridge University Press; 2019, 1693–1702. https://doi.10.1017/dsi.2019.175.

[9] Albers A, Bursac N, Wintergerst E. Produktgenerationsentwicklung– Bedeutung und Herausforderungen aus einer entwicklungsmethodischen Perspektive. In: Binz H, Bertsche B, Bauer W, Roth D, editors. Stuttgarter Symposium für Produktentwicklung SSP 2015. Stuttgart, Germany, 19.06.2015. Stuttgart: Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO; 2015.

[10] Albers A, Altner M, Rapp S, Valeh B, Redinger H, Winter R. Evaluation of Engineering Changes Based on Variations from the Model of PGE – Product Generation Engineering in an Automotive Wiring Harness. In: Proceedings of the 17th International Design Conference. 23.-26.05.2022. Cambridge: Cambridge University Press; 2022, 303–312. https://doi.10.1017/pds.2022.32.

[11] Roe BE, Just DR. Internal and External Validity in Economics Research: Tradeoffs between Experiments, Field Experiments, Natural Experiments, and Field Data. American Journal of Agricultural Economics 2009;91(5):1266–71. https://doi.org/10.1111/j.1467-8276.2009.01295.x.

[12] Albers A, Bursac N, Heimicke J, Walter B, Reiß N. 20 Years of Co-creation Using Case Based Learning: An Integrated Approach for Teaching Innovation and Research in Product Generation Engineering. In: Auer M, Guralnick D, Simonics I, editors. Proceedings of the 20th International Conference on Interactive Collaborative Learning 2017: Teaching and Learning in a Digital World. Advances in Intelligent Systems and Computing, 2nd ed. Cham: Springer; 2018, 636–647. https://doi.10.1007/978-3-319-73204-6_69.

[13] Walter B, Klippert M, Kunz M, Albers A, Reiß N. Kreativitätsmethoden im digitalen Umfeld – Aktive Förderung von Innovationsimpulsen in standortverteilten Entwicklungsteams. In: Brökel Fea, editor. 15. Gemeinsames Kolloquium Konstruktionstechnik 2017; 2017.

[14] Doellken M, Lorin A, Nelius T, Matthiesen S. Identifying an opportunistic method in design for manufacturing: an experimental study on successful a on the manufacturability and manufacturing effort of design concepts. In: 31st CIRP Design Conference 2021: Accelerating Product Development. Twente, The Netherlands, 19.-21.05.2021. Amsterdam: Elsevier; 2021, 720–725. https://doi.10.1016/j.procir.2021.05.090.

[15] van Vliet HW, van Luttervelt K. Development and application of a mixed product/process-based DFM methodology. International Journal of Computer Integrated Manufacturing 2004(17):224–34. https://doi.org/10.1080/09511920310001600868.

[16] Blessing LTM, Chakrabarti A. DRM, a Design Research Methodology. London: Springer; 2009.

[17] Thaler RH, Sunstein CR. Nudge: Improving decisions about health, wealth, and happiness. New Haven: Yale University Press; 2008.

[18] Tanaiutchawoot N, Bursac N, Rapp S, Albers A. Investigating the Influence of the Decoy Effect in Pairwise Comparison in Terms of Idea Selection in the Product Development Process. In: The Design Society, editor. Proceedings of the 22nd International Conference on Engineering Design (ICED19). Delft, The Netherlands, 05.-08.08.2019. Cambridge: Cambridge University Press; 2019, 1195–1204. https://doi.10.1017/dsi.2019.125.

[19] Bursac N, Tanaiutchawoot N, Rapp S, Albers A, Breitschuh J, Eckert C. Decision Heuristic in PGE - Product Generation Engineering. In: Horváth I, Rivero JPS, Hernandez PM, editors. Proceedings of the Twelfth International Symposium on Tools and Methods of Competitive Engineering - TMCE 2018. Las Palmas, Spain, 07th -11th May 2018. Delft, Netherlands: Delft University of Technology; 2018, p. 385–394.

[20] Hofelich M, Mantel KV, Omidvarkarjan D, Matthiesen S, Meboldt M, Schneider T. Attributes of Research Environments for modelling Engineering Simulators for design support validation. In: 31st CIRP Design Conference 2021: Accelerating Product Development. Twente, The Netherlands, 19.-21.05.2021. Amsterdam: Elsevier; 2021, 678–683. https://doi.org/10.1016/j.procir.2021.05.143.