

Book of Abstracts

22. – 23.09.22

Hamburg

33. SYMPOSIUM

# Design X 2022

Veranstaltet durch



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# **Book of Abstracts**

## 33. Symposium Design for X

22. und 23. September 2022

Hamburg



Das Symposium Design for X findet in diesem Jahr in Hamburg zum 33. Mal statt. Nachdem die beiden letzten Symposien in Erlangen und Tutzingen aufgrund des Coronavirus online stattfinden mussten, freue ich mich umso mehr, Professorinnen und Professoren sowie Wissenschaftlerinnen und Wissenschaftler aus ganz Deutschland, aber auch Gäste aus der Industrie persönlich zum 33. Symposium Design for X in Hamburg begrüßen zu dürfen. Die Pandemie scheint vorerst überwunden zu sein, die Zeiten haben sich aber nicht weniger turbulent weiterentwickelt. Inzwischen stehen wir vor neuen wirtschaftlichen und gesellschaftlichen Herausforderungen, denen es auch in der Produktentwicklung entgegenzutreten gilt. Sich verkürzende Entwicklungszeiten, die Entwicklung nachhaltiger Produkte und Prozesse, Digitalisierung und stockende Lieferketten stehen nur exemplarisch für zahlreiche Hürden, die es zu meistern gilt. Dies erfordert die Erforschung und Weiterentwicklung in allen Bereichen des Produktlebenszyklus, der durch die Bandbreite der eingereichten Beiträge widergespiegelt wird.

Auch in diesem Jahr besteht dankenswerter Weise die Möglichkeit, die erarbeiteten und auf dem Symposium vorgestellten Beiträge über die Design Society zu veröffentlichen und somit der Fachwelt zur Verfügung zu stellen. Gemäß unserer Tradition definieren sich auch diesem Jahr die thematischen Schwerpunkte

- Modularisierung & Variantenmanagement
- Strukturanalyse, Simulation & Test
- Leichtbau

Neu in der Reihe gliedert sich neben dem Design for X der Bereich

- Modellbasierte Entwicklung/Systems Engineering

mit zahlreichen Beiträgen ein.

In der Natur des DfX-Symposiums steckt neben den lebhaften Diskussionen auch den Blick für Bereiche außerhalb des Eigenen zu schärfen, weshalb es umso erfreulicher ist, auch in diesem Jahr zwei Keynotevorträge aus verschiedenen Bereichen der Produktentwicklung aus der Industrie präsentieren zu können, die den Teilnehmerinnen und Teilnehmern den ein oder anderen Impuls mit auf den Weg geben.

Ich danke meinen beiden Mitveranstaltern und Kollegen Kristin Paetzold und Sandro Wartzack für Ihr eingebrachtes Engagement und die konstruktive Zusammenarbeit, meinen Mitarbeitern für die Organisation des Symposiums und natürlich allen Teilnehmerinnen und Teilnehmern für ihre Beiträge. Ich freue mich auf die vielen, interessanten Vorträge, sowie auf die sicherlich intensiven und lebhaften Diskussionen.

Mit freundlichen Grüßen



Prof. Dr.-Ing. Dieter Krause





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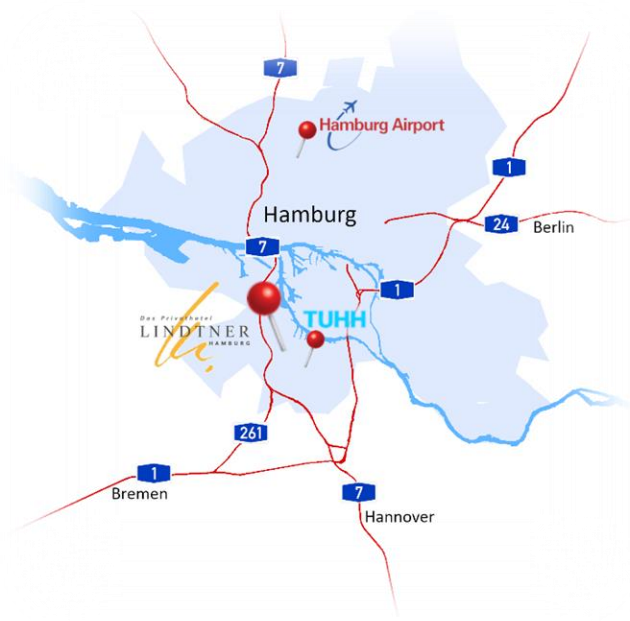
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Nehmen Sie von den Fernverkehrsbahnhöfen Hamburg oder Hamburg-Harburg die S3 in Richtung Neugraben bis zur Haltestelle Heimfeld. Von dort nehmen Sie den BUS 142 bis zur Haltestelle Hotel Lindtner.

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Modularisierung & Variantenmanagement

Strukturanalyse, Simulation & Test

Leichtbau

Modellbasierte Entwicklung /  
Systems Engineering

Design for X

# Donnerstag, 22. September

09:00 – 09:15 Uhr  Begrüßung

09:15 – 09:45 Uhr **Keynote: Human-centered product development tomorrow – a utopia**  
(Dr. Sabine Muschik, TRUMPF SE + Co. KG)

09:45 – 10:45 Uhr **Session 1 „Strukturanalyse, Simulation & Test“**

- Quantifizierung des materialbezogenen ökologischen Impacts von topologieoptimierten Multimaterialbauteilen  
(Kevin Herrmann, Leibniz Universität Hannover)
- Combined environments - challenges and potentials in the realistic component testing  
(Philipp Hüttich, Technische Universität Hamburg)

10:45 – 11:15 Uhr Kaffeepause

11:15 – 12:45 Uhr **Session 2 „Leichtbau“**

- Directional Effects of Load Deviations on the Buckling of Cylindrical Shells in Experiment and Design  
(Stefan Panek, Technische Universität Hamburg)
- Spider web inspired composite structures - a new concept for load introduction in fiber-reinforced-plastics sandwich structures  
(Michael Franz, Friedrich-Alexander-Universität Erlangen-Nürnberg)
- Ansatz zur lastpfadoptimierten Gestaltung von Sandwichstrukturen mithilfe virtueller Tests und realitätsnahen Testaufbauten  
(Lukas Schwan, Technische Universität Hamburg)

12:45 – 13:45 Uhr Mittagspause

13:45 – 14:15 Uhr **Keynote: Modular Circularity**  
(Dr. Bahram Hamraz, Siemens Healthineers AG)

14:15 – 15:00 Uhr **Postersession**

- A concept for a novel hybrid augmented reality computer workstation for virtual product development  
(Jakob Harlan, Friedrich-Alexander-Universität Erlangen-Nürnberg)
- Heterogene Studierendengruppen als Herausforderung in der Konstruktionslehre  
(Frederike Kossack, Ruhr-Universität Bochum)
- Introduction of a Standardized Notation of Design Heuristics for Knowledge Formalization  
(Gerald Kremer, Technische Universität Berlin)
- Utilizing a graph data structure to model physical effects and dependencies between different physical variables for the systematic identification of sensory effects in design elements  
(Benjamin Kraus, Technische Universität Darmstadt)
- Procedural Concept Design with Computer Graphic Applications for Light-Weight Structures using Blender with Subdivision Surfaces  
(Martin Denk, Friedrich-Alexander-Universität Erlangen-Nürnberg)
- Synthesis of passive lightweight orthoses considering human-machine interaction  
(Patrick Steck, Friedrich-Alexander-Universität Erlangen-Nürnberg)
- Test-driven Development to Overcome Challenges in the Design of Sensor-integrating Machine Elements  
(Julian Peters, Karlsruher Institut für Technologie)
- Recommender Systems for Variant Management in the Automotive Industry  
(Thorsten Schmidt, Helmut-Schmidt-Universität Hamburg)
- Optimized planning of the integration of a Reference Plant into existing brownfield environments based on an entity model  
(Jonathan Leidich, Technische Universität Dresden)



# Donnerstag, 22. September (Fortsetzung)

15:00 – 15:30 Uhr Kaffeepause

15:30 – 17:00 Uhr **Session 3 „Modellbasierte Entwicklung / Systems Engineering“**

- Modellierung und Analyse funktionaler Varianz komplexer technischer Systeme  
(*Bastian Menninger, Rheinisch-Westfälische Technische Hochschule Aachen*)
- Analyse von Degradationsmodellen zur Modellierung der Lebensdauerheterogenität komplexer Systeme  
(*Robin Steve Bauer, Technische Universität Clausthal*)
- A Classification Method for the Systematic Identification of Models and Workflows in MBSE  
(*Gregor Höpfner, Rheinisch-Westfälische Technische Hochschule Aachen*)

Ab 17:30 Uhr  Bootstour mit anschließendem Konferenz-Dinner

# Freitag, 23. September

09:00 – 10:30 Uhr **Session 4 „Modellbasierte Entwicklung / Systems Engineering“**

- A model-based approach for early robustness evaluation – Combination of Contact and Channel Approach with tolerance graphs in SysML  
(*Dennis Horber, Friedrich-Alexander-Universität Erlangen-Nürnberg*)
- Potentiale der Integration von MBSE und LCA zur Handhabung von Unsicherheiten und Varianten in der frühen Entwicklung  
(*David Inkeremann, Technische Universität Clausthal*)
- Digital Twins of existing long-living assets: reverse instantiation of the mid-life twin  
(*Keno Moenck, Technische Universität Hamburg*)

10:30 – 11:00 Uhr Kaffeepause

11:00 – 12:30 Uhr **Session 5 „Modularisierung & Variantenmanagement“**

- Feature-Based Reconstruction of Non-Beam-Like Topology Optimization Design Proposals in Boundary-Representation  
(*Johannes Mayer, Friedrich-Alexander-Universität Erlangen-Nürnberg*)
- Analyzing Dependencies between Product Architecture and Module Drivers  
(*Marc Züfle, Technische Universität Hamburg*)
- Development of Business Model Families for Product-Service Systems  
(*Christoph Rennpferdt, Technische Universität Hamburg*)

12:30 – 13:30 Uhr Mittagspause

13:30 – 14:00 Uhr  Verabschiedung mit Preisverleihung

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## Quantifizierung des materialbezogenen ökologischen Impacts von topologieoptimierten Multimaterialbauteilen

Kevin Herrmann<sup>1,\*</sup>, Behrend Bode<sup>1</sup>, Johanna Wurst<sup>1</sup>, Paul Christoph Gembarski<sup>1</sup>, Iryna Mozgova<sup>1</sup>, Roland Lachmayer<sup>1</sup>

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When developing products, engineers face challenges in solving technical, economical, but also ecological conflicts of objectives. A common technical conflict is the contradictory behaviour between the stiffness and mass of components. A possibility to resolve this contradiction is offered by multi-material components, which are made possible by a load-optimised design. Taking the example of topology-optimised multi-material components, this article shows a method for taking the ecological impact of raw material extraction into account in selecting suitable designs by offsetting a performance index with the results of ecological impact assessment calculations. These results are analysed in order to identify a possible solution according to the technical-ecological conflict of objectives.

Keywords: *topology optimization, environmental impact, life cycle assessment, tailored forming, light weight design*

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## Combined environments - challenges and potentials in the realistic component testing

Philipp Hüttich<sup>1,\*</sup>, Stefan Panek<sup>1</sup>, Dieter Krause<sup>1</sup>

<sup>1</sup>Institute of Product Development and Mechanical Engineering Design, Hamburg University of Technology (TUHH)

Structural components can be exposed to extreme environmental conditions during operation over their service life. For this reason, they have to pass corresponding tests during development and certification in which they are tested for these loads. However, those tests are carried out separately, while in practice the loads occur in combination. This paper discusses the challenges arising from this, using the example of sandwich structures under combined mechanical and thermal loads and cylinder shells under combined mechanical loads. For this purpose, existing investigations, procedures and approaches are analysed, the necessity for combined testing is shown and a possible approach for a structured and reproducible procedure for testing components under combined loads is described.

Keywords: *Combined Loads, Combined Environments, Environmental Engineering, Structural Testing, Lightweight Structures*

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# Directional Effects of Load Deviations on the Buckling of Cylindrical Shells in Experiment and Design

Stefan Panek<sup>1,\*</sup>, Tobias S. Hartwich<sup>1</sup>, Dieter Krause<sup>1</sup>

<sup>1</sup>Institute of Product Development and Mechanical Engineering Design, Hamburg University of Technology (TUHH)

Exploiting the lightweight design potential of thin-walled shells requires precise buckling load predictions. Due to numerous scattering parameters affecting the buckling load, probabilistic approaches are often used to model these effects. However, developing a stochastic model requires test data while making some simplifying assumptions. In this contribution, the influence of different load deviation types on the buckling load of axially loaded cylindrical CFRP shells is investigated. It is shown that effects are direction-dependent and vary between types. The extent to which probabilistic approaches account for such effects is discussed. Finally, the results are transferred to other load cases and the importance of considering directional effects in design and testing is highlighted.

Keywords: *Buckling, Cylindrical Shells, Load Imperfections, Combined Loading, Probabilistic Design*

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# Spider web inspired composite structures - a new concept for load introduction in fiber-reinforced-plastics sandwich structures

Michael Franz<sup>1,\*</sup>, Harald Völkl<sup>1</sup>, Sandro Wartzack<sup>1</sup>

<sup>1</sup> Engineering Design, Friedrich-Alexander-Universität Erlangen-Nürnberg

Sandwich structures represent a lightweight design method which leads to very light and at the same time stiff components through the combination of stiff outer skins and light core material. A major challenge in the design of sandwich structures is load introduction. In order to realize improved load introduction in sandwich structures and to leverage further possible lightweight design potential, the following paper presents a new concept using spider web inspired structures made of fiber reinforced plastic materials. In order to investigate the potential of the spider web concept, simulative comparative studies between the spider web structures and conventional load introductions are carried out.

Keywords: *Composite structures, load introduction, spider web inspired*

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# Ansatz zur lastpfadoptimierten Gestaltung von Sandwichstrukturen mithilfe virtueller Tests und realitätsnahen Testaufbauten

Johann Schwenke<sup>1,\*</sup>, Lukas Schwan<sup>1</sup>, Michael Hanna<sup>1</sup>, Dieter Krause<sup>1</sup>

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The design of sandwich structures is challenging due to the large number of constituents and materials used. Existing design approaches do not include the consideration of the occurring initial damage as well as application-oriented boundary conditions in testing and optimization. Therefore, a general approach to the design optimization is presented consisting of the four parts problem definition, physical test, virtual test and design optimization, as well as an initialization phase and subsequent iterations. An exemplary application is performed for the novel design concept of optimizing the geometry of the core filling. From the initial results, the potential of the new design approach becomes clear, which can be used as a basis for the design optimization of any sandwich structures.

Keywords: *Sandwich Design, Sandwich Optimization, Virtual Testing, Test Setups, Inserts*

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# A concept for a novel hybrid augmented reality computer workstation for virtual product development

Jakob Harlan<sup>1,\*</sup>, Benjamin Schleich<sup>1</sup>, Sandro Wartzack<sup>1</sup>

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Extended reality user interfaces for engineering design often suffer from gaps in the user's workflow. Usually, the user must at least put on hardware, but often also data preparation is needed. This research aims to close these gaps by proposing a setup fusing desktop and immersive user experience into a hybrid augmented reality computer workstation. Here the user can decide for each operation what modality is best suited, using the strengths of both interfaces while avoiding their drawbacks. In this paper, a concept for such a hybrid computer workstation is developed using the morphological matrix method. Different solutions for the main features, holographic stereo display, spatial interaction, and the software architecture, are discussed and a reasoned combination is proposed as a feasible concept.

Keywords: *CAD, Augmented Reality, Product Design, Morphological Matrix, Computer workstation*

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## Heterogene Studierendengruppen als Herausforderung in der Konstruktionslehre

Frederike Kossack<sup>1,\*</sup>, Beate Bender<sup>1</sup>

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For the successful development of technical products, well-educated and trained engineers are key. To acquire the required knowledge and competences, very large groups of first-year engineering students currently participate in basic design engineering courses. Most of these students have differing levels of knowledge and experience caused by their various secondary education backgrounds, vocational trainings or completed preengineering courses. Within this paper this heterogeneity and the resulting challenges for the students by attending courses with frontal lecture formats with additional self-study time during the transition from high school to college is analysed through studies at the Ruhr-University Germany for developing improved teaching activities in the future.

Keywords: *design engineering, design education, student survey*

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## Introduction of a standardized Notation of Design Heuristics for Knowledge Formalization

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A wide range of tools simplify product development, e. g. Knowledge-Based Engineering Systems (KBES). Many KBES draw on knowledge derived from DfX methods. The knowledge of these methods is often available in varying degrees of detail, arising from the explicit knowledge of experts and scientists. When passing on knowledge, product developers often do so in the form of easy-to-understand rules of thumb, so-called design heuristics (DH). However, published DH do not offer sufficient clarity and usability to be integrated in daily engineering practice. This paper describes the development of a standardized notation form to make DH describable as a first step towards automated integration into KBES and towards integrating implicit knowledge of designers in future MBSE models.

Keywords: *Design Heuristics, Knowledge-Based Engineering, implicit knowledge, knowledge formalisation*

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## Utilizing a graph data structure to model physical effects and dependencies between different physical variables for the systematic identification of sensory effects in design elements

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Gaining accurate data from technical systems has become of interest, particularly in the context of condition monitoring and predictive maintenance. Hereby it is important to gather precise and reliable data. To accomplish this task, various sensors with different physical effects are used. Depending on the sensor's position and measurand, different models are necessary to describe the path from the desired variable of interest to the actual measured one. To support designers, a physical effect catalog was digitalized using a graph data structure, which uses the inherent properties of a graph to represent physical variables, physical effects and their relationships. This graph structure together with its applicability in a sensor selection process will be shown in this paper.

Keywords: *Sensory function, synthesis method, effect catalog, support tool, SuDE*

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# Procedural Concept Design with Computer Graphic Applications for Light-Weight Structures using Blender with Subdivision Surfaces

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In today's concept development, it is important to develop customer requirements in advance via prototypes with little effort. Some of these requirements can be pre-tested through virtual product development, although creating them with computer aided design (CAD) software can be time-consuming. In the context of this work, tools commonly used in animation design are adapted to the early phase of virtual product development. This is primarily to limit the time effort of prototyping in product development. However, the models must be led to non-intersecting 3D manifolds to ensure a transfer into computer aided engineering (CAE) or possible manufacturing. Therefore in this work, so-called procedural designs based on computer graphic applications are described and examined for their suitability for CAE.

Keywords: *Subdivision Surfaces, Concept Design, Light Weight, Procedural, Parametric*

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# Synthesis of passive lightweight orthoses considering human-machine interaction

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With increasing age, the probability of neurological diseases such as strokes, cancers, meningitis and Parkinson's also increase. A stroke, for instance, often leads to damage to the central nervous system and therefore subsequent problems within the musculoskeletal system occur. Such movement restrictions are currently treated with the help of orthoses. However, commercial passive orthoses have the disadvantage that not all functions are covered, e. g. supporting all phases of the gait cycle. Full functionality can only be ensured with heavier active orthoses. The aim of this contribution is to develop a new hybrid user-centered/lightweight-design approach with which fully functional, passive lightweight orthoses can be designed and developed effectively in the future. Therefore, the methodology according to PAHL/BEITZ is expanded by including user-specific functions and attributes. The developed approach is applied on an ankle-foot-orthosis.

Keywords: *Lightweight design, Orthosis, Design methodology, User-centered design, Modell order reduction*

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## Test-driven Development to Overcome Challenges in the Design of Sensor-integrating Machine Elements

Julian Peters<sup>1,\*</sup>, Christoph Zimmerer<sup>1</sup>, Thomas Gwosch<sup>1</sup>, Felix Herbst<sup>2</sup>, Claas Hartmann<sup>2</sup>, Romol Chadda<sup>2</sup>, David Riehl<sup>3</sup>, Ferdinand Keil<sup>3</sup>, Mario Kupnik<sup>2</sup>, Klaus Hofmann<sup>3</sup>, Sven Matthiesen<sup>1</sup>

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Sensor-integrating machine elements (SiME) are essential enablers for digitization in the industry. There are major challenges in the development of SiME as an interdisciplinary mechatronic system, requiring methodical support.

In this work, we address these challenges and aim to provide methods and tools by analyzing the state-of-the-art and ten ongoing projects of sensor integration in machine elements. Clustering shows similarities for example in the identification of design space or weakening of the structure. Based on this, a test-driven development process with a focus on interdisciplinary negotiations and iterations is described to overcome the challenges in developing SiME.

Keywords: *Sensor integration, machine element, method, support, testing*

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## Recommender Systems for Variant Management in the Automotive Industry

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<sup>1</sup> Institute of Machine Elements and Computer Aided Product Design (MRP), Helmut Schmidt University Hamburg

This paper transfers some state-of-the-art methods of recommender systems for an application in the product development process of variant rich products in the automotive industry. Therefore, an introduction into the characteristics of the rule-based description of variant-rich products is given, followed by a presentation of three selected recommendation approaches, namely Collaborative Filtering, Association Rule Mining and Bayesian Networks. The presented approaches are then evaluated against the background of the variant-rich product configuration. Advantages and disadvantages of the methods in regard of this special use-case are highlighted and possible applications and limitations are discussed. In conclusion, further research needs for future implementation are identified.

Keywords: *recommender systems, variant-rich product description, automotive industry*

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## Optimized planning of the integration of a Reference Plant into existing brownfield environments based on an entity model

Jonathan Leidich<sup>1,\*</sup>, Tizian Dagner<sup>1</sup>, Peter Robl<sup>1</sup>

<sup>1</sup> Siemens AG

In plant engineering, due to the very individual brownfield environments, there is an enormous mass and heterogeneity of requirements that arise when a plant that was initially developed independently of the customer is to be integrated. This leads to the fact that specifications and requirements for the integration of a plant are often in the form of prose text, not standardized and not automatically processable further. The developed method describes a way to uniformly record the circumstances of the customer's brownfield environment and to automatically derive which requirements or conflicts arise during the integration of a pre-developed plant.

Keywords: *requirements elicitation, plant engineering, object detection, reference plant, customer brownfield*

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## Modellierung und Analyse funktionaler Varianz komplexer technischer Systeme

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Complexity of variances in systems leads to challenges in structuring and in making development decisions. Models can collect system information to make them available and transparent. Currently, no approach to model the variance of systems along relevant engineering artifacts exists. This research aims to develop a consistent variant modeling approach: In a literature review (1), relevant approaches in model-based variant management are identified to derive requirements for variant modelling (2). Based on the requirements, approaches are evaluated in a matrix (3). Since no approach satisfies all requirements, one approach is extended (4). For evaluation purpose (5), applicability of the approach is demonstrated and assessed by experts. The result is a modeling method for variant modeling.

Keywords: *Model-Based Systems Engineering, Variants, function-oriented Complexity*

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# Analyse von Degradationsmodellen zur Modellierung der Lebensdauerheterogenität komplexer Systeme

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Lifetime heterogeneity results from differing lifetimes of subsystems and components (entities) within a system and is a key criteria to evaluate life cycle options, like upgrading or reuse, for more sustainable products. In early design stages of products for new use cases only limited information for lifetime prognosis are available. This paper proposes a concept to forecast the lifetime of products without experimental data. For purpose a systematic review is conducted to analyze degradation models of Li-ion batteries and electric motors. By analyzing and comparing similarities regarding influencing factors and their impact, fundamentals for degradation modelling are derived. Based on these findings a procedure for lifetime prediction in early design stages for emerging products, like Li-ion batteries and electric motors, are derived.

Keywords: *Lifetime heterogeneity, degradation, modelling, aircraft, battery*

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### A Classification Method for the Systematic Identification of Models and Workflows in MBSE

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Modern engineering uses models for virtual verification of systems. Such models are usually combined in workflows, where the results of models are linked to verify system requirements. Model-Based Systems Engineering (MBSE) has evolved as an approach to ease the usage of models and workflows. One goal in MBSE is to reuse models and workflows from libraries. However, the step of identifying and classifying both models and workflows for such a library is not yet systematized. We propose a method on how to identify models and workflows for an MBSE model library. Possible purposes of models are identified and afterwards models satisfying that purpose are retrieved. The identified models are systematically combined to workflows. Thereby a systematic approach to create a model library is given.

Keywords: *MBSE, Model Libraries, Model Classification, Workflows*

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## A model-based approach for early robustness evaluation – Combination of Contact and Channel Approach with tolerance graphs in SysML

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Considering variations is essential for the development of robust products, but the applicability of existing robust design approaches in early stages is challenging due to the lack of product information and high levels of abstraction. To overcome this, a combined model is presented, which enables a holistic robustness evaluation in a linked approach. This approach uses the contact and channel approach to identify the relations between embodiment and functions as well as the robustness evaluation based on tolerance graphs. The combined model is implemented with the Systems Modeling Language (SysML) and applied to a coining machine use case. An initial assessment of the model combination and a proposal for a methodically supported workflow for the holistic robustness evaluation is given.

Keywords: *Robust Design, Variation Management, Contact and Channel Approach, SysML, Model-based Development*

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### Potentiale der Integration von MBSE und LCA zur Handhabung von Unsicherheiten und Varianten in der frühen Entwicklung

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There is an increasing need to support the evaluation of the environmental impacts of product concepts in early design stages. However, the application of Life Cycle Assessment is challenged by the complexity of modern products and a lack of data consistency. This paper indicates basic potentials of integrating Model-based Systems Engineering and Life Cycle Assessment by systematically reviewing the uncertainties in the first two phases of an LCA as well as challenges in handling of product variants and differing use cases. To ensure more efficient application and data handling a first concept for the methodical integration as well as the integration of data is proposed. Based on the analysis and initial concept fields for further research are

derived.

Keywords: *Model-based Systems Engineering, Life Cycle Assessment, Uncertainties, SysML, EcoDesign*

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## Digital Twins of existing long-living assets: reverse instantiation of the mid-life twin

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The added value of long-living assets declines during their lifespan, especially if they do not undergo regular planning-intensive maintenance. Here, the Digital Twin (DT) concept can support the physical asset's most recent information and data and information from the depicted domain, but often do not have access to the data presented in current context. Instead, in the case of long-living assets, only a usecase-specific demand-actuated Digital Twin is attainable. The instantiation requires a solid procedure, which will be elaborated on in this work.

Ab hier weiter anpassen!

Keywords: *digital twin, long-living assets, retrofit*

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## Feature-Based Reconstruction of Non-Beam-Like Topology Optimization Design Proposals in Boundary-Representation

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Geometry reconstruction from 3D topology optimization results to Computer Aided Design (CAD) is challenging, especially for automation and non-beam-like geometry. While the optimized model has polygonal format, product development with CAD requires analytical surfaces in Boundary Representation (BRep). In this paper, we present two approaches for an automated interpretation of surface-skeletons for CAD-reconstruction. This includes the question, when to convert the skeleton's polygonal to analytical surfaces and how to conceptually incorporate CADfeatures. One approach is based on decomposing the input in analytical, the other in polygonal surfaces. Both approaches work with specific skeleton-features and lead to a CAD-model with BRep-reconstruction. Exemplary results are presented.

Keywords: *Topology Optimization, Computer Aided Design, Geometry Post-Processing, Medial Axis Transform, Skeletonization*

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## Analyzing Dependencies between Product Architecture and Module Drivers

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A company's business model focuses on delivering personalized products or changing its offering to a Product-Service System impacts the underlying product architecture. Depending on the aim, different product architectures need to be designed. Therefore, modularization utilizing module drivers offers the advantage that additional objectives can be addressed. This contribution identifies module drivers focusing on the architecture design of personalization, collaboration, or PSS, which are not yet known. Analyzing existing literature and empirical findings, dependencies between different module drivers and product architectures are identified. As a result of this contribution, an extended view of module drivers in various product architecture applications is given.

Keywords: *Modularization, (Modular) Product Architecture, Product-Service Systems (PSS), Personalization, Modular Systems Design*

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## Development of Business Model Families for Product-Service Systems

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To access new market segments, a growing number of manufacturing companies are changing their business models and are transforming themselves into providers of so-called Product-Service Systems (PSS). These are a combination of product and service components. Since a complete transformation of the business model often involves uncertainties and risks, companies often offer different types of PSS simultaneously. However, this increases the variety and thus the variety-induced complexity for the companies. Therefore, this paper introduces an approach that allows the development of suitable PSS-based business models that can be offered simultaneously as a business model family and are based on existing products. The approach is applied to the example of a manufacturer of industrial valves.

Keywords: *Product-Service Systems, PSS, Variety, Business Model Family*

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