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Lightweight design in product development: a conceptual framework for continuous support in the development process

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Abstract

To get closer towards achieving the climate targets and the resulting reduction in CO2 emissions, one possible strategy is to consider lightweight activities across all industries. In product development, this means that lightweight design should be integrated at a very early stage, as this is the only way to achieve the highest lightweight potential. However, such an integration is very complex, since necessary lightweight activities cannot be applied sequentially or universally to all products. Even multiple usage of different lightweight design strategies is not sufficient to achieve a targeted lightweight design on the overall system level. Therefore, it is necessary to support the product developer in the application of lightweight design by providing a framework with necessary methods and processes as well as recommendations regarding their timing. The possibility to apply them individually to different systems and related problems has to be given.

To develop such a framework, different projects with respect to lightweight design were analyzed and evaluated. The main focus was on the determination of lightweight design strategies that were applied in the projects and the subsequent derivation of requirements in order to raise further lightweight potential.

Based on this analysis and evaluation, a conceptual framework was developed that focuses on the overall system to be optimized, which can be part of a previous generation, for example. Subsequently, the available lightweight activities and design strategies were linked with supporting tools and methods from knowledge management. Therefore, this conceptual framework provides continuous support for the product developer throughout the entire product development process in lightweight activities.

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Keywords: lightweight design; product development; development process; lightweight design strategies

1. Introduction

For years, greenhouse gas emissions have been described as the strongest driver of global warming, therefore it is necessary to reduce their emissions as much as possible. Above all, CO2, which is emitted during transportation, in production facilities or in everyday mobility, must be reduced. In this context, lightweight design is of particular importance and can make a major contribution to reducing emissions if the lightweight design philosophy is applied across all industries [1]. In product development, there is a high savings potential, especially in the early phases [2]. This includes, for example, product conception, where 70-80 % of the used resources are already set [3].

However, the potential for further savings can be increased if lightweight design is considered at system level instead of component level and across all phases of the product development process. Through such an approach, it is possible to detect interactions of different lightweight activities on the system at an early stage [4].

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2. State of the Art

2.1. The Model of PGE – Product Generation Engineering

Product engineering includes production preparation, production and product development activities [5]. The latter are of special interest in the context of this paper, as there is a great lightweight potential in this area of product engineering [2].

According to Albers et al. the development of new products is always based on a reference system [6]. The elements of this reference system may originate from previous product generations, competitor products or other disciplines such as research. These elements are adapted through the development activities of Carryover Variation (CV), Attribute Variation (AV) and Principle Variation (PV). Their systematic combination subsequently generates new products. [7]

This is described in the model of PGE – Product Generation Engineering. It is a descriptive model for the development of technical products, which allows to research and develop new methods and approaches for planning and controlling product development processes. [8]

By using the model of PGE, it is possible to assess the impact of decisions made within the product specification. This not only reduces the development risk, but also increases the potential for saving resources. [9]

2.2. Lightweight design strategies

The aim of lightweight design is always to reduce the weight of components, structures or products to a certain extent [10]. One way of achieving these efforts is the targeted application of the design methods, materials and production technologies available in lightweight design [11]. The lightweight design strategies serve this goal-oriented application and exist in various numbers and forms in literature [12–15]. For this paper the following lightweight design strategies including their definition are used:

- *Conditional lightweight design* comprises the requirements or conditions for the lightweight structure. These requirements arise from the general conditions of society, politics and legislation as well as the markets. [11] Furthermore, this strategy includes functional requirements such as a specific range for electric vehicles, required lightweight performance indicators e. g. load to weight ratio or the necessary lift of ships and airplanes related to their weight.
- The aim of *material lightweight design* is to produce the structure with the lightest possible material for the given requirements. The weight of a structure can be reduced by replacing one material with another material with a lower density. [11]
- The goal of *form lightweight design* is to adapt a structure to the given requirements in such a way that a structure with minimum weight is created through optimal distribution of force and shaping. [11]
- The term *manufacturing lightweight design* refers to the weight saving potential through manufacturing, production and assembly processes. However, manufacturing lightweight design can rarely be considered in isolation, as it is very closely linked to the two strategies of material and form lightweight design. [11]
- *System lightweight design* is the holistic optimization of a technical system with regard to weight and inertia, taking into account all relationships and interactions in the system as well as general technical and economic conditions. This strategy thus represents a method of lightweight design that covers all materials and products. [4]

2.3. Classification of lightweight design strategies in the product development process

Every lightweight design strategy already has a major influence on the lightweight potential in the overall system. However, it is necessary to apply the strategies at the right time in the product development process in order to achieve lightweight design throughout all phases and to generate the greatest possible lightweight potential.

According to Kopp et al. the lightweight design strategies are performed in an iterative process. The conditional lightweight design is the starting point and is only considered once at the beginning. Afterwards the further strategies (see chapter 2.2) can be applied in different iteration loops through the development process. These iterations can refer to components, assemblies, modules or the entire lightweight structure. [11]

The authors Schmidt et al. assign the lightweight design strategies to the phases *planning*, *conception*, *design* and *elaboration* within the product development process according to Feldhusen et al. [16]. In this classification, the system lightweight design extends over all phases. The remaining strategies are each assigned to one or two phases. Thus, form and conditional lightweight design are only used in the design and development phase. In contrast, material and manufacturing lightweight design is addressed exclusively in the development phase. [17]

3. Problem statement and Goal

The large number of different lightweight design strategies, their characteristics as well as possible points in time of application in the product development process show that a generally valid integration of lightweight activities into product development is not possible. Neither an iterative application of lightweight design strategies nor their exclusively consideration in assigned phases of the product development process seems sufficient to achieve the maximum lightweight potential.

Therefore, this contribution investigates how the product developer can be supported in the application of lightweight activities in product development. The goal is to derive a framework with supporting methods and processes as well as recommendations regarding their application timing. It must be possible to apply these methods and processes individually to different systems and related problems. This leads to the research questions to be answered in this paper:

What can a framework look like to support the product developer in lightweight activities throughout the entire product development process?

Which kind of portfolio for methods and processes can support this framework?

4. Methodology

In order to answer these research questions, a large number of publicly funded projects in the context of product development with regard to lightweight design were searched, analyzed and evaluated. The focus of the evaluation and analysis is mainly on which lightweight design strategies are applied and whether the lightweight design efforts are made on the overall system or on component level. Based on the evaluation and the results, a conceptual framework for the continuous support of the product developer (see chapter 5) is presented and discussed.

To ensure that projects with direct industrial relevance as well as fundamental research, but also individual projects and large project consortia are considered, both national and international databases of public funding institutions were searched. In particular, the databases of the German Research Foundation (DFG), the German Federation of Industrial Cooperative Research (IGF) and the European Commission were used [18–20]. Thereby, it did not matter whether the project is currently in progress or has already been completed.

First, the databases were checked for projects in the area of product development and lightweight design separately from each other in order to capture the maximum possible number of projects. The terms "Leichtbau" and "lightweight" as well as "Produktentwicklung" and "product development / product engineering" were used for the search. An advanced categorization including synonyms for the terms was not used here, since incorrectly identified projects were eliminated in a subsequent step by manual filtering with title, keywords and abstract. The result of the search is illustrated in Fig. 1. It shows that 2054 projects are listed in the "Leichtbau" and "lightweight" section. The search for "Produktentwicklung" or "product development" results in 1855 projects.

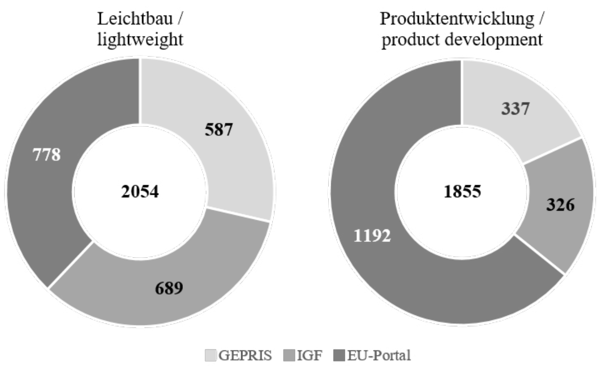

Fig. 1: Results of the project search in the area of lightweight design (left) and product development (right)

By refining the search using a combination of the terms "Leichtbau" and "Produktentwicklung" as well as "lightweight" and "product development" in one search string or by adjusting the existing filter masks specifically to the two terms, the results were reduced significantly to 155 (Fig. 2 left). The subsequent analysis of titles, keywords and abstracts further reduced the results to 25 projects (Fig. 2 right). Especially the projects from the database of the European Commission were reduced by approximately 90%. This is due to the fact that a large number of the projects contained the word "product development" or "lightweight" in the abstract or title, but were located in a completely different subject area such as biology or chemistry.

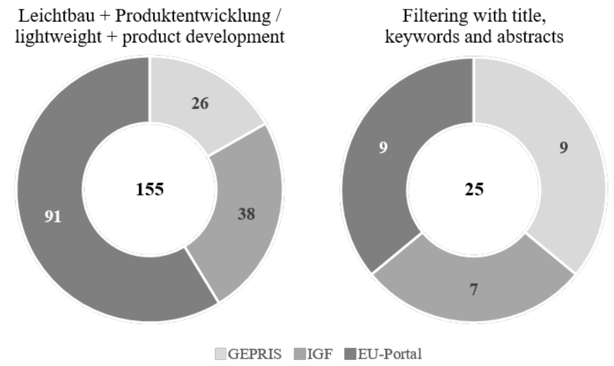

Fig. 2: Results of the project search by combined search string (left) and after filtering with title, keywords and abstracts (right)

The final step in the project search was examining the 25 remaining projects with regard to their use of lightweight design strategies. In addition to the abstracts, further project information such as publications were included and evaluated. The result of this evaluation is illustrated in Fig. 3. It appears that system lightweight design was addressed to a much lower extent in the projects than the material, form and manufacturing lightweight design strategies. The conditional lightweight design is not shown in the figure, since none of the projects addresses this lightweight design strategy directly. This is due to the fact that the requirements in conditional lightweight design are mainly influenced by society, politics or legislation or the requirements for the development task stated in the system of objectives are not linked to this strategy [21]. Regarding the number of strategies used, it is noticeable that their sum is greater than the number of projects. This is due to the fact that one project can serve several lightweight design strategies simultaneously.

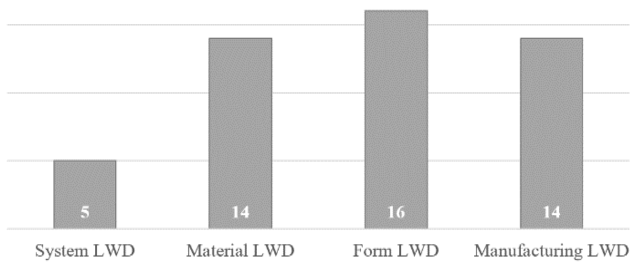

Fig. 3: Distribution of the used lightweight design strategies in the 25 resulting projects out of the search

With regard to the division of whether the lightweight design efforts took place on the overall system or component level, only five of the 25 projects took place on the system level, as shown in Fig. 3. The remaining 20 projects related to individual components and were thus carried out at component level.

The project search shows that in the context of product development, in most cases conditional lightweight design is used to fulfill boundary conditions and requirements which cannot be directly influenced by the product developer without explicitly using this lightweight design strategy. The additional project information (publications, conference contributions, etc.) illustrate that mainly the areas of material and manufacturing lightweight design are carried out by material or manufacturing scientists to support product development. Thus, a large number of the projects in which one of the two strategies was applied show the additional information that no specific product was in their focus, but rather a new manufacturing process or material was developed to open up new opportunities for the product developer in the context of lightweight design. In contrast, system and form lightweight design is actively researched and applied in product development in the projects to create new product solutions. However, in most cases these were only carried out on individual components without taking into account the surrounding system. As an outcome, the resulting interactions within the overall system are often neglected.

Approaching the problem from this point of view reduces weight, but does not nearly exploit the full lightweight potential. It is assumed on the basis of own findings and project experience that the application to only individual components has a reason in the lack of available methods and/or processes as well as knowledge about their existence. Therefore, a framework should be available that includes existing methods as well as processes and supports the product developer in the application of lightweight activities without neglecting lightweight design strategies.

5. Conceptual Framework

Based on the results of the analyzed projects as well as in-house projects and many years of experience in the fields of product development and lightweight design, such a framework was conceptual developed. In this context, the ambition is not to provide a defined step-by-step procedure, but to offer a portfolio of different methods and processes as support. This conceptual framework and its effect on a technical system is reflected in Fig. 4.

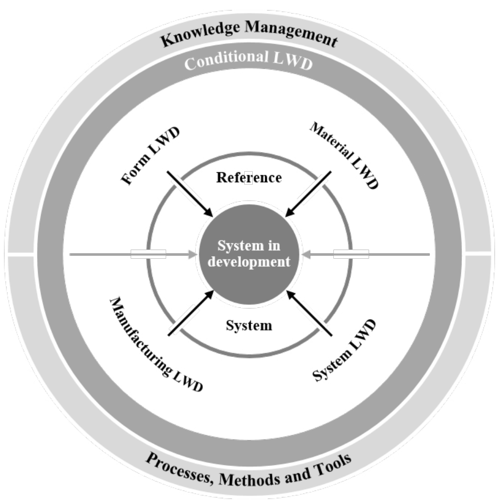

Fig. 4: Schematic illustration of the conceptual framework to support the product developer in lightweight activities

The mindset of the PGE is central to the conceptual framework, since it states that product development is based on a reference system. This means that lightweight design activities can also be adapted to the system in development. So, it could be a solution to adapt lightweight approaches from other industries or even other domains (like bionic approaches). System, material, form and manufacturing lightweight design strategies serve as instruments available to the product developer, while the conditional lightweight design strategy represents a boundary condition. To structure, target and apply the different strategies, supporting activities are necessary. Since each lightweight activity can be supported with different methods, processes and tools as well as activities from knowledge management, these are included in the framework as supporting tools.

Since thinking in terms of *systems*, *processes* and *methods* has shown to be effective in the field of product development, the presented framework is structured based on this mindset. Each of these three areas is described below in the context of the framework and associated supporting tools are presented.

Systems

In each development process and thus also in this framework, the system in development has to be in center of interest and must be specified first. For this purpose, different methods and tools can be applied, such as e. g. the Extended Target Weighing Approach (ETWA) according to Albers et al. or the approach for multi-criteria derivation of lightweight design potential according to Laufer et al. [22, 23]. The selection of the methods and tools is depending on the requirements of the system.

Processes

In addition, the process for achieving the lightweight goal must be defined for each system. This process definition is a decisive step for the success of the lightweight activities. As discussed above, a single iteration through the product development process is not a promising approach. Instead, the right lightweight activities must be applied at the right stages of development so that the lightweight mindset is present throughout the whole development process. This can only succeed if the system is sufficiently clear delineated and defined. Specifying goals in a system of objectives as well as the planning of the available resources in the operation system are part of this. In order to identify the right activities in each phase and support the planning of activities, the Integrated Product Engineering Model (iPeM), for example, can be used in conjunction with the lightweight design strategies mentioned above and the experience from previous projects with the help of the model of PGE [21]. The systematic planning of development activities using the model of PGE in particular helps to open up lightweight potential across product generations. Through the strategic use of embodiment and principle variations, subsystems for lightweight activities can be defined and, for example, major measures realized over several generations. In addition, the consequent re-use of existing knowledge in the reference system as a central part of knowledge management is supported. This allows to select the optimal methods and tools, depending on the given requirements and the system in development.

Methods

Further elements in the operation system are the lightweight design strategies. Based on the results of the search, material lightweight design in the context of product development is usually understood as the correct selection and situation-specific use of already developed materials. Manufacturing lightweight design describes the selection of established and used technologies. For the selection of such materials or manufacturing technologies, methods and supporting tools such as GRANTA EduPack, the Mass Manager or A2Mac1 are available to the product developer [24–26]. Conditional lightweight design triggers lightweight activities, which become necessary by their related boundary conditions and requirements, for example. To support system and form lightweight design there are a number of different methods and tools provided. The ETWA offers a possibility to apply system lightweight design under consideration of reference systems [23]. Here, the mass of individual functions within a system is assigned in order to identify areas in the system with high lightweight potential. Form lightweight design can also be supported by tools such as structural optimization. However, in addition to its application in the design/development phase, such an optimization can also be used in the concept phase, for example to stimulate creativity. Furthermore, the entire problem-solving process of lightweight design can be supported by specific methods. The Innofox, for example, helps to identify situation-specific methods based on the current phase in the development process [27]. Also, the use of design guidelines, which is popular among engineers, can support the generation of new concepts or the specific design of the components. Due to the fact that there are significantly more materials on the market today than there were a few years ago, design guidelines need to be adapted to the requirements of today by distinguishing between generally valid and material-specific design guidelines and making them available to the product developer as such. Fiberfox, for example, is a supporting tool for this purpose [28].

6. Application Example

Following, the developed framework and the associated support of the product developer will be presented by an application example. A strut tower, which was already used in the EU project ALLIANCE, serves as such an application example. The weight of the strut tower was reduced by 22 % and its CO2 emissions by 6 %. At the same time, the price was increased by a maximum of 3 € for each kilogram of reduced weight. [29]

Thus, the strut tower was the system in development. In order to develop it further in terms of lightweight design, it was necessary to use the right lightweight activities as well as methods and processes at the right time in the development process. To achieve this, several of the presented tools were used in combination with different lightweight design strategies.

Initially, all information from previous generations of the strut tower as well as competitor products were included in the reference system in order to create the largest starting basis possible. With the help of the iPeM it was possible to plan the lightweight activities throughout the whole project. It supported the holistic view on the product development process including production and validation activities. In the context of system lightweight design, the ETWA was used as a supporting tool to identify components in the strut tower with too much weight with regard to their importance for the product. Within the concept phase, computer-aided optimizations belonging to form lightweight design were used in addition to conventional creativity methods like the 6-3-5 method or Brainwriting Pool in order to find new designs. These optimizations served as inspiration as well as a rough estimation of component design space. In the design phase, these optimizations, together with new boundary conditions, helped to further reduce weight and to design the structure of the strut tower. In the context of material lightweight design, new materials were developed by material scientists in the EU project, but without direct relation to product design. The new materials as well as established materials were only used as input for new designs. Thus, in the context of product development, the focus was not on the development of new materials but their application, which is coincidental in line with the findings from the search (see chapter 4). To iteratively improve the strut tower, the ETWA was run through several times and the activities described were repeated until the desired weight reduction was achieved. As a result, a multi-material design showed the potential for achieving weight, costs and CO2 emission targets. Achieving the targets was only possible by restructuring the design spaces within the assembly and by focusing on the right material assignment for the occurring loads.

This application example shows that lightweight design can be implemented more comprehensively by using different lightweight activities in combination with the appropriate methods and processes as well as taking previous generations into account. The individual application of lightweight design strategies would certainly also have led to a reduction in weight, but probably not to the same extent.

7. Discussion

Every product development process is unique, which is why the framework presented here is not intended to show a generally applicable procedure, but rather a framework to support the product developer with a portfolio of processes, methods and tools for the selection, application and implementation of lightweight activities. Depending on the development task, the principles of the framework described (see chapter 5) can be adapted individually and situation-specific. Nevertheless, product development can be structured into different phases and repetitive activities in order to select the adequate process elements, methods and tools [21]. This enables the product developer to use this conceptual framework based on identifiable phases and activities to select the necessary actions.

Since besides phases and repetitive activities experience in the area of product development has shown that thinking in systems, methods and processes is effective, this mindset is central in the presented framework. Each of these three areas can be supported by applications in knowledge management as well as supporting tools (see chapter 5).

This strong interaction of the individual elements with each other is also shown in Fig. 4. The product developer operates in a connected environment that requires a product-specific adaptation to the development environment, which must be evaluated at any time. Therefore, the authors consider it useful to provide a portfolio as presented, which can be used depending on the specific situation.

8. Conclusion and Outlook

Lightweight activities confront the product developer with major challenges, especially in highly connected systems, since change propagations are difficult to oversee and therefore cannot be fully taken into account right from the beginning. It is therefore not feasible to implement lightweight design strategies sequentially along the development phases. Instead, a strong, individual integration into the entire product development process is required.

The presented framework addresses this finding by providing the product developer with a portfolio of supporting methods, processes and tools to help in the selection, application and implementation of lightweight activities. Besides lightweight specific methods, processes and tools, elements of knowledge management are used, as this is of crucial importance for the success of a new product.

In addition to the ALLIANCE project (see chapter 6), the framework discussed in this paper has also been used in other projects. For example, it found application in the battery environment and ensured the desired weight reduction. The framework has also been applied in the field of air conditioning technology and in hand-held devices in the packaging industry. With the help of the gained experience from these projects as well as future projects in which the presented framework is applied, it will be further developed and evaluated. An extension through elements of machine learning is conceivable in order to lower the barrier of specific applications such as topology optimization. Furthermore, the early validation of design alternatives in the development process could be facilitated by computer-aided, integrated platform solutions.

References

[1] Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit. Klimaschutzprogramm 2030 der Bundesregierung zur Umsetzung des Klimaschutzplans 2050.
[2] Leichtbau BW GmbH. Mit Konzeptleichtbau ungenutzte Potentiale heben:: Ökonomischer und ökologischer Nutzen.
[3] Leichtbau BW GmbH. Systemeffizienter Hybrider Leichtbau in Baden-Württemberg – Positionspapier. 2014
[4] Albers A, Burkardt N. Systemleichtbau - ganzheitliche Gewichtsreduzierung. In: Henning F, Moeller E, editors. Handbuch Leichtbau: Methoden, Werkstoffe, Fertigung, 2020.
[5] Albers A, Braun A, Heimicke J, Richter T. Der Prozess der Produktentstehung. In: Henning F, Moeller E, editors. Handbuch Leichtbau: Methoden, Werkstoffe, Fertigung, 2020.
[6] Albers A, Rapp S, Spadinger M, *et al.* The Reference System in the Model of PGE: Proposing a Generalized Description of Reference Products and their Interrelations. In: Design Society, editor. Proceedings of the 22nd International Conference on Engineering Design (ICED19) 2019; 1693–702.
[7] Albers A, Rapp S, Fahl J, *et al.* Proposing a generalized description of variations in different types of systems by the model of PGE – Product Generation Engineering. Proc. Des. Soc.: Des. Conf. 2020; 1: 2235–44 [https://doi.org/10.1017/dsd.2020.315]
[8] 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, 2015.
[9] 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 2017
[10] Tempelman E. Lightweight Materials, Lightweight Design? In: Materials Experience. Elsevier 2014; 247–58.
[11] Kopp G, Burkardt N, Majic N. Leichtbaustrategien und Bauweisen. In: Henning F, Moeller E, editors. Handbuch Leichtbau: Methoden, Werkstoffe, Fertigung, 2020.
[12] Krause D, Schwenke J, Gumpinger T, Plaumann B. Leichtbau. In: Rieg F, Steinhilper R, editors. Handbuch Konstruktion. 2., aktualisierte Auflage. München Hanser; 487–507.
[13] Öchsner A. Leichtbaukonzepte. Wiesbaden: Springer Fachmedien Wiesbaden 2018.
[14] Schmidt W, Puri W. Systematische Entwicklung gewichtsoptimierter Bauteile. In: Meerkamm H, editor. Design for X - Beiträge zum 11. Symposium. Schnaittach 2000; 37–40.
[15] Ellenrieder G, Gänsicke T, Goede M, Herrmann HG. Die Leichtbaustrategien. In: Friedrich HE, editor. Leichtbau in der Fahrzeugtechnik. Wiesbaden: Springer Fachmedien 2013; 43–118.
[16] Feldhusen J, Grote K-H. Pahl/Beitz Konstruktionslehre. Berlin, Heidelberg: Springer Berlin Heidelberg 2013.
[17] Schmidt W, Puri W, Meerkamm H. Strategies and Rules for Lightweight Design. In: Culley S, editor. Design research - theories, methodologies, and product modelling. Bury St. Edmunds: Professional Engineering Publ 2001.
[18] Deutsche Forschungsgemeinschaft (DFG). GEPRIS - Geförderte Projekte der DFG [cited 2020 November 17] Available from: URL: https://gepris.dfg.de/gepris/OCTOPUS.
[19] IGF - Industrielle Gemeinschaftsforschung. Forschungsergebnisse für den Mittelstand [cited 2020 November 17] Available from: URL: https://www.aif.de/foerderangebote/igf-industrielle-gemeinschaftsforschung/igf-projektdatenbank.html.
[20] European Commission. European Commission - Search [cited 2020 November 17] Available from: URL: https://ec.europa.eu/search/.
[21] Albers A, Reiß N, Bursac N, Richter T. The integrated Product engineering Model (iPeM) in context of the product generation engineering. Procedia 26th CIRP Design Conference, Stockholm: 100–5.
[22] Laufer F, Roth D, Binz H. An approach for the multi-criteria derivation of lightweight potential. Proc. Des. Soc.: Des. Conf. 2020; 1: 977–86 [https://doi.org/10.1017/dsd.2020.21]
[23] Albers A, Revfi S, Spadinger M. Extended Target Weighing Approach – Identification of Lightweight Design Potential for New Product Generations. In: Proceedings of the 21st International Conference on Engineering Design (ICED). Red Hook, NY, 2017; 367–76.
[24] Ansys Incorporated. GRANTA EduPack [cited 2020 November 17] Available from: URL: https://www.ansys.com/products/materials/granta-edupack/.
[25] Ierides M, Mbang S. FORM Forum - Proceedings 2018. In: European Automotive Research Partners Association.
[26] A2mac1. A2mac1 - Automotive Benchmarking [cited 2020 November 17] Available from: URL: https://portal.a2mac1.com/.
[27] Albers A, Reiß N, Bursac N, Walter B, Gladysz B. InnoFox – Situationsspezifische Methodenempfehlung im Produktentstehungsprozess. In: Binz H, Bertsche B, Bauer W, Roth D, editors. Stuttgarter Symposium für Produktentwicklung 2015.
[28] Butenko V, Albers A. CoDiCo-FiberFox – Decision-Support System in Early Phases of Product Development with Fiber-Reinforced Composites. In: Böhlke T, Henning F, Hrymak A, Kärger L, Weidenmann KA, Wood JT, editors. Continuous-discontinuous fiber-reinforced polymers: An integrated engineering approach. Munich: Carl Hanser Verlag 2019; 276–93.
[29] Revfi S, Tamm C, Thirunavukkarasu D, Timmer A. Methodology for the Identification of Lightweight Solutions in Vehicle Applications. ATZ Worldw 2020; 122(6): 60–3 [https://doi.org/10.1007/s38311-020-0248-3]