

# Daily Book of Abstracts

**Wednesday**

**7 August 2019**

iceo

responsible  
design for  
our future

## Themes

'Responsible design for our future' is the general theme of the conference. It manifests itself at four different levels, ranging from society as a whole to the individual future designer. They are:

Responsibility for **future designers**

Responsibility for **our future society**

Responsibility for **our future products, production and service systems**

Responsibility for **the future organisation**

In this Daily Book of Abstracts, you will notice that on top of every right page, all Discussion and Podium sessions are allocated to a specific sub-theme. 'Responsibility for future designers' refers to topics related to design creativity and how can we build an educational system that stimulate lifelong learning. 'Responsibility for our future society' is about the role of design engineering in solving grand societal challenges in areas such as healthcare, sustainability or mobility. The third subtheme is 'Responsibility for our future products, production and service systems', focusing on systems design, service design and design methods and tools. Finally, 'Responsibility for the future organisation' addresses how companies should organise their design (engineering) departments and processes so that they are capable of managing and realising responsible products and services.

## How to use this daily book of abstracts?

On behalf of the entire community we would like to express our gratitude to the work performed by our Scientific Committee. The reviews of the Scientific Committee were used by the Programme Committee to make informed accept/reject decisions for each submission and by the authors to make the appropriate amendments to their papers.

In addition, the reviews also allowed the Programme Committee to acknowledge the top 10% of papers based on the scores given by the reviewers. This is indicated by the following sign:



Following our topic "Responsible Design for our Future", there is only a reduced number of printed versions of the daily book of abstracts available, as our preferred point of access is via the conference app. For the most updated information, please check the Guidebook Conference app, available in the App Store and on Google Play, by searching ICED19. For all general information, please consult the Conference Book Bambook. It includes an overview of the conference agenda, information about the keynote speakers, refreshments, lunches and social events. Finally, the daily books of abstracts are dedicated to single days of the conference, to provide you with a printed version of all sessions and corresponding papers, divided per day. All papers are open access and, therefore, online. In this daily book of abstracts, you are able to access them via individual QR codes.

## WEDNESDAY, AUGUST 7

KEYNOTE 4 TRACY BHAMRA Auditorium Aula

TRANSITION

COFFEE BREAK

P-Bio-inspired Design Hall 6	P-Lightweight Design   Simulation Wim Crowwel	P-Design Methods   Approaches IDE Arena	P-Product Architecture & Modularization   Platform Design Hall M	P-Design for Car Safety Hall L	P-Healthcare   Strategies Hans Dirken	P-Sustainability   Sustainability Designs Hall 5	P-Systems Engineering   Methods Bernd Schierb.
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MARKETPLACE  
Studios 1-11

LUNCH

DESIGN SCIENCE JOURNAL MEETING  
IDE Arena

D-Collaborative Design   Frameworks Hall 6	D-Lightweight Design   Methods Wim Crowwel	D-Design Methods   Requirements IDE Arena	D-Prod.Arch.& Mod.   Modular Engineering Hall M	D-Prototyping Hall K	D-Product-Service-System   Challenges Hall 4	D-Process-oriented Tol.   Tolerancing Hans Dirken	D-Sustain-ability   Eco-Design Hall 5	D-Systems Engineering   Tools Bernd Schierb.
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COFFEE BREAK

D-Collaborative Design   Innovation Hall 6	D-Cyber Physical Systems Hall L	D-Design Methods   Tools IDE Arena	D-Prod.Arch.& Mod.   Product Architecture Hall M	D-Ideation Hall K	D-Product-Service System   Design Hall 4	D-User-centred Design   User Integration Wim Crowwel	D-Sustain-ability   Buildings Hall 5	D-Value-driven Design Bernd Schierb.
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DESIGN SOCIETY GENERAL MEETING  
Joost van der Grinten

DESIGN SOCIETY AB/BOM MEETING  
Wim Crowwel

BUSES TO CONFERENCE DINNER

CONFERENCE DINNER & PARTY  
(18:45-00:00)  
Het Wapen van Zoetermeer

## Podium Sessions Wednesday 7 August 2019 10:15 – 11:45

### Bio-inspired Design

Pulse Building, Hall 6

6

### Lightweight Design | Simulation

IDE Faculty, Wim Crowwel

8

### Design Methods | Approaches (1)

IDE Faculty, IDE Arena

10

### Product Architecture and Modularization | Platform Design

IDE Faculty, Hall M

12

### Design for Car Safety

IDE Faculty, Hall L

14

### Healthcare | Strategies

IDE Faculty, Hans Dirken

16

### Sustainability | Sustainable Designs

Pulse Building, Hall 5

18

### Systems Engineering | Methods

IDE Faculty, Bernd Schierbeek

20



### Application search in solution-driven biologically inspired design

**Torben Anker Lenau**

*Technical University of Denmark*

In solution-driven BID (sol-BID) a challenge is to identify suited applications that will benefit from the solutions principles found in nature. A well-known example of sol-BID is the self-cleaning lotus plant, that has inspired lotus paint and other coating methods. However, sol-BID is often performed by biologists with insight into the biological strategy and organism and typically only little knowledge of technical applications and design methodology. Searching for applications is therefore a challenge to many. Sol-BID has many things in common with technical application search where new applications are sought for a specific production technology or another competence characterizing a company. Experiences from technical application search could therefore form a valuable input for how to perform sol-BID. The paper presents two case studies of application search and proposes a procedure to be used in solution driven BID.



### How does biologically inspired design cope with multi-functionality?

**Nicklas Svendsen, Torben Anker Lenau**

*Technical University of Denmark*

As catalysts for product innovation and product development, different approaches for biologically inspired design (BID) are exciting options. However, while general BID theory require a focus on single functions, real world products are characterized by performing multiple functions. The development of an anterior eye-chamber model is used to showcase the issue. In a systematic literature review (SLR), state-of-the-art methodologies, methods and tools BID practice are discovered and the current state of multi-functionality in BID are assessed. The SLR revealed 18 contributions with 8 BID methodologies and 12 stage-specific BID tools (of which 50% addressed the solution search phase) in addition to 5 papers addressing multi-functionality in BID. At present multi-functionality in BID is only treated in a limited set of papers. While designers interested in BID are advised to discover multi-functional analogies, the present approach to handling multi-functional problems in BID suggest functional decomposition and multiple BID efforts. Therefore, the development of design support for handling multi-functional problems, including tools for problem analysis are needed.



### Engineers' and biologists' roles during biomimetic design processes, towards a methodological symbiosis

**Eliot Graeff, Nicolas Maranzana, Améziane Aoussat**

*École Nationale Supérieure d'Arts et Métiers*



The strength of biomimetics comes from its ability to draw from life mechanisms and strategies to design innovative solutions. In spite of recent methodological progresses, more specifically on tools and processes, biomimetics' implementation still faces strong difficulties. Among other things, design teams have a hard time finding and selecting relevant biological strategies. Facing these challenges, we consider an alternative, yet well recognized, approach: the integration of profiles having a training in natural science within biomimetic design teams. As biologists aren't used to work in design teams, there is a need for a process actually guiding their practice in biomimetics and determining the way they will interact with the "traditional" design team. After studying the literature and asking for experts' opinion on the matter, we introduced a biomimetic design process considering this new profile as an integral part of biomimetic design teams. With the final goal of making biomimetics implementable, this proposed theoretical process is currently tested in both a student and an industrial project in order to optimize our methodological contribution with practical feedbacks.



### Bio-Inspired Design for Additive Manufacturing – case study: microtiter plate

**Helena Hashemi Farzaneh, Ferdinand Angele, Markus Zimmermann**

*Technical University of Munich*

Bio-inspired design is an innovative methodology for transferring biological solutions into technical solutions, for example for the design of weight- and load-optimized components. Bio-inspired design therefore offers great potential for meeting the challenges of designing additively manufactured components, such as avoiding warpage, supporting structures and material minimisation. Nevertheless, apart from bio-inspired topology optimization tools, bio-inspired design is rarely used in industrial practice because for many companies the practical applicability up to the prototype is not obvious. The aim of this work is therefore a practical approach to the search for biological systems, analysis, abstraction and transfer of analogies. We apply bio-inspired design on the design of a microtiter plate manufactured by stereolithography, whose dimensional accuracy is impaired by warpage. Here, the venus' flower basket, a deep-sea sponge, can serve as a model. It has a hierarchical structure of silicate needles whose elements are abstracted for bio-inspired transfer. We show and evaluate the transfer of different analogies using a prototype.



## Factors preventing the use of a lightweight design workflow that is inspired by the human locomotive system

*Eike Uttich, Marcel Bartz, Beate Bender*  
Ruhr-University Bochum

A workflow for the design process of technological products was derived from a model that describes the interplay of lightweight design principles in the human locomotive system. This workflow is not yet ready to be used. In this paper, starting points for new research with the goal to enable the use of the workflow are discussed. Using the interplay of lightweight design principles of the human body in technical applications is approached because it is claimed that the interplay leads to an additional reduction of mass. This was proven for a technological system in a previous study. This study lead to a workflow to consider the interplay of the principles in the design process of the technological system. In this paper, the essential parts of this workflow are described in an abstract diagram as a calculation workflow. Subsequently, inputs and outputs of the workflow are identified. Then, the calculation workflow is integrated into the process of design. Afterwards, it is discussed that tension chording, which is one of the lightweight design principles, needs further investigation, because the interplay of the principles can only be used if the principles themselves are used.



## Design for Composites: Derivation of Manufacturable Geometries for Unidirectional Tape Laying

*Harald Voelkl, Andreas Kießkalt, Sandro Wartzack*  
Friedrich-Alexander-Universität Erlangen-Nürnberg



Even though providing excellent specific stiffness and strength properties, high specific energy absorption and a great degree of design freedom, fibre-reinforced plastics still have to make their way into higher volume applications. Addressing the manufacturing challenges, particularly efficient production techniques are Automated Tape Laying (ATL) and Automated Fiber Placement (AFP), as pointed out by various studies and use cases. However, current Computer Aided Engineering approaches for optimised laminate design still lack the capability to produce results suitable for ATL/AFP. A new method for deriving tape courses from any finite element laminate optimisation result is presented and applied to a virtual demonstrator. An outlook is given on further necessities of extending current laminate optimisation approaches.



## Design of hybrid components joining zone through sensitivity analysis

*Renan Siqueira, Sean Shugar, Iryna Mozgova, Roland Lachmayer*  
Leibniz University Hannover, Institute for Product Development

Multi-material structures are a trending topic for the industry. With a high application potential, such as lightweight or extended life cycle, different manufacturing technologies are further developed for this intent. One of these technologies is Tailored Forming, a process-chain capable of joining different metals and creating massive hybrid components. In parallel to this development, new challenges rise for design, which has the responsibility of finding an optimal use of this technology and produce higher-performance products. However, this task cannot be solved by conventional engineering approach, since strong manufacturing constraints are involved and a lack of understanding about the joining zone formed between the materials still exists. To fill this gap, the objective of this study is to analyse the influence of the joining zone design over the structure behaviour and establish a suitable design method. For that, a computer-aided environment was constructed and a parametric sensitivity analysis was executed, taking a hybrid shaft as example. At the end, the simulation's results allowed a multi-objective optimisation and were able to generate first design guidelines.



## A straightforward approach to the derivation of topologies

*Enno Garrelts, Daniel Roth, Hansgeorg Binz*  
University of Stuttgart



The design of topologically optimized structures is straightforward, although the main problem is really to derive the correct structure in each instance. During the development of structures for additive manufacturing in particular, saving weight is crucial because weight is proportional to cost. In this contribution firstly, different approaches to topological optimization are presented and discussed. While computer-assisted tools provide high accuracy and demand defined conditions, approaches utilizing a pen and paper can be conducted relatively quickly, although these only provide little guidance. Secondly, a new approach is presented which is advantageous with regard to effort and affordability, yet which maintains an accuracy of results. To support the designer, an artificial neural network is trained to adapt suitable Michell structures within a given design area. These structures depict optimal paths to conduct the loads through a component and provide guidance in designing an appropriate topology. Evaluation has demonstrated that this new approach is capable of supporting designers in achieving lightweight structures.



## Organisation design seen through systematic design

Thomas Cornelis (1,2), Patrice Dubois (1), Jean-François Omhover (1), Alain Fercoq (2)

1: Arts et Métiers ParisTech; 2: Proconseil

Organizations seeking to improve their performance, like Corporate Social Responsibility targets, face a key organisational design challenge. Designing the key components of the organization and their layout will have major impact on performances, and needs thus a robust design process. Organisation theory provides several models and methods to answer that need. Yet this design process has not been confronted to design methods literature, such as systematic design. The aim of this paper is to provide a synthesis of multiple theoretical elements coming from organization sciences, confronted with a classical engineering design model, to reveal similarities, differences and lacks of current literature on organization design. Our analysis of the available literature on organisation theory, organisation design and change management showed that this design process is close to systematic design, but we also highlighted several breaks in the design process, such as the lack of functional approach.



## A lifecycle cost-driven system dynamics approach for considering additive re-manufacturing or repair in aero-engine component design

Lydia Lawand (1), Khalil Al Handawi (1), Massimo Panarotto (2), Petter Andersson (3), Ola Isaksson (2), Michael Kokkolaras (1,2)

1: McGill University; 2: Chalmers University of Technology; 3: GKN Aerospace Systems Sweden

Aero-engine component design decisions should consider re-manufacturing and/or repair strategies and their impact on lifecycle cost. Existing design approaches do not account for alternative production technologies such as the use of additive manufacturing in life extension processes. This paper presents a modeling and optimization methodology for examining the impact of design decisions in the early development stage on component lifecycle cost during the in-service phase while considering the potential use of additive manufacturing in life extension strategies. Specifically, a system dynamics model is developed to assess different end-of-life scenarios. Finally, an optimization problem is formulated and solved to minimize lifecycle cost with respect to design variables related to re-manufacturing.



## The first steps towards innovation: A reference process for developing product profiles

Miriam Wilmsen, Katharina Dühr, Jonas Heimicke, Albert Albers

Karlsruher Institut für Technologie

Successful companies spend many of their resources in the initiation and realisation of innovation projects, which might be successful at the market. Especially in the early phase of these projects, there is a high degree of uncertainty and therefore, product profiles established themselves as methodological support for product developers. However, it is not possible to give developers a straight and always equal process to follow for developing these product profiles. Based on this problem, this contribution investigates context-independent process steps to develop promising product profiles. Thus, this work provides a possible reference process to develop product profiles to support product developers in the early stage of innovation projects. Therefore, 631 process steps of 16 innovation projects were analysed and 100 process steps were derived from literature. Based on an expert workshop, 48 of these process steps were identified as relevant to consider in a context-independent reference process model. In a further empirical Live-Lab study, process patterns were investigated and the usability and relevance of the process steps were evaluated as positive.



## Giving Meaning To Products Via A Conceptual Design Approach

Naz Yıldız (1), Mark Bailey (2)

1: Anlam Tasarım Atölyesi; 2: Northumbria University

Although the conceptual design is a fundamental process through which design decisions are made, its focus is on finding the right solution. Is finding the right solution enough for a good design? Defining the problem or applying a solution-focused process may not be enough to create the differences that must be present in today's variable conditions. This can be overcome through seeking meaning instead of seeking a solution. The purpose of this article is to develop an approach that focuses on seeking meaning for products by starting with a design-thinking approach to the conceptual design process in engineering design. Focusing on a search for meaning in engineering design will provide advantages, such as creating unique values and sustainable competition.



## A weighted set cover problem for product family design to maximize the commonality of products

Hyeongmin Han (1), Sehyun Chang (2), Harrison Kim (1)

1: University of Illinois at Urbana-Champaign; 2: Hyundai Motor Company

In product family design, the commonality of products and performance are competing objectives when designers build platforms. The commonality makes it efficient to manufacture products while it will cause performance loss of products. In this paper, we assume that performance functions evaluate the performance of a product. Targets of performance functions are set for each product depending on the product's property. The designs that satisfy the target of performance functions are denoted as 'good' design points. By using 'good' design points, a weighted set cover problem (WSC) is applied to formulate the combinatorial optimization problem, which maximizes the commonality by minimizing the number component attributes. A recursive greedy algorithm is proposed to handle the general cost function in the problem for product family design. The formulation and the algorithm are tested for a linear three-degree-of-freedom (3DOF) model. In numerical experiment, the proposed method determines optimal values of the components which are suspensions, stabilizer bars, and tires in the vehicle model.



## Supporting The Modelling And Managing Of Relations In The Design Platform

Samuel André, Fredrik Elgh

Jönköping University



A common strategy which has in many cases become a necessity in product developing companies is to apply platform thinking to some extent. Engineer-to-order (ETO) companies are firms that need to invest in a significant amount engineering time in each product ordered by customers. These companies have in the past been known to not be fully able to apply platform strategies. An area of concern to product development is the design and manufacture of machine tools aimed for part manufacturing which is a large investment and a critical bottle neck. As a response to these challenges the design platform (DP) concept was developed which is founded on the re-use of company assets. This paper aims to investigate the application of the DP in a company designing and producing unique high-pressure die casting tools for different applications and customers. To enable companies of this character to utilize platform thinking to a higher degree and thus increase the efficiency in product development, a focus is set on modelling and managing relations within the DP. In addition, a PDM system setup is proposed together with an integrated support application for the realisation in industry.



## A new method to assess platform changes over successive generations of product variants from multiple design perspectives

Foo Shing Wong, David C. Wynn

The University of Auckland

This paper introduces a new method to help designers assess the impact of changes to a product platform when introducing a new variant. The method evaluates a platform design by investigating how changing some components will impact other platform design perspectives such as material, function, manufacturing processes and assembly time. To assess the usefulness of this method, it was applied to assess platform changes resulting from successive generations of scanner heads from two manufacturers. The method indicated that one manufacturer improved their scanner head design by improving the functionality of its components and assembly time. Whereas, the other manufacturer's new scanner head used more material and manufacturing processes without benefiting other design perspectives. Compared to existing product family evaluation methods which focus only on maximising commonality between product variants, the proposed method considers potential platform design improvements and assesses them from multiple design perspectives before deciding on reusing existing components or implementing the new design. The information from this method will also complement existing commonality indices.



## Challenges and architectural approaches for automotive PLM in multi-brand organisations - a discussion paper

Stefan Kehl (2), Carsten Hesselmann (1), Patrick Stiefel (2), Jörg P. Müller (1)

1: Clausthal University of Technology; 2: Volkswagen group

Today, top-down processes, centralized IT infrastructures, and one-vendor strategies prevail in Product Lifecycle Management (PLM) of large multi-brand Original Equipment Manufacturer (OEM) groups. Given the usually decentralized organisation and structures and processes that emerge from cross-brand collaboration, these centralized approaches are challenging the adaptiveness and performance of the OEM groups. In this concept paper, we investigate challenges for cross-brand and cross-domain cooperation from the perspective of processes and IT systems. The main contribution of this paper is that we motivate and outline a novel technical architecture approach combining service-orientation with an event-driven software architecture and asynchronous event processing to support users from different brands and domains in their collaboration along the development process. We analyse related work on collaboration models as well as on event processing and discuss our approach before the background of the state of the art. Finally, we summarize our findings and give an outlook to future research venues.



### Global optimisation of car front-end geometry to minimise pedestrian head injury levels

Mohammed Reza Kianifar, Felician Campean  
University of Bradford, Automotive Research Centre



The paper presents a multidisciplinary design optimisation strategy for car front-end profile to minimise head injury criteria across pedestrian groups. A hybrid modelling strategy was used to simulate the car-pedestrian impact events, combining parametric modelling of front-car geometry with pedestrian models for the kinematics of crash impact. A space filling response surface modelling strategy was deployed to study the head injury response, with Optimal Latin Hypercube (OLH) Design of Experiments sampling and Kriging technique to fit response models. The study argues that the optimisation of the front-end car geometry for each of the individual pedestrian models, using evolutionary optimisation algorithms is not an effective global optimization strategy as the solutions are not acceptable for other pedestrian groups. Collaborative Optimisation (CO) multidisciplinary design optimisation architecture is introduced instead as a global optimisation strategy, and proven that it can enable simultaneous minimisation of head injury levels for all the pedestrian groups, delivering a global optimum solution which meets the safety requirements across the pedestrian groups.



### Empirical study of car crash simulation analysis within the development phase

Naouress Fatfouta (1,2), Julie Stal-Le Cardinal (1), Christine Royer (2)  
1: Laboratoire Génie Industriel, centralSupélec, Université paris-Saclay, Gif-Sur- Yvette; 2: Renault SAS Technocentre, Guyancourt

Car crash simulation analysis is an important phase within the vehicle development. It intends to analyse the crashworthiness of the vehicle model and examine the level of passive security. However, this activity is not trivial because of the considerable collaboration within the project, the large amount of analysed and exchanged data and a high exigency. Consequently, a solution to assist, ease and reduce the time of the process is desired. To study the current practices followed in the car crash simulation analysis an empirical study has been conducted. This study has been applied within the simulation analysis team, in the development phase, within an automotive company. This paper describes a qualitative analysis of the industrial context and diagnoses the dysfunctions in the current practices. This paper also highlights the current challenges encountered in the car crash simulation analysis.



### Functional Safety Concept Generation Within the Process of Preliminary Design of Automated Driving Functions at the Example of an Unmanned Protective Vehicle

Robert Graubohm, Torben Stolte, Gerrit Bagschik, Markus Steimle, Markus Maurer  
Technische Universität Braunschweig - Institute of Control Engineering

Structuring the early design phase of automotive systems is an important part of efficient and successful development processes. Today, safety considerations (e.g., the safety life cycle of ISO 26262) significantly affect the course of development. Preliminary designs are expressed in functional system architectures, which are required to form safety concepts. Thus, mapping tasks and work products to a reference process during early design stages is an important part of structuring the system development. This contribution describes the systematic creation and notation of the functional safety concept within the concept phase of development of an unmanned protective vehicle within the research project aFAS. Different stages of preliminary design and dependencies between them are displayed by the work products created and used. The full set of functional safety requirements and an excerpt of the safety argument structure of the SAE level 4 application are presented.



### Potentials for the Integration of Design Thinking along Automotive Systems Engineering focusing Security and Safety

Julian Tekaot, Aschot Kharatyan, Harald Anacker, Roman Dumitrescu  
Fraunhofer Research Institute for Mechatronic Systems Design IEM

The increasingly intelligent, highly complex, technical systems of tomorrow - for instance autonomous vehicles - result in the necessity for a systematic security- and safety-oriented development process that starts in the early phases of system design. Automotive Systems Engineering (ASE) as one approach is increasingly gaining ground in the automotive industry. However, this approach is still in a prototype stage. The consideration of security and safety within the early stages of systems design leads to so-called ill-defined problems. Such are not covered by ASE, but can be addressed by means of Design Thinking. Therefore we introduce an approach to combine both approaches. Based on this combination, we derive potentials in the context of the consideration of security and safety. Essential advantages are the possibility to think ahead of threat scenarios at an early stage in system design. Due to an incomplete database, this is not supported or only partially supported by conventional approaches. The resulting potentials are derived based upon a practical example.





## Design Supporting a 'Customer-Perceived Intimacy'-Strategy in Healthcare Services

**Carmen Martens (1,2), Jasmien Herssens (1), Cécile Delcourt (2)**

1: University of Hasselt; 2: University of Liege

Given that we live in a time within a growing competitive healthcare market, the customer experience and healing opportunities are on top of the priority list. However, little attention has been dedicated on how to merge the disciplines of architecture, healthcare and management to create healthcare environments to enhance the customer experience and the healing process. The goal of this paper is to explore how design can foster customer-perceived intimacy within a healthcare context to achieve enhanced customer outcomes, such as customer well-being. Understanding the importance of customer-perceived intimacy is paramount, as customers are constantly exposed to intimate situations. The study suggests that there is potential for such situations to be wrought with problems involving complexities associated with human cognition, emotions, physiological responses, and behaviors. A literature review is undertaken to highlight the antecedents and the short-term and long-term outcomes of customer-perceived intimacy. As a result, the paper provides a conceptual framework that raises many questions that need to be answered. In doing so, a solid foundation for future inquiry has been laid.



## Medical device design practitioner strategies for prototype-centered front-end design stakeholder engagements in low-resource settings

**Marianna Coulestantos, Ilka Rodriguez-Calero, Shanna Daly, Jocelyn Burrige, Kathleen Sienko**

University of Michigan

Prototypes have the potential to provoke discussion and to encourage stakeholders to play an active role during design engagements in the front-end phases of a design process. However, detailed descriptions of stakeholder engagement strategies in front-end design are lacking. The aim of this research study was to understand how design practitioners prepare and manage stakeholders for engagements involving prototypes in the front-end phases of a medical device design process. Design practitioners at companies developing mechanical and electromechanical medical devices for use in low- and middle-income countries were interviewed following a semi-structured interview guide. Interview transcripts were analysed, and inductive codes were developed. The findings suggest that design practitioners manage the group composition of stakeholders, review the project and prototype(s) with stakeholders at the start of the engagement, and show the progress of prototypes to stakeholders over multiple engagements. These strategies shed light on the importance of handling interpersonal relationships during stakeholder engagement with prototypes.



## Automotive IVHM: Towards Intelligent Personalised Systems Healthcare

**Felician Campean (1), Daniel Neagu (1), Aleksandr Doikin (1), Morteza Soleimani (1), Thomas Byrne (1), Andrew Sherratt (2)**

1: University of Bradford, Automotive Research Centre; 2: Jaguar Land Rover

Underpinned by a contemporary view of automotive systems as cyber-physical systems, characterised by progressively open architectures increasingly defined by their interaction with the users and the smart environment, this paper provides a critical and up-to-date review of automotive Integrated Vehicle Health Management (IVHM) systems. The paper discusses the challenges with prognostics and intelligent health management of automotive systems, and proposes a high-level framework, referred to as the Automotive Healthcare Analytic Factory, to systematically collect and process heterogeneous data from across the product lifecycle, towards actionable insight for personalised healthcare of systems.



## Designing for better healthcare: A systemic approach utilising behavioural theory, technology and an understanding of healthcare delivery systems

**Nicholas Ciccone, François Patou, Anja M Maier**

Technical University of Denmark

An ageing population leading to more chronic disease is straining healthcare systems. This paper makes two core contributions to healthcare systems design research: Firstly, a systemic techno-behavioural approach is presented to support intervention design with value-effective health outcomes. The systemic techno-behavioural perspective takes into consideration the interaction between three angles: The current healthcare system in place, the technological opportunities for addressing an issue and a broader and deeper understanding of the behaviour of those involved. The purpose of considering these three angles is to create interventions that are more robust. This will help inform healthcare systems design researchers and other stakeholders. Secondly, it is proposed that interventions should be grounded in behavioural theory, a collection of theories are presented to be incorporated in the design process of interventions. The systemic techno-behavioural approach is applied to dementia care highlighting the need to understand the dynamic relationship between the context of the current healthcare delivery system, technology, and behaviour to improve quality of care during the progression of the disease.



### Designing for packaging sustainability. The effects of appearance and a better eco-label on consumers' evaluations and choice

Sophie Krah, Tea Todorovic, Lise Magnier  
Delft University of Technology



The environmental burden of packaging is huge. However, redesigning packaging to make it more sustainable without damaging its other functions is not always easy and can have a negative impact on consumers' choice. In this paper, we adopt a user-perspective and test the effects of packaging appearance and a better eco-label on consumers' responses. Based on the literature, we designed an eco-label using a traffic light system with an objective sustainability score enabling to compare the sustainability of different packages. The results of our experimental study (N=120) show that while a sustainable (vs. typical) appearance in packaging has a positive effect on perceived sustainability, it has a negative effect on perceived usability. However, we demonstrate that the presence of a high score on the eco-label positively impacts the perceived sustainability of both the sustainable and the typical packages and the choice intentions. This eco-label also enabled to mitigate the negative effects of the sustainable appearance on perceived usability. Designers and policy-makers can use the results of this paper to positively influence evaluations of and choice for sustainable packaging.



### Design against the plastic soup - the effect of small product designs in sustainable design education

Els Du Bois, Dirk Van Gogh, Lore Veelaert, Karine Van Doorsselaer  
University of Antwerp, faculty of Design Sciences, department of Product Development

Plastics are ubiquitous in our daily life due to their versatile characteristics, however, these excellent characteristics also contributed to the emergence of a gigantic garbage of floating plastics in our ocean, called the plastic soup. Within this research project we investigated the opportunities by design to cope with this wicked problem. The hypothesis is that picking small opportunities in a wicked problem can have a large impact on the related ecosystem. In addition, we also wanted to investigate how design students would deal with the problem to create larger awareness of the designers' impact and responsibility. Although there is no ideal answer to a systemic problem such as the plastic soup, intervening on systems is possible. As the characteristics of a product directly influence the way the entire value chain works, designers have a large responsibility / opportunity to influence the system. An experiment was executed with 69 design students to explore the opportunities. The resulting design concepts were discussed by experts, reasoning towards relationships, needs to elaborate the design practices, and ecodesign education in a circular economy.



### Preliminary Results Testing What Different Design Solutions Arise From Different Sustainable Design Methods

Jeremy Faludi (1), Omar Ali (2), Ola Srour (2), Selim Mecanna (2), Rami Kamareddine (3), Tejaswini Chatty (1)

1: Dartmouth College; 2: American University of Beirut; 3: University of Balamand

Do different sustainable design methods generate different sustainable design ideas? Do they also drive different product innovation ideas? This project empirically tested three design methods: The Natural Step, Whole System Mapping, and Biomimicry. Testing involved qualitatively categorizing 1,115 design ideas from 23 workshops for over 30 companies, including consultancies and manufacturers in consumer electronics, furniture, and apparel. The categorized ideas were then counted to determine if the different design methods caused different kinds of ideas. They did. For example, The Natural Step drove more ideas on green material choice, circular end of life, and social impacts, while Biomimicry drove more durability ideas and Whole System Mapping drove more cost reduction ideas, among other differences. Overall, The Natural Step generated the highest percentage of sustainability ideas, Biomimicry generated the most innovation ideas, and Whole System Mapping generated a balance of both. These preliminary results should help designers and engineers choose design methods suited to the types of design solutions they desire.



### Impact of generational commonality of short-life cycle products in manufacturing and remanufacturing processes

Jinju Kim, Harrison Kim  
University of Illinois at Urbana-Champaign

Short-life cycle products are frequently replaced and discarded despite being resource-intensive. The short life span and the low utilization rate of the end-of-life products cause severe environmental problems and waste of resources. In the case of short-life cycle products, a new generation of products is released sooner than other products, therefore there are the opportunities to have various generations of products during the remanufacturing process. The commonality between generations increases the intergenerational component compatibility, which increases the efficiency of the manufacturing and remanufacturing processes, while at the same time weakening the performance difference between generations. This paper proposes a mathematical model to investigate the effect of commonality among generations on the overall production process. Based on various given new generation product designs with different commonality, we aim to propose optimal production planning and pricing strategies to maximize the total profitability and investigate how the results vary according to the commonality strategies between product generations.



## Towards Model-based Process Engineering

David Inkermann  
TU Braunschweig



The high interaction between process and product models in product development and systems engineering (SE) is common sense. However, most research in the field of model based systems engineering (MBSE) focusses on physical systems (hardware and software). The authors claim that this focus is a main reason for the low acceptance and high effort for implementation of SE and MBSE in industrial practice. Thus, this contribution aims at supporting an integrative analysis and synthesis of process and product models by introducing the concept and framework of Model-based Process Engineering. Based on established research this framework introduces three main systems, namely the system of processes, system of product models, and system of tools to describe complex product development. The main contribution of this work is a preliminary concept to structure and link the systems of processes and product models. Besides from the description of the main relations between the systems an integrated modelling concept to represent links between the process and product model system is proposed.



## Multi-level decomposed systems design: Converting a requirement specification into an optimization problem

T. F. Beernaert, L. F. P. Etman  
Eindhoven University of Technology

Complex technological artefacts are often decomposed into smaller components to keep their design manageable. The resulting challenge is to coordinate decisions that involve multiple components and to design components such that high-level targets are met. Analytical Target Cascading (ATC) is an analytical coordination method for the optimization of decomposed systems, which we aim to incorporate in systems engineering design process. To this extent, we relate the domain of engineering optimization to the domain of requirements engineering, and propose a method that constructs an ATC problem from functional specifications and requirements written in the newly developed Elephant Specification Language. The proposed method is demonstrated in the two-level design of an automotive powertrain. This contribution is a step towards design automation and is expected to increase the usability of decomposed optimization techniques.



## Early stage model based system design under uncertainties

Kazuya Oizumi, Akio Ito, Kazuhiro Aoyama  
The University of Tokyo

System design at the early stage of design plays an important role in design process. Model based systems engineering is seen as a prominent approach for this challenge. System design can be explored by means of system simulation. However, as the system is a complex system, system model tends to have high level of abstraction. Therefore, the models cannot depict every details of the system, which makes optimization unreasonable. Furthermore, at the early stage of design, there are many uncertainties such as success of technological developments. By properly incorporating uncertain factors in system design, the system can be tolerant. Currently system design is conducted by experienced experts. However, for more complex system, it would be difficult to continue the current practice. Therefore, a method to support design team to make decision in system design is needed. This paper proposes a computational support for the system design. Design constraints, which seems the core information that design team wants at system design, are modeled. By visualizing constraints quantitatively and intuitively, the proposed method can support design team to conduct system design and design study.



## Inconsistency management in heterogeneous models - an approach for the identification of model dependencies and potential inconsistencies

Niklas Kattner, Harald Bauer, Mohammad R. Basirati, Minjie Zou, Felix Brandl, Birgit Vogel-Heuser, Markus Bšhm, Helmut Krcmar, Gunther Reinhart, Udo Lindemann  
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In today's engineering projects, interdisciplinary work leads to an increase in interfaces between different departments and domains. As each stakeholder pursues different goals and tasks, a heterogeneous model landscape is required. In each domain, a variety of different model and software implementations provide the essential basis for efficient work. On the interfaces, the risk of model inconsistencies increases. To handle occurring inconsistencies, various approaches have been presented. For model-based systems engineering projects, rule-based methods are considered as the most suitable technique. However, said approaches require a high manual effort in identifying model dependencies and establishing consistency rules. Unfortunately, in particular these steps are not well described and supported. Therefore, this paper presents an easily applicable approach for the identification of model dependencies in interdisciplinary projects. The method is supported by a software implementation and is directly integrated in engineering workflows. A first industrial case study has shown positive effects of the approach and revealed further research goals.

**Discussion Sessions**  
**Wednesday**  
7 August 2019  
13:30 – 14:30

<b>Collaborative Design and Group Creativity   Frameworks</b> <i>Pulse Building, Hall 6</i>	<b>24</b>
<b>Lightweight Design   Methods</b> <i>IDE Faculty, Wim Crouwel</i>	<b>26</b>
<b>Design Methods   Requirements</b> <i>IDE Faculty, IDE Arena</i>	<b>28</b>
<b>Product Architecture and Modularization   Modular Engineering</b> <i>IDE Faculty, Hall M</i>	<b>30</b>
<b>Prototyping</b> <i>IDE Faculty, Hall K</i>	<b>32</b>
<b>Product-Service-System (PSS) Design   Challenges</b> <i>Pulse Building, Hall 4</i>	<b>34</b>
<b>Process-oriented Tolerancing and Robust Design   Tolerancing</b> <i>IDE Faculty, Hans Dirken</i>	<b>36</b>
<b>Sustainability   Eco-Design</b> <i>Pulse Building, Hall 5</i>	<b>38</b>
<b>Systems Engineering   Tools</b> <i>IDE Faculty, Bernd Schierbeek</i>	<b>40</b>



## An integral design framework for multi-disciplinary design

Wim Zeiler  
TU Eindhoven

A comprehensive domain independent system-level perspective of conceptualization of design is a major driver for successful product development. Such a general design model, Integral Design, was developed based on a specific Dutch design method, Methodical design, which was aimed specifically for applications in the Mechanical Engineering domain. The design method was specifically developed with the help of experiences designers and is meant for young students in a multi-disciplinary design context, such as building design. Integral design provides a suitable framework, existing of phases and specific steps, for guiding users through the design process. It support not only the designers but also helps them to make the process explicit and to communicate the actions and results to their stakeholders. The focus in this paper is on presenting the overall frame work of the design method. In the Netherlands in several bachelor and master educational programs at Technical High schools and the University of Technology Eindhoven use this model to teach students mechanical engineering design and building services design. As such it is one of the most popular design method in the Netherlands.



## A research through design framework from the evaluation of a meta-design platform for open and collaborative design and making processes

Massimo Menichinelli (1,2)

1: Aalto University - School of Arts, Design and Architecture - Department of Media - Media Lab Helsinki; 2: RMIT University

The democratisation of technologies, knowledge and activities have been changing the world of designers, blurring the boundaries between amateur and professional designers, especially within the connected phenomena of the Maker Movement and Indie Designers. Within this context, how can be collaborative design processes documented, analysed, managed, shared? This article investigates the role of meta-design digital tools for the facilitation of distributed systems of creative agents, formally trained and informal amateurs that collaboratively design and produce artefacts. It documents a research study organised for testing a digital meta-design platform with users and the researcher as meta-designer: the results provide insights for improving the platform but also for building a comprehensive research through design framework that connects meta-design research and practice for exploring the role and nature of meta-design and meta-designers in facilitating collaborative design processes starting from their description with digital ontologies.



## Observations on the Effects of Skill Transfer through Experience Sharing and In-Person Communication

Håvard Vestad, Carlo Kriesi, Kristoffer Slåttsveen, Martin Steinert  
Norwegian University of Science and Technology

An essential part of any space in which physical prototyping and prototype-driven product development is being conducted is the education of its users in the necessary skills to fully utilise the material resources of the space. This paper describes how two different skills were transferred between five projects in our research laboratory, TrollLABS. Based on the observed skill-transfers in the production of PCBs and use of RF-communication in mechatronics projects certain tendencies emerged: How the use of forced vocal experience sharing; And in-person transferring of skills has impacted the acquired skills of the learner. The observations further show that through the guidance of a more experienced user the learner is able to make Öskill-jumpsÖ: Intermediate skill steps, as well as underlying detailed knowledge, are skipped and the learner is able to reach a high skill level in a shorter time than the original acquirer of the skill. Furthermore, skills are retained in the space through cross-generational collaboration and communication. This article aims to share these insights and provide a starting point for answering some of the challenges of modern maker spaces.



## The Influence of Collaborative Information Technology Tool Usage on NPD

Tucker Marion (1), Sebastian Fixson (2)  
1: Northeastern University; 2: Babson College

Information Technology (IT) and the process of new product development (NPD) have become completely intertwined. From computer-aided-design (CAD) to video conferencing to traditional tools like email, the act of design, iterating and communicating with team members is touched at every point in the process by IT. Over the last ten years, new, collaborative information technology (CIT) has entered into the NPD process to make the activity of communication and team information sharing easier, more frequent, and distributed. What is not known is how these tools are influencing the design process itself. This research uses a longitudinal multi-method, ethnographic approach to deep dive into actual use cases. Our results indicate that CIT can have a substantial impact on NPD, but does not automatically alleviate traditional problems during NPD. We also find that the propagation of tools via new firms startups has developed a single tool per task paradigm, which is counter to the development of complex platforms offered by established firms. These single use tools are easily adopted but also easily discarded by development teams.



### Agile Lightweight Design - the Extended Target Weighing Approach in ASD - Agile Systems Design using functional Modelling with the C&C?-Approach

Albert Albers, Sven Matthiesen, **Sven Revfi**, Christopher Schönhoff, Patric Grauberger, Jonas Heimicke

Karlsruhe Institute of Technology, Institute of Product Engineering

The context of product development can be understood as transformation of needs into technical solutions under the continuous handling of uncertainties. These result particularly in early development phases from a lack of technical knowledge. In order to counter the uncertainties, companies are increasingly implementing agile approaches, which mostly originate in the area of software development. Although these are suitable for flexible handling of project management activities and lead to an increased reactivity of the development team, they do not address the early and continuous integration of technical knowledge into the process. With the aim of optimizing mechatronic systems with regard to their lightweight design potentials, in this article a method is developed that supports agile development with the goal of lightweight design. Therefore, it combines a method for functional modelling with a function-based lightweight design method. The targeted integration of technical knowledge has shown that lightweight design potentials can be optimized iteratively in agile approaches. As an initial validation, the applicability of the method was demonstrated in a development project.



### Variation analysis of design parameters of fibre-reinforced plastic parts

Michael Franz, Benjamin Schleich, Sandro Wartzack

Friedrich-Alexander-Universität Erlangen-Nürnberg

Lightweight Design as an engineering domain is becoming more and more important in terms of sustainable mobility. Therefore, a large number of researchers is developing methods for utilisation of modern, but as well more complex materials with high lightweight potential. One subgroup of these materials are fibre-reinforced plastics (FRP). A lot of work is done supporting the design engineer in exploiting the structural and mechanical behaviour as good as possible. Whereas variations of laminate parameters, resulting from production, are poorly studied. Their impact especially on defined measures under load is of high importance, e.g. having a look on clearances in automotive industry. Because of the high complexity of FRP-parts, resulting from many laminate parameters, tolerancing is not an intuitive process. This is reflected in the fact that there is no defined procedure for tolerancing of FRP-parts. To support the design engineer the authors perform sensitivity analysis for simple loadcases to identify layers with a high importance on a defined measure. The results then are generalised to provide general guidelines to the design engineer.



### Function-based Material Selection for Cross-component Lightweight Design within the Extended Target Weighing Approach

Sven Revfi (1), Jerome Kaspar (2), Michael Vielhaber (2), Albert Albers (1)

1: Karlsruhe Institute of Technology; 2: Saarland University

Shortening product development cycles while improving cost efficiency and quality epitomize a key challenge in today's competitive market environment. Integrated approaches simultaneously taking into account a conceptual design, material and processing definition methodologically facilitate the progress of promising product solutions most effectively. However, assorted approaches in the field of lightweight design as well as material selection mostly trying to cover alternative solutions on a component-specific level exclusively, yet. Thus, this contribution outlines a cross-component material selection for function-based lightweight design within the Extended Target Weighing Approach covering the identification and evaluation of lightweight design potentials. The developed method is based on Ashby's material selection additionally taking into account project objectives for mass, costs and CO2 emissions in individual functional design spaces. Resulting in material combinations fitting to clearly stated project targets, the product engineer is already supported in an early phase of product development when initially assessing feasible materials for the overall system development.



### Derivation of criteria for identifying lightweight potential - a literature review

Felix Laufer, Daniel Roth, Hansgeorg Binz

University of Stuttgart

Lightweight potential is a powerful indicator but not as powerful as it could be. Current methods for analyzing a product's potential to be reduced in mass only deal with a few of the most important criteria for lightweight design. The amount of literature dealing with lightweight design is significant, yet it can help to understand these versatile criteria. Firstly, the literature on this topic will therefore be reviewed to derive a broad set of criteria used in contemporary lightweight design. Secondly, a further review will reveal the criteria used to derive lightweight potential. Subsequently, both sets will be compared to identify the missing criteria used for the derivation of lightweight potential. This will support designers in two ways. On the one hand, matching and combining both criteria sets will enable the most representative criteria for a particular design case to be chosen, thus leading to a more comprehensible derivation of lightweight potential. On the other hand, the combination set will provide a basis for designers and design teams to refine their understanding of their own motivations for conducting lightweight design.



## The cost of learning from failures and mistakes in product design: Reviewing the literature

**Ali Shafqat (1), Josef Oehmen (2), Torgeir Welo (1), Pelle Willumsen (2)**

1: Norwegian University of Science and Technology; 2: Technical University of Denmark

In the design phase of product development (PD) process, most new products face significant uncertainties and risks. Uncertainty is typically associated with a lack of information, while learning is a process that acquires information. Therefore, learning fast and at low cost decreases the uncertainty and increases the efficiency of the product design phase. This paper investigates the concept of the cost of learning in PD's design phase. Reviewing the literature, we conceptualize the cost of learning and review the learning methods considering three aspects in the design phase of the PD process: (1) costs associated with learning from mistakes and failures, (2) learning methods and (3) categories of learners. This paper thus provides the conceptual foundations for future work to increase the efficiency of the PD process by reducing the cost of learning from mistakes and failures.



## A Conceptual Framework for Breakthrough Technologies

**Andreas Makoto Hein (1), Juliette Brun (2)**

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Breakthrough technologies introduce a radically new capability or a drastic performance improvement. However, the existing engineering design literature does not specifically pay attention to them. In this paper, we present a conceptual framework for breakthrough technologies, aiming for a more detailed characterization of breakthrough technologies. First, based on a literature survey, we reflect on the relationship between breakthrough technology and innovation. In addition, we explore the relationship between breakthrough technologies at the component and system level. Next, we propose a conceptual framework with dimensions in which breakthroughs may occur and the corresponding expansion of concepts and knowledge, drawing from C-K theory. We subsequently apply the framework to the case of a laser sail-propelled interstellar probe. We conclude that the relationship between component and system-level breakthrough technologies requires further exploration. Furthermore, the coupling between the breakthrough technology and market breakthrough in the form of a new business model seems interesting for future work.



## Developing design methods - A conceptual requirement framework

**Lucia Becerril (2), Matthias Guertler (1), Emmanuel Longa (1,2)**

1: University of Technology Sydney; 2: Technical University of Munich

Design methods can provide valuable support in structuring and solving complex product design problems. However, the application and the transfer of methods from academia to industry is limited. To date, research has tended to focus on solving this through improved method selection, method adaptation and training. The development of design methods itself has attracted surprisingly low attention. This paper closes this gap and adds a quite new perspective of systematic requirement management of method development. However, the variety of methods, method users and application contexts is a key challenge and does not allow for a universal set of requirements. Thus, this paper transfers the concept of solution-neutral requirements frameworks, which are established in product design, to method development. The framework is derived from analysing and structuring different requirements found in literature. Different requirement sub-/categories allow for accommodating the varying levels of detail of requirements. The framework works like a checklist and helps design researchers to consider the most important requirement categories, which subsequently can be detailed project-specifically.



## Systematic literature reviews: an introduction

**Guillaume Lame**

The Healthcare Improvement Studies Institute, University of Cambridge

Systematic literature reviews (SRs) are a way of synthesising scientific evidence to answer a particular research question in a way that is transparent and reproducible, while seeking to include all published evidence on the topic and appraising the quality of this evidence. SRs have become a major methodology in disciplines such as public policy research and health sciences. Some have advocated that design research should adopt the method. However, little guidance is available. This paper provides an overview of the SR method, based on the literature in health sciences. Then, the rationale for SRs in design research is explored, and four recent examples of SRs in design research are analysed to illustrate current practice. Foreseen challenges in taking forward the SR method in design research are highlighted, and directions for developing a SR method for design research are proposed. It is concluded that SRs hold potential for design research and could help us in addressing some important issues, but work is needed to define what review methods are appropriate for each type of research question in design research, and to adapt guidance to our own needs and specificities.



## A preliminary proposal towards unambiguous definitions for Modular Interfaces and Interactions

**Lorenzo Fiorineschi, Federico Rotini**  
University of Florence



Modularity is acknowledged to provide benefits across the whole product lifecycle. Accordingly, many literature contributions can be found about modularization methods, metrics and definitions. In particular, recent studies focused on the development of heuristic principles for exploiting modularity early in the design process. However, to design modules it is necessary to define their mutual interactions, the related interfaces and their production strategies. Concerning interfaces and interactions, this paper highlights that current definitions are often ambiguous and overlapping each other. Therefore, extracting univocal information about interfaces and interactions of existent modular products could be difficult. This could hinder the identification of comprehensive heuristic design guidelines, about how to design modules from a structural point of view. This paper proposes a new set of interface and interaction definitions, which allows to overcome the flaw observed for current ones. The proposed set and the classical one have been applied on 110 products identified on the web, showing that the new definitions allow to extract more reliable information.



## Entrepreneurial Ideation: Effects of Morphology and Complexity

**Antonio Esparza, Ricardo Sosa, Andy Connor**  
Auckland University of Technology

Studies of product architecture identify a mirroring process between the product and the organisation. Parallel, empirical studies of effectual entrepreneurship show an accumulation of commitments between stakeholders while negotiating the features of the product in a similar fashion to product mirroring. This paper presents a study that looks at the effects of mirroring architectural complexity in early stages of entrepreneurship. The survey asked participants to interpret parametrically generated artefacts with the purpose of starting a new firm. Responses were analysed for complexity in the lexical semantic structure of ideas. Results show that the effects of artefact complexity are not as straightforward as hypothesised and provide evidence that suggests an important role of artefact morphology in entrepreneurial ideation. These findings support a model of product architecture mirroring that is filtered by design morphology.



## Empirical Study of Good, Bad and Ugly Modular Engineering Solutions in Machinery Manufacturing Industry

**Tero Juuti, Jarkko Pakkanen, Timo Lehtonen**  
Tampere University

This study examines the relationship between the product structuring principles chosen in modular product families and the business results of companies. In the three case studies of the article, it can be seen that products that meet the modularity definitions discussed in the literature have been able to utilise the benefits of modularity in a very varied way. In one business case, the effect of modularity on business has been negative. In two other cases, the effect has been positive - in one of these even the profitability of the business has significantly improved. The aim of this article is to identify whether product designing consistently has been following some product structuring principles previously mentioned in modularisation literature or whether case studies bring new principles to consciousness. In all case studies, the product structuring principles used are also discussed in the previous modularisation studies at a varying extent. In the discussion section, we raise the question of whether the recording and use of product structuring principles in design briefs could lead to making the product design decisions that affect the business positively.



## The hidden feat behind development cost escalation - how engineering design enables functional expansion in the aerospace industry

**Agathe Gilain, Pascal Le Masson, Benoît Weil**  
MINES ParisTech

The aerospace industry experiences a considerable growth in product development costs. Many research works aim at identifying evolution laws characterizing this large-scale phenomenon and at developing design strategies which could help mitigate it. This paper aims to clarify the evolution dynamics governing this phenomenon by studying how the products delivered by these costly projects evolve with time. Increasing complexity is often held responsible for surging costs. If complexity is generally defined as the price to be paid for improving product functionalities, it is rarely specified whether the improvement affects existing functionalities or involves new ones. We aim to identify the patterns of cost growth which can be associated with phenomena of existing functionalities upgrade and new functionalities introduction, and to identify the associated design capabilities that designers need to deploy in order to keep product change and cost growth under control. To that end, we introduce a model which generates curves, each of which featuring a trend of cost growth, specific to a scenario of product evolution and being interpretable as a signature of a strategy used by designers.





## The state of prototyping practice in the industrial setting: Potential, challenges and implications

Sarah Diefenbach (1), Lara Christoforakos (1), Bettina Maisch (2), Kirstin Kohler (3)

1: Ludwig-Maximilians-University Munich; 2: Siemens AG; 3: University of Applied Sciences Mannheim

Prototyping as a central method within innovation- and product development processes has a high acceptance in industry. Various prototyping tools provide impressive visualizations of product ideas in early development stages and especially low fidelity prototyping methods seem easily applicable. However, a closer look at prototyping in practice reveals a number of misunderstandings and barriers regarding effective prototyping, often related to different stakeholders' (e.g., developer, designer, client) ideas about the purpose of prototyping. Based on a combination of literature analysis, adapting existing models and methods in user centered design (e.g., personas, double diamond design process) and empirical results from industrial research cooperation, we introduce a focus group format and a first model of prototyping maturity, which can help organizations to reflect on their state of practice in prototyping on an individual, team, and organizational level. The maturity model also forms a valuable theoretical lens for design research. Thus, our research aims at researchers in the field of prototyping as well as practitioners involved in prototyping and innovation processes.



## Purpose-Oriented Modelling of the Learning Process when Using Prototypes

Stefan Schork, Eckhard Kirchner

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Prototypes are often used as a tool in the product development process and their usage is advised in many guidelines, frameworks and product development methods. Those prototypes achieve different goals of which most relate to getting new insights and information about the product in development. For the development of those prototypes however, significantly less development methods are available compared to the number of methods for the development of products. Investigating the process of using a prototype leads to the idea that the main purpose of those prototypes is describable as learning about the product. This idea is elaborated further and followed by the introduction of the detailed process model for prototyping which is primarily based on the detailed process model for products. However, the purpose of the prototype differs from the purpose of the product which leads to some significant changes of the model. To give an example of a prototyping process, the development of a sensor-integrating elastic claw coupling is introduced and analysed. In addition, this paper discusses the question, how other product development models may be applied to the development of prototypes.



## The Concept of Purposeful Prototyping: Towards a New Kind of Taxonomic Classification

Konstantinos Petrakis, Abigail Hird, Andrew Wodehouse

University of Strathclyde

A prototype can be generally defined as a preliminary version of a final product and it can represent both aesthetic and functional features. Prototyping, the process of building a prototype, constitutes an indispensable part of product development processes. Many classifications of prototypes which use a different range of criteria have already been developed and are known as Prototype Taxonomies. This paper proposes an agenda towards the development of a new taxonomic classification which will be based on a prototype's attributes and its intended purpose. This work is justified from the results of an analysis of 8 existing prototype taxonomies which indicate that there is not a taxonomy that explicitly uses the prototype's purposes as its basic taxonomic dimension. A definition of the term 'Prototype Purpose' is proposed through discussing the differences and relations to the term 'Prototype Role'. This work results in a list of 23 explicit prototype purposes which arise from 7 roles of prototyping found in relevant literature: Learning, Communication, Demonstration, Integration, Refinement, Exploration and Requirement Elicitation.



## Unveiling the Multiple and Complex Faces of Fidelity

Lorenzo Fiorineschi, Federico Rotini

University of Florence

Fidelity is one of the most important parameters to consider when dealing with prototypes, which affect the related costs and performances. Current literature contributions often rely on generic definitions of Fidelity based on the concept of closeness. However, the review performed in this paper revealed that Fidelity is a more complex concept, which considers (at least) eight main dimensions, mutually interrelated, and potentially characterized by many other potential sub-dimensions. The identified set has been applied to an industrial case study where a real engineering prototype has been assessed in terms of Fidelity. In particular, the case study application shows how the different dimensions can be interrelated each other. Furthermore, some important research hints have been highlighted in this paper, where the identified set of Fidelity dimensions paves the way for the related future activities.



### Intra-firm and inter-firm challenges in servitization ecosystem: Experiences from five product-centric firms in different industries

**Koteshwar Chirumalla (1), Oyetola Emmanuel-Ebikake (2), Luna Leoni (3), Mohsen Servati (4)**

1: Mälardalen University; 2: Edge Hill University; 3: Tor Vergata University of Rome; 4: Jönköping University

The purpose of this paper is to analyse the challenges in the servitization journey of product-centric firms from an ecosystem perspective, considering both intra-firm and inter-firm levels. Prior research addresses the challenges of servitization in many sectors from different perspectives. However, the majority of studies primarily focus on the provider of an offering. There is a lack of in-depth studies on analysing servitization challenges from the broader set of network actors including customers, suppliers, and sub-suppliers at the intra-firm and inter-firm levels. A multiple case study method was used to analyse five product-centric firms from different industries that were engaged in servitization. At intra-firm level, our analysis shows that 'coordination' is a major challenge for the provider, supplier, and sub-suppliers, and that 'uncertainty' and 'risk' is a major challenge for the provider, customer, and supplier. At inter-firm level, 'partnership management' found to be a most significant challenge for provider, customer, supplier, and sub-suppliers. The study contributes to the discussion of the relational view approach for servitization research.



### How are End-of-Life strategies adopted in Product-Service Systems? A systematic review of general cases and cases of medical devices industry

**Leticcia Giovana Damha, Adriana Hofmann Trevisan, Daniel Guzzo Costa, Janaina Mascarenhas Hornos Costa**

University of São Paulo

Little study has been done on the adoption of End-of-Life (EoL) strategies on the medical devices industry, despite the reasons why it is an important area of study for the implementation of circularity. The rates of waste in the medical field are alarming and tend to grow. Though presenting a wide potential for EoL strategies implementation, the medical field is also inherently challenging, considering the rigid regulations and product's risk to patients life. This paper analyses 17 Product-Service System case studies identified in the literature. Eleven of them are from various fields of industry, whereas the other six are applied to the medical devices industry. The adoption of EoL strategies - namely repair, reconditioning, remanufacture and recycling - is analysed in each case and compared for the two categories of cases. This adoption is related to the sources of value creation in Circular Economy, to the PSS typology and, at last, special EoL treatment for medical devices is discussed.



### Who are the stakeholders mentioned in cases of Product-Service System (PSS) Design?

**Sânia da Costa Fernandes, Luiza Diegues Martins, Henrique Rozenfeld**

University of São Paulo

Product-service systems (PSS) are solutions that integrate product and services in order to fulfill the customers' needs by means of greater value in use. Multiple stakeholders should be involved in the design process for the development of a successful PSS value proposition. However, it is not clear who could be the potential stakeholders of a PSS. The aims of this study are to consolidate the stakeholders cited in PSS case studies and to reveal the terms used to refer to "stakeholder" in PSS literature. A systematic literature review was carried out, and an inductive content analysis procedure was applied. A total of 28 stakeholders were listed from the selected studies, whose PSS cases were classified as use-oriented or result-oriented services. Multiple terminologies are used to refer to stakeholders. This study contributes for showing the potential stakeholders that can be involved and engaged in the PSS design and operation. Also, it indicates the terms from which they can be addressed in the PSS literature.



### Effective Innovation Implementation of Mechatronic Product-Service Systems considering Socio-Technical Aspects

**Gennadiy Dmitrovic Koltun (1), Carlos Alberto Romero Viturro (2), Johan Buchholz (1), Juliane Wissel (1), Michael Zaggi (1), Felix Ocker (1), Birgit Vogel-Heuser (1)**

1: Technische Universität München; 2: Universidade de Vigo

It is estimated that about half of all innovations, such as innovations in mechatronic product-service systems (PSS), fail to deliver the expected benefits to the adopting organization. Different studies point out that one of the main reasons for this is an ineffective implementation process. In this paper, we argue that, apart from several organizational challenges, insufficient integration of technical and social aspects is one of the reasons for ineffective innovation implementation in the environment of mechatronic PSS. In order to remedy this weakness, this paper builds on the work of interdisciplinary research collaboration. Experts from technical, socio-technical, and management fields integrate their work within a conceptual innovation implementation management system (IIMS). This IIMS is capable of capturing various methods and models that foster the socio-technical integration in mechatronic PSS. The approach is assessed in a lab-scale demonstration case that is representative of industrial environments. The presented approach supports an effective innovation implementation process, while the IIMS facilitates individual alignments for future practitioners.



## A modeling approach for elastic tolerance simulation of the body in white hang-on parts

Hanchen Zheng (1), Frank Litwa (1), Benjamin Reese (2),  
Chenyang Li (2), Martin Bohn (1), Kristin Paetzold (3)

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Computer aided tolerancing (CAT) in the automobile industry is implemented by CAD tools. These tools analyze the manufacturability of complex assemblies with rigid single parts in an early stage to reduce the product development time and the cost for hardware prototypes. This paper proposes an approach to implement tolerance simulation for a compliant assembly, which includes manufacturing processes such as clinching, bolting and hemming by applying tolerance simulation tool. The fender-BIW system is simulated as a compliant rigid system and the simulation model is applied to two production scenarios. The simulation results are compared with real measurement data, which demonstrates the efficacy of using simulation in early production as opposed to prototyping or other methods of design by showing the strong correlation between simulation results and as-built products.



## An Overview and Classification of Tolerance Compensation Methods

Alexander Aschenbrenner, Benjamin Schleich, Sandro Wartzack  
Friedrich-Alexander-Universität Erlangen-Nürnberg

Technological advances as well as novel manufacturing and design paradigms, such as industry 4.0 and digitalization, offer new opportunities for innovative products. However, they also increase the product complexity and cause new challenges in the production process. Therefore, agile production approaches are crucial. Tolerance compensation provides more flexibility in the production process, as demands on dimensional accuracy of the components are reduced. As a result, tolerance compensation also offers the possibility of reducing production costs without compromising product quality. Nevertheless, tolerance compensation is often considered a reactive intervention to reduce the number of out-of-spec parts a posteriori instead of including it in the early stages of Geometrical Variations Management. The contribution tackles this issue by characterizing and categorizing different methods of tolerance compensation as well as providing design guidelines for the application of tolerance compensation methods. This enables design engineers to select a suitable tolerance compensation method for different applications.



## Analysis of Approaches of Tolerance Allocation regarding to Economic Efficiency

Peter Gust, Alina Sersch, Tobias Steger, Christoph Schluer  
University of Wuppertal

The aim of this paper is to examine the current state of research on tolerance-induced costs in Germany. Through a literature research already existing approaches for the determination of costs related to tolerances during the specification of technical components are pointed out and possible approaches for the reduction of these costs are presented. In addition, the actuality of these approaches will be considered. One question that is supposed to be answered here is to what state of standard for the specification of components these approaches can be assigned to. On the other hand, it should be clarified whether the existing approaches are applicable to the currently valid standard system of the Geometrical Product Specification (GPS). Can the economic efficiency of the specifications selected for tolerancing be determined in a technical drawing during the product development process in accordance with GPS on the basis of the current state of research?



## Perceived quality evaluation with the use of extended reality

Kostas Styliadis, Andreas Dagman, Håkan Almius, Liang Gong, Rikard Söderberg  
Chalmers University of Technology

If designers want to communicate quality aspects of the product, there is a need to bring these characteristics into the measurable space of perceived quality (PQ) attributes. To illustrate the solution for designers' dilemma of the "best design choice" in this study we applied the PQ attributes importance ranking (PQAIR) method, with the example of a bread toaster. We choose for evaluation three PQ attributes which can significantly influence visual quality of a product: Gap, Flush and Parallelism. We performed the experiment measuring subjective preferences over the toaster designs of two respondent's groups - "Designers" and "Customers." We used sequentially: (i) web-survey (still images); (ii) desktop system; and (iii) fully immersive head-mounted display system (Virtual Reality). Consequently, we conducted a post-experiment survey regarding subjective preferences, related to the PQ communication channels that have been implemented during the study. Our results indicate advantages and drawbacks for each PQ communication method that we applied in this experiment and encourage further research in the area of products' perceived quality assessment



## Ecodesign from high school to bachelor level: a French case study

Catherine Perpignan (1), Vincent Robin (2), Yacine Baouch (1), Benoit Eynard (1)

1: Université de Technologie de Compiègne; 2: Université de Bordeaux

Nowadays, our society needs that an awareness be made about our impact on the planet. Many more or less alarmist reports tell us that there is a need to change our consumption patterns, production and energy consumption ... One of the main axes to achieve these goals is education. Thus integrating sustainable development into the skills of future engineers is an essential challenge but above all a necessity to modify and reduce our impact on the environment and to allow a global understanding of the complexity of our society. For this, companies must also evolve. Some will do so in a strategy of greening their image, others will have to comply with the various regulations of their sector of activity and a final category of these companies will use this opportunity as a vector of innovation. Each at their level will make a contribution, the integration over time of new sustainability skills within their staff will expand their action. In this article, we will focus our study on the integration of ecodesign in the industry and the impact that this generates in terms of skills to acquire, values ??to evolve and knowledge to master.



## Eco-Innovation by Anticipatory Failure Determination (AFD) Method

Jahau Lewis Chen, Chuan-Jr Hung

National Cheng Kung University

This paper presents an eco-innovation method by revised the "Anticipatory Failure Determination (AFD)" method which is the failure analysis tools in TRIZ theory. Using the functional analysis to list the system process and make the functional analysis model. Based on the environmental efficiency factors and functional analysis model, Substance-Field inverse analysis can find a lot of failure modes in the system. In order to assess the priority of risk improvement, the designer can calculate the environmental risk priority number including controlling documents, public image and environmental consequences. Designer can quickly find out the potential failure mode in the complex engineering system with the systematic steps. The TRIZ methods are used for finding eco-innovation idea to solve failure problem. The capability of the whole eco-innovative design process was illustrated by the electrical motorcycle case.



## Ecological Advanced Innovation Design Approach For Efficient Integrated Upstream And Downstream Processes

Pavel Livotov (1), Mas'udah Mas'udah (1), Arun Prasad Chandra Sekaran (1), Richard Law (2), David Reay (3)

1: Offenburg University of Applied Sciences; 2: Newcastle University; 3: David Reay & Associates

Process engineering industries are now facing growing economic pressure and societies' demands to improve their production technologies and equipment, making them more efficient and environmentally friendly. However unexpected additional technical and ecological drawbacks may appear as negative side effects of the new environmentally-friendly technologies. Thus, in their efforts to intensify upstream and downstream processes, industrial companies require a systematic aid to avoid compromising of ecological impact. The paper conceptualises a comprehensive approach for eco-innovation and eco-design in process engineering. The approach combines the advantages of Process Intensification as Knowledge-Based Engineering (KBE), inventive tools of Knowledge-Based Innovation (KBI), and main principles and best-practices of Eco-Design and Sustainable Manufacturing. It includes a correlation matrix for identification of eco-engineering contradictions and a process mapping technique for problem definition, database of Process Intensification methods and equipment, as well as a set of strongest inventive operators for eco-ideaation.



## An eco-knowledge tool to support eco-design implementation inside design departments

Marta Rossi (1), Claudio Favi (2), Anna Costanza Russo (1), Michele Germani (1)

1: Università Politecnica delle Marche - Department of Industrial Engineering and Mathematical Sciences; 2: Università degli Studi di Parma - Department of Engineering and Architecture

In last years, an increasing attention on environmental matters is registered. Companies face environmental matters to increase the environmental performances of their products, forced by numerous legislations, normative and protocols and induced to the growing attention of consumers toward environmentally friendly products. However, observing the industrial context, it emerges there are several barriers for implementation of eco-design strategies inside design departments. The paper presents a tool which aims at both providing a basic guide on environmental sustainability issues and favouring the knowledge sharing among the different actors of the product design process. The core of the tool is a repository in which company materials, organized and collected in different forms, are collected. The repository contains several parts: training, guidelines, knowledge and milestone, accordingly to the type, structure and form of materials stored. The eco-design tool functions, structure, and workflow are presented and then preliminary test cases are described.



## A Critical Review of the Integrated Logistics Support Suite for Aerospace and Defence Programmes

*Ljubisa Vaskic, Kristin Paetzold*  
Bundeswehr University Munich

The Integrated Logistics Support (ILS) can be described as an approach for optimisation of in-service (logistics) activities and minimisation of the life cycle costs of a system. ILS is an integral part of systems engineering in aerospace and defence programmes. More recently, the Aerospace and Defence Industries Association of Europe (ASD) has released a broad set of specifications for ILS, the so-called ASD ILS Suite. Most of these specifications are published in cooperation with the Aerospace Industries Association of America (AIA) and one specification with AIA and the Airlines for America (A4A). Thus, the ASD ILS Suite is recognised and used in the largest aerospace and defence markets. The aim of this paper is to present the results of a critical review on the readiness of the ASD ILS Suite for its applicability in aerospace and defence programmes.



## MBSE-integrated parametric working surfaces as part of a PLM design approach

*Tim Katzwinkel, Manuel Löwer*  
BUW University of Wuppertal

This paper demonstrates a concept for a cross-domain strategy for the sustainable processing and dissemination of product information. Important functional product features are explicitly mapped as working surface information in different domain tools with the help of the contact channel method and are integrated using a model-based systems development approach. The approach uses established state of the art design tools and can be integrated into existing product development processes, knowledge based engineering concepts and product (system) lifecycle management strategies.



## An Approach to integrate risk management in cross-structure SysML-models

*Steffen Georg Kunnen, Dmytro Adamenko, Robin Pluhnau, Arun Nagarajah*  
University Duisburg-Essen

Demands on developers are increasing due to the growing complexity of products in engineering. As many different disciplines are involved in planning the communication and data exchange becomes difficult. Systems engineering and especially the model-based development have proven themselves for this sector. However, the different languages for system modeling, such as SysML, offer considerable potential for optimization. A corresponding data model must be modelled so that data is available continuously and across all levels. Based on this data model, various engineering processes like risk management can be integrated into this model. New stereotypes are defined within SysML so that errors and risks can be implemented in the system model. This makes it possible to determine influences and effects that risks and errors have on other components of a product across all structures.



## Consistent Modelling of the Impact Model of Modular Product Structures with Linking Boundary Conditions in SysML

*Lea-Nadine Schwede, Michael Hanna, Nadine Wortmann, Dieter Krause*  
Technical University Hamburg

The challenges related to product structures, which go hand in hand with megatrends such as individualization, can be met with the modularity of product structures. With the help of various modularization methods, modular product structures are created with regard to different goals. There are many references to the effects of modular product structures on life phases and economic targets in the literature. These effects were collected in previous research in a generic impact model. Since there is a lot of information about the effects, such models become very comprehensive and thereby difficult to handle. For this reason, the impact model is consistently generated using SysML. The adaptation to company scenarios is possible through the use of simulations with which, for example, company-related and product-related boundary conditions can be controlled by means of a User Interface.

**Discussion Sessions**  
**Wednesday**  
7 August 2019  
15:00 – 16:00

<b>Collaborative Design and Group Creativity   Innovation &amp; Creativity</b> <i>Pulse Building, Hall 6</i>	<b>44</b>
<b>Cyber-Physical Systems (CPS) Design</b> <i>IDE Faculty, Hall L</i>	<b>46</b>
<b>Design Methods   Tools</b> <i>IDE Faculty, IDE Arena</i>	<b>48</b>
<b>Product Architecture and Modularization   Product Architecture</b> <i>IDE Faculty, Hall M</i>	<b>50</b>
<b>Ideation</b> <i>IDE Faculty, Hall K</i>	<b>52</b>
<b>Product-Service-System (PSS) Design   Design of PSS</b> <i>Pulse Building, Hall 4</i>	<b>54</b>
<b>User-centred Design   User Integration</b> <i>IDE Faculty, Wim Crouwel</i>	<b>56</b>
<b>Sustainability   Sustainable Buildings</b> <i>Pulse Building, Hall 5</i>	<b>58</b>
<b>Value-driven Design</b> <i>IDE Faculty, Bernd Schierbeek</i>	<b>60</b>



### Inventions and scientific discoveries: impact of designers' collaborations on creativity. An analysis towards fixation effects

**Quentin Plantec (1,2), Pascal Le Masson (1), Benoit Weil (1)**

1: MINES ParisTech; 2: Institut National de la Propriété Industrielle

Scientific discoveries and inventions have long been established as two distinct and sequential activities. It has nonetheless been showed that projects aiming at producing both scientific discoveries and inventions could record impressive results. Our investigations are focusing on the creativity of collaborations outputs: a first agent is entailed to design a scientific discovery and another one invention. We use fixation effects as a performance measurement indicator for creativity based on Design Theory. We propose a first set of elements that can be suffering from fixation effects in both invention and scientific models designers reasoning. We propose a series of defixed inputs that could be shared between both designers to overcome their fixation effects. We highlight that if partners are engaged in one-way knowledge transfer it can conduct to "fixation traps". We define a set of restrictive conditions that could conduct to a "cross-defixation process": both actors would be able to create conjoint new inventions and scientific models in the non-fixed design path. In particular this process does not required designers to be defixed before starting the collaboration.



### Three-dimensional approach for assessing uncommonness of ideas

**Lorenzo Fiorineschi, Francesco Saverio Frillici, Federico Rotini**

University of Florence

A posteriori novelty metrics are often used in design research, in order to extract important information about creativity. However, different assessment approaches can be found in the literature, each of them with related pros and cons. In particular, weighted uncommonness, overall uncommonness and uncommonness across groups are the three main families of a-posteriori novelty metrics identified in this paper. Each of the considered literature metrics can provide specific types of information about the uncommonness of ideas, but in certain experimental circumstances, it could be difficult to rapidly identify the best-suited approach. This paper proposes an integrated procedure where the advantages offered by the three families of metrics can be applied concurrently. A generic case study is used for a first application of the proposal, and the obtained results show that a more comprehensive set of information about a-posteriori novelty can be extracted. In particular, novelty data from the three families of metrics are extracted in a single assessment process.



### Towards Creativity Stimulating Design Intervention For Multidisciplinary Innovation Teams

**Sander Vălk, Céline Mougnot**

Dyson School of Design Engineering, Imperial College London

The aim of our research is to stimulate cross disciplinary design collaboration to improve innovation processes in product and service design domain. We focus on the intersection of biotechnology and design as this field poses great challenges and opportunities for innovation, and it has received little attention in light of technological advancements of digital goods over the past decades. Experimental studies in the area expose challenging interactions, rising from lack of common vocabulary and preconceptions. Organisational management studies suggest that creativity is a prerequisite for innovation in group processes. As such, we are interested in enhancing collective creativity. Numerous studies investigate external creativity triggers, however only on individual level. Our review suggests that external triggers can be effective when the task is problem solving or styling, but ambiguous goals like innovation require stimulation of intrinsic triggers, such as group incidental learning and tacit knowledge. To explain this, we propose a hypothetical innovation approach, that draws attention to cognitive stimulation methods leading to creativity in multidisciplinary teams.



### From invention disclosures to innovation - Challenges in transforming practice

**Senni Kirjavainen, Tua A. Björklund**

Aalto University

Adopting design thinking and innovation-oriented approaches in organizations is crucial but not always simple. New practices of collaboration, user-orientedness and exploration require a compatible culture to be successfully integrated into product development. This paper presents a case study based on 12 interviews of employees and managers in a large Finland-based technology company, introducing new ways of working to product development. Silos, focusing on inventions, and a lack of resources for exploration were highlighted as key challenges in transitioning from incremental development to innovations. Perhaps counterintuitively, introducing new ways of working requiring a collaborative culture - the most widely recognized shortcoming in the current practice in the case - were best received, and support and feedback could be found for pilot projects in these arenas. When the gap between the practice and culture was smaller, change efforts could perhaps be more challenging, as there was less of a consensus on a need to change. The results suggest than developers need not automatically shy away from piloting new ways of working even when existing cultures are not compatible.



## Simple integration of sensory functions

**Sven Vogel, Eckhardt Kirchner**

Technical University Darmstadt

The digitalization of the Industry is one of the megatrends taking place, but many companies struggle to follow this trend. The main reason is the absence of simple solutions for the integration of sensory functions, which are applicable to the existing system. Therefore, this paper discusses the aspects of simplicity in the context of integrating sensory functions into existing systems, to support the development of digitalized products. Two general requirements can be formulated for a solution to be applicable simple: The first requirement is affected by the product structure. The solution must affect the least possible amount of modules and must not interfere with the interfaces of the modular platform. The second requirement is affected by the effort to model the behaviour of the desired information and the possible data a sensory function is delivering. The effort to develop a reliable solution has to be compared with the commercial potential of the solution. To consider the mentioned requirements, the paper explains three approaches to assess the simplicity of solutions on an example of the desired monitoring of the functions of a rotary plug valve.



## Streamlined assessment to assist in the design of Internet-of-Things (IoT) Enabled Products: a case study of the smart fridge

**Elies Dekoninck, Francesca Barbaccia**

University of Bath

This paper shows how designers of IoT-enabled products can assess the environmental impacts associated with the user behaviour and the service system around the product. High-quality secondary data and a user-behaviour survey were able to highlight critical aspects of a smart fridge's design. A streamlined LCA looked at just the in-use phase of the product within 4 PSS scenarios. The system included: the effects on the food waste; grocery shopping methods; fridge door openings; and how the users interact with the smart fridge features. The results show that a smart fridge as within a PSS can reduce the impact on the environment (GWP of 21,700 kg CO<sub>2</sub>-eq within the 'average PSS scenario' and GWP of 23,100 kg CO<sub>2</sub>-eq for the normal fridge with 'typical scenario'). The product's increased emissions are counteracted by the reduction in GWP due to: reduction in food waste; and shifts from brick-and-mortar grocery shopping to e-commerce. Therefore some of the critical aspects of the product's design that are most influential on the environmental impact of an IoT fridge are: the design of the web-browsing capability; and the use-by date tracking system.



## Munich Agile MBSE Concept (MAGIC)

**Vahid Salehi, Shirui Wang**

Munich University of Applied Sciences

Model-based systems engineering (MBSE) is well-known in gaining the control over the complexity of systems and the development processes, while agile is a project management methodology originally from software development that uses short development cycles to focus on continuous improvement in the development of a product or service. In this paper, we adopt the concept of agile into MBSE and then proposed the new approach - Munich Agile MBSE Concept (MAGIC). The highlights of the MAGIC approach can be concluded as 1) the requirements which have been defined in the first stage will be examined and traced at each following stages; 2) communication between every 2 stages always exists in order to have a close connection during each system development phase; 3) the idea of Industry 4.0 has been included and reflected to achieve automation and data exchange with manufacturing technologies; 4) the concept of IOT (Internet of Things) is also considered when it comes to the usage and service of the system to satisfy the customer's needs; 5) the whole spirit of agile is reflected as the iterative and incremental design and development



## An Axiomatic Categorisation Framework for the Dynamic Alignment of Disparate Functions in Cyber-physical Systems

**Thomas Byrne (1,2), Aleksandr Doikin (1,2), Felician Campean (1,2), Daniel Neagu (1,2)**

1: University of Bradford, Faculty of Engineering and Informatics; 2: Advanced Automotive Analytics Research Centre

Advancing Industry 4.0 concepts by mapping the product of the automotive industry on the spectrum of Cyber Physical Systems, we immediately recognise the convoluted processes involved in the design of new generation vehicles. New technologies developed around the communication core (IoT) enable novel interactions with data. Our framework employs previously untapped data from vehicles in the field for intelligent vehicle health management and knowledge integration into design. Firstly, the concept of an inter-disciplinary artefact is introduced to support the dynamic alignment of disparate functions, so that cyber variables change when physical variables change. Secondly, the axiomatic categorisation (AC) framework simulates functional transformations from artefact to artefact, to monitor and control automotive systems rather than components. Herein, an artefact is defined as a triad of the physical and engineered component, the information processing entity, and communication devices at their interface. Variable changes are modelled using AC, in conjunction with the artefacts, to aggregate functional transformations within the conceptual boundary of a physical system of systems.





## Doll based design tool in corporate contexts: A qualitative comparison with storyboard in a new product development project

Kaho Kagohashi (1), Yuki Taoka (1), Takehiko Ohno (2), Nana Hamaguchi (2), Xinlei Chen (2), Kenta Amano (2), Shigeki Saito (3)

1: Tokyo Institute of Technology, School of Engineering; 2: NTT TechnoCross Corporation; 3: Tokyo Institute of Technology, School of Environment and Society

Various tools for participatory design approach have been developed to support users to engage design process. Doll scenario is proposed as a generative tool for letting participants make and enact scenarios. However, suitable context to practice doll scenario is unclear in comparison with other tools using scenario. Therefore, our overall objective is to increase understanding of characteristics of making scenario in two different ways of expression; with doll and storyboard. We developed a doll scenario method, doll staging. The tool was evaluated in comparison to storyboard at a workshop which is a part of a new product development project in a corporate. The workshop was evaluated by semi-structured interviews with the participants and observations of the workshop and design outcome. The result suggests that doll staging allows participants to think from users' perspective in developing new idea. These findings provide new direction to choose scenario based design tools according to objective or context of design project. We also discuss potentials and research directions to use tools for developing scenario in corporate contexts.



## The Reference System In The Model Of PGE: Proposing A Generalized Description Of Reference Products And Their Interrelations

Albert Albers, Simon Rapp, Markus Spadinger, Thilo Richter, Clemens Birk, Florian Marthaler, Jonas Heimicke, Victor Kurtz, Holger Wessels

Karlsruhe Institute of Technology

Samsung recently introduced a new smartphone display with increased breaking resistance, which will probably be relevant for future cars as well. This example shows that subsystems, in general artefacts from former development processes can be relevant for subsequent projects. Their integration has to be planned, i.e. even before the original product is in the market and across branches. The research on supporting methods requires a suitable description model for this phenomenon. Research in design reuse and PGE – product generation engineering addresses this only partially yet. Design reuse focuses on the informational aspect, PGE refers primarily to reference products. This contribution aims at closing this gap as a basis for future research. Two case studies from industry projects by the authors and an example from foresight and product planning show the role of artefacts from former development processes in running projects. It is described which artefacts are used as a reference, why they are used and when. Based on these findings the authors propose the term “reference system” to depict the whole set of artefacts, which serves as a basis for every product development project.



## French biological philosophy of technology as a candidate perspective furthering design methodology

Sander Mulder

Delft University of Technology

A first exploration is conducted to what the French biological philosophy of technology perspective has to offer to the field of design methodology. If this French perspective is combined with contemporary speculative pragmatism a generative design methodology emerges offering novelty in what is sensed as important in a design situation. Within this perspective, drawing upon the late French philosopher Gilbert Simondon, technical objects have their own mode of existence and their own trajectory of development apart from human intention. Designers working with such a generative design methodology follow the constitutive value of openness and attune to the regulative value of techno-aesthetic judgments. By way of a ‘vignette+’, a paradigmatic example from a real case, a more encompassing argument is made towards design situations where a sophisticated machine is ‘inserted’ into a domestic setting. The example taken is the use of an artificial kidney machine in a domestic setting and the development of a novel machine with a design team. Four aspects were sensed as important in the unfolding design situation and directions for further research are discussed.



## Design for extremes: A contour method for defining requirements based on multivariate extremes

Andreas Haselsteiner (1), Rafael Reisenhofer (2), Jan-Hendrik Ohlendorf (1), Klaus-Dieter Thoben (1)

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The design of various products is driven by requirements that describe extremes. In marine structural design, joint extremes of environmental variables like wave height and wind speed are used to define load cases. Similarly, in ergonomic design minimum and maximum values of anthropometric variables are considered to make sure a product is suitable for a wide range of users. Here, we present a method that supports designers to define requirements using joint extreme values: the requirements contour method. The method is based on structural engineering's environmental contour method and uses a dataset and statistical methods to specify a region in the variable space that must be considered in the design process. That region's enclosure is the requirements contour and holds the joint extremes. After formally describing the method, we give an illustrative example of its usage: we use it to define requirements for the design of an ergonomic handle for a power tool. The requirements contour method is a field-independent approach to design for extremes. In the tradition of design for X, we think that a design project can benefit from applying methods that focus on different 'X's.



## Development of a Configure-to-Order-based process for the implementation of modular product architectures: A case study

*Florian Michael Seiler, Erik Greve, Dieter Krause*  
Hamburg University of Technology

As today's global market trends lead to an increasing demand for individualised products, manufacturers need to cope with a high degree of internal and external variety, which has a severe impact on complexity and therefore costs. When implementing modular product architectures, it becomes obvious, that the actual Engineer-to-Order (ETO) processes cannot cope with the requirements of such a product architecture. It is crucial to develop a complying Configure-to-Order (CTO) process in order to make full use of its supposed benefits. As there is no existing approach about how to methodically change an existing ETO process into an adequate CTO process, we intend to fill this gap with this paper by showing an approach for the development of a CTO process for modular product architectures. Furthermore, we show the application and evaluation of this approach in a case study with a special equipment manufacturer (SME), that is already implementing modular architectures.



## Tracing paths and connecting multiple design domains: An information visualisation approach to product architecture modelling

*Agzam Idrissov, Pedro Parraguez, Anja M. Maier*  
Technical University of Denmark

Visual representation of product architecture models is crucial in complex engineering systems design. However, when the number of entities in a model is large and when multiple levels of hierarchies are included, visual representations currently in use need to be more intuitive. As such, improved visual representations that enable better system overview and better communication of essential product-related information among design participants are needed. This paper uses interactive information visualisation techniques – collapsible hierarchical tree, edge bundling and alluvial diagram – and provides the foundations of a computerised tool that improves the traceability of connections between design domains, including stakeholders, requirements, functions, behaviours and structure. The case of a cleaning robot is used as an illustrative example. The approach supports designers by providing an enhanced overview during the development of complex product architecture models, in particular in the communication with external stakeholders, in the identification of change propagation paths across several design domains, and in capturing the design rationale of previous design decisions.



## Conceptual Design for Assembly in aerospace industry: a method to assess manufacturing and assembly aspects of product architectures

*Francois Bouissiere (2), Claude Cuiller (2), Pierre-Eric Dereux (2), Corentin Malchair (2), Claudio Favi (1), Giovanni Formentini (1)*  
1: University of Parma; 2: Airbus S.A.S.

In recent years, the air transport market has quickly grown, creating new civil aircrafts demand, challenging the actual production rate of aerospace industries. The bottleneck of the current civil aircrafts production rate lies in the capability of the manufacturing and assembly facilities in relation to the aircrafts architecture design. The aim of this work is to develop a methodology and a related mathematical model that can be used at the conceptual design phase for the assessment of criticalities related to the product assemblability. The methodology allows to recognize modules and/or interfaces which are mostly affecting the assembly time providing a design tool for the comparison and evaluation of product architecture alternatives. A preliminary application has been done on the nose-fuselage of a civil aircraft for passenger transport. The test case provides interesting outcome in the identification of modules and module interfaces which are strongly affecting the assembly phase and required a re-arrangement (new architecture design) for the process improvement.



## A Framework for Development Architecture for Modular Products: Cross-Domain Variety Management Perspective

*Kwansuk Oh, Jong Wook Lim, Seongwon Cho, Junyeol Ryu, Yoo S. Hong*  
Department of Industrial Engineering & Institute for Industrial Systems Innovation, Seoul National University

Variety management is a cross-domain issue in product family design. In the real field, the relationships across the domains are so complex for most of the existing product families that they cannot be easily identified without proper reference architecture. This reference architecture should provide the cross-domain mapping mechanisms in an explicit manner and be able to identify the proper units for management. From this perspective of cross-domain framework, this paper introduces development architecture (DA) to describe the relationships between elements in market, design, and production domains and to give insights for the cross-domain variety management in the product development stage. DA has three parts: (1) the arrangement of elements in each domain, (2) the mapping between elements, and (3) the identification of management sets and key interfaces which are the proper units for variety management. The proposed development architecture framework is applied to the case of front chassis family of modules of an automobile.



## Cross-Cultural Differences In Creative Ideation: A Comparison Between Singaporean And Portuguese Students

**Georgios Koronis (1), Rianne Wally Meurzec (1), Arlindo Silva (1), Marco Leite (2), Elsa Henriques (3), Christine Yogiawan (1)**

1: Singapore University of Technology and Design; 2: Department of Mechanical and Industrial Engineering, Faculty of Science and Technology; 3: Instituto Superior Técnico, Universidade de Lisboa

The purpose of this work is to compare the creative outcome in the educational context of students belonging to two different cultures, namely Singaporean and Portuguese and determine whether they respond differently to the same design brief. The participants from both samples equal 121 student designers and span from 18 to 25 years old. Students were randomly distributed within a uniform, standard of student performance, which allowed for fair comparison between groups. Expert judges were employed to judge the creativity of concept sketches generated during a Collaborative Sketching exercise. To evaluate the creative outcome, we employed the Consensual Assessment Technique based on a rubric-based system developed in our earlier works. The analysis of variance procedure revealed no statistically significant difference between the averaged total scores of the two groups on the appropriateness measure. However, the student designers from both samples showed statistically significant differences when provided with a baseline brief in the novelty measure. In consideration of the overall creativity scores, a relatively equivalent performance is observed across the two universities.



## Exploring the role of linguistic abstraction in idea-generation sessions

**Rafaella Antoniou, Elies Dekoninck, Jérémy Bonvoisin**

University of Bath

For many years, both academia and industry have been interested in increasing the efficiency of idea-generation meetings. Alex Osborne's (1953) rules for brainstorming are an early attempt to do so, and have extensively been used in engineering design, however their effectiveness has been questioned with recent research, and a need for fundamental research to establish which practices are useful arises. This study is an attempt in investigating linguistic abstraction in idea-generation meetings, in order to establish whether any best practices can be distilled from the language used. Engineering design group meetings were recorded and transcribed, and was analysed using a coding framework which was developed for analysing linguistic categories as well as the ideas that were generated during those meetings. More particularly, the study investigates the average abstractness/concreteness of speech throughout the duration of the meetings, as well as the switching between abstract and concrete language and vice versa while comparing idea-related discourse and non-idea related discourse switching. The coding framework proposed is considered robust enough to carry out further work.



## Visual sensemaking of massive crowdsourced data for design ideation

**Yuejun He (1), Bradley Camburn (1), Jianxi Luo (1), Maria C. Yang (2), Kristin L. Wood (1)**

1: Singapore University of Technology and Design; 2: Massachusetts Institute of Technology

Textual idea data from online crowdsourcing contains rich information of the concepts that underlie the original ideas and can be recombined to generate new ideas. But representing such information in a way that can stimulate new ideas is not a trivial task, because crowdsourced data are often vast and in unstructured natural languages. This paper introduces a method that uses natural language processing to summarize a massive number of idea descriptions and represents the underlying concept space as word clouds with a core-periphery structure to inspire recombinations of such concepts into new ideas. We report the use of this method in a real public-sector-sponsored project to explore ideas for future transportation system design. Word clouds that represent the concept space underlying original crowdsourced ideas are used as ideation aids and stimulate many new ideas with varied novelty, usefulness and feasibility. The new ideas suggest that the proposed method helps expand the idea space. Our analysis of these ideas and a survey with the designers who generated them shed light on how people perceive and use the word clouds as ideation aids and suggest future research directions.



## A systematic brainstorming ideation method for novice designers based on SECI theory

**Taegyun Kim, Alison McKay, Briony Thomas**

University of Leeds

Design ideation is a critical early step in any design process and especially challenging for novice designers. This paper introduces the "Systematic Brainstorming Ideation (SBI)" method that, as part of a wider design ideation process, improves the range and number of design concepts generated by novice designers. In this paper we give a brief introduction to the design ideation method to set a context for SBI and then introduce SBI in more detail. Evaluation experiments with 101 novice designers, based in UK and South Korea, are reported. Results indicate a 30% improvement in the number of design concepts generated.



## The Structure of DevOps in Product-Service System Development

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We study a DevOps software development process for a Product-Service System (PSS) using a design structure matrix (DSM) representation. We find unique features such as nested, planned iterations at differing rates which are not evident in conventional engineering development projects. We describe the impact of integrating ongoing operations into a development process and identify some of the enablers that lead to adoption of a DevOps process. We conclude by discussing the implications of our findings and raise questions for further research.



## Representing the value proposition of Product-Service Systems (PSS) in a value-based perspective

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Product-service systems (PSS) are being increasingly employed as opportunities to keep innovating. The design of PSS value propositions should focus on the value visualization for stakeholders. However, the PSS representations are still oriented to the customer's perspective and focus on a process or technological role. This study aims to represent the PSS value proposition in a structured-diagram adapted from the journey map method in combination with the use of the elements of value. A case research was conducted with a high-tech agricultural start-up for representing its value proposition by following a process founded in the practices of journey mapping. Qualitative data analysis was employed to associate the elements of value with the solution, and to verify the consistency of the results. The representation enables the visualization of the stakeholders' perception regarding the content of the solution as well as the potential value that may be related to it. The experience-centric perspective derived from the journey map associated with the value-related information provides a richer view of the PSS value proposition, which can lead to reflections regarding the solution.



## Towards an uncertainty framework for Product Service Systems of Systems

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Product Service Systems (PSS) are increasingly complex and collaborative. For instance, manufacturing companies, service providers, and other companies collaborate and jointly develop and operate a PSS (ex: smart grid), where its constituent elements are managed and operated independently. Managerial independence and operational independence are commonly considered key characteristics of a System of Systems (SoS). Hence, a collaborative PSS exhibits System of Systems (SoSs) characteristics. These systems have previously been introduced as Product Service Systems of Systems (PSSoSs). In this paper, we propose to identify relevant uncertainties in the PSSoS design process. For this purpose, we go beyond the PSSoS concept definition and propose a comprehensive framework for PSS and PSSoS characterization. Moreover, based on both a literature review and an industrial diagnosis, we identify PSSoS-specific design uncertainties.



## An Approach for choosing the cost effective design for a product-service system while maintaining its desired reliability

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With the spread of product-service systems as business models the life cycle costs are of increasing importance as a measurement of product cost. A key factor that drives these costs is the desired reliability of the products used to provide the service. Since the customer usually expects as uninterrupted service availability, it is imperative to achieve the the required reliability. Therefore a large variety of methods has been developed to maximize the reliability of a product. But these approaches focus on the maximization of the reliability and disregard the resulting product costs. This can lead to designs that over perform concerning their reliability requirements but also exceed their target costs. Which will result in the product-service system not being competitive in the marketplace or lowering the company's profit. This paper shows an approach on how to use markov chains to enable a quick comparison of life cycle costs from different product-service system designs. With this it will be possible to make better informed decisions about the costs of a system while still meeting the reliability targets.



## A Concept for Physiological User Description in the Context of Dual User Integration

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In order to ensure the user's acceptance towards a product, the user has to be captured with all his facets and requirements. In this context, many user-centred design methods only focus on single aspects such as subjective expectation or ergonomic product design. Correlations and connections or a common consideration of several user parameters are often neglected, even if this can provide useful information for improving the design of products. Dual user integration tries to close this gap to a certain extent and considers the user's subjective expectation in combination with their physiological capacities. An integral part of this approach is a target-oriented evaluation of the user. Currently available methods of physiological and subjective evaluation of the user are only partially applicable for dual user integration. Especially physiological measurement techniques are time-consuming and expensive. For this reason, this contribution presents a new concept for capturing and describing the physiological capacity of the user via semantic differentials. Thereby, motor functions, cognition and perception are considered.



## Comparing Utility-Based and Network-Based Approaches in Modeling Customer Preferences for Engineering Design

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Customer preference modeling provides quantitative assessment of the effects of engineering design attributes on customers' choices. Utility-based approaches, such as discrete choice model (DCM), and network analysis approaches, such as exponential random graph model (ERGM), have been developed for customer preference modeling. However, no studies have compared these two approaches. Our objective is to identify the distinctions and connections between these two approaches based on both the theoretical foundation and the empirical evidence. Using the vehicle preference modeling as an example, our study shows that when network structure effects are not considered, results from ERGM are consistent with DCM in most of the test cases. However, in one case where customers have varying choice set with multiple alternatives, inconsistencies are observed, possibly due to the discrepancies of the two models in taking different information when calculating choice probabilities. The insights will lead to valuable guidance for choosing the technique for customer preference modeling and co-developing the two frameworks to support engineering design.



## Definition of a "sport-health" semantic space

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Product success depends on its capacity to meet users' expectations. Human Centred Design approach helps to reach this success by focussing on users' needs in the design process. These needs are as well functional as hedonic. Designing products requires then to design hedonic properties affecting users' perception. For sport products, people wants to improve their performances while maintaining their health. Sport products are then considered not only "sporty" but also "healthy". Thus, integrating both health and sport expectations into the design process are necessary. Last decades, Affective Engineering was developed to integrate perception into the design process. Applying this approach for sport products may allow defining and mixing sport and health perceptual characteristics all along the design process. However, defining these characteristics into requirements implies to translate them into semantic terms. If we observe semantic descriptors for sport products and for health products, they seem opposite. In this paper, we aim defining a semantic space representative and respectful of both domains, sport and health, while they oppose.



## An innovative framework for managing the customization of tailor-made shoes

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Product customization aims to consider individual customers preferences in the design of new products, in order to directly involve them in the product development process and to maximize their satisfaction. It can be considered a key competitive factor and a "hot topic" in several industrial sectors, including luxury apparel goods and high-end footwear products. However, currently the design and manufacturing of customized shoes are carried out through artisanal and non-standardized processes, based on the individual expertise of operators. The objective of this study is to define an innovative framework to support the different processes affected by customization. This framework is enabled by different digital technologies, as CAD-based tools, virtual/augmented reality systems, etc., opportunely integrated in the product development process. The main benefits related to the framework implementation in real industrial contexts are an increase of flexibility, the repeatability of processes, a higher efficiency in information exchange, a more effective involvement of final customers, and, as a consequence, the reduction of time to market and production costs for tailor-made shoes.



## Design contributions to building technology: goals, interfaces and responsiveness

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In this paper, I identify issues that arose in a recent pilot project in which designers contributed to the construction field. The project was led by an overall responsible innovation goal for sustainability impact: contribute to global CO2 reduction. The innovation solution being developed to achieve this goal was a sustainable renovation concept intended for upscaling. In this pilot project, it was applied to a social housing block of 12 apartments. The designers sought to help align technical solutions with the residents' later use of their homes, because the latter is an important factor in achieving a zero-energy outcome. The paper identifies four issues that arose in the collaboration between design and construction and installation professionals. The issues are goal translation, goal dissipation, the contested service interface and the contested responsiveness to residents. I argue that designers can engage and contribute through design intervention and applying care in the collaboration, in order to support the success of responsible innovation.



## Design for Sustainability and Innovation: A Kansei Engineering Evaluation of the Adaptive Reuse of Old Buildings

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The aim of our study was to use Kansei Engineering Evaluation to examine the renewal of old buildings with sustainability and innovation by comparing to new buildings. First, we conducted a questionnaire survey, with 84 participants, on 18 buildings from Asian and European countries; the survey used 16 adjectives. Second, we studied the characteristics of new and renewed old buildings in terms of the elements crucial to sustainable and innovative design. The results suggest that the adaptive reuse of old buildings is more sustainable than constructing new buildings. Further, the adjectives preferred by the survey show that the adaptive reuse of old buildings has higher influence with character of 'creative' from the innovation viewpoint. This paper presents a project to address sustainability and innovation of adaptive reused of old building at a later stage. This study contributes to the renewal of existing infrastructure to improve its longevity and chance of future reuse, and to ensure environmental sustainability for future society.



## Bio-Brick - Development of sustainable and cost effective building material

**Priyabrata Rautray (1), Avik Roy (2), Deepak John Mathew (1), Boris Eisenbart (3)**

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Building construction is one of the fastest growing industries in India and it puts a huge burden on its limited natural resources. Fired clay bricks are one of the major constituent materials for the construction industry and it produces a huge amount of greenhouse gases. This research tries to highlight the use of alternative materials and how they can be modulated to suit the Indian construction industry. Bio-brick or agro-waste based brick is one such material that has the potential to be a sustainable and cost-effective solution. It acts as good heat and sound insulator and at the same time has overall negative carbon footprint. Additionally, it also acts as a deterrent to stubble burning, prevalent in northern India which causes severe air pollution. Due to its low density, it reduces dead load in high rise structures, thereby making RCC construction more economical. The study also highlights the use of Bio-brick in various areas of a structure. Another important objective of this research is to inspire and motivate architects, designers, researchers and builders to encourage and support the development of such sustainable and eco-sensitive material in construction industry.



## Sustainability research implementation in product development - learnings from a longitudinal study

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Industry is a main stakeholder when it comes to realising the transition towards a sustainable future. Academia, with its, knowledge and methods, needs to support the industry on this journey. This paper, focuses on the practical learnings on how to implement sustainability research from an industrial perspective. It aims to share some lessons learnt from a longitudinal case study and a development journey in implementing sustainability research in the product innovation process at GKN Aerospace Engine System. The paper gives an overview, based on a literature study, of what is required to successfully implement sustainability in product development. It also provides a summary of the different research projects at the company with learnings from practical and academic perspectives, and the main learnings and changes in relation to different development phases in the sustainability journey. Although, this journey began over ten years ago, and shows the importance of long-term collaboration, it provides key-factors that can be applied also in short term collaborations and for faster implementation of research in general and sustainable product development research in particular.



## Integration Of Value Adding Services Related To Financing And Ownership: A Business Model Perspective

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It is an agreed fact among scholars that services are more sustainable compared to the products. By offering services, traditional companies can lock their customers into a long-term and sustainable revenue generation settlement. Available academic literature is abundant with methodologies related to service development. However, this study investigates various value adding service options related to financing and ownership of a product that can be offered on top of the existing products. It is important to understand these options from the consumer as well as supplier perspective. The most well established options available for financing/ownership are compiled, and sorted with respect to intangibility, ownership, financing and value addition scale. The study argues that the identified options incrementally add value to the existing offering by increasing the purchasing power and reducing the ownership obstacles for the customers. However, for the supplier, the decision depends on the trade-off between value addition for the customers and the business model changes required.



## Axioms of value

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Extensive work exists on value in multiple domains. However, there are different interpretations, highlighting a lack of clarity about the fundamental characteristics. To address this, we present seven value axioms resulting from inductive research. The axioms may be viewed as general rules describing value in any context, therefore conveying the fundamental characteristics of the phenomenon. They reveal that value is: (1) connected to people; (2) an output of a cognitive process; (3) in requirement of a determination process; (4) a matter of a given situation; (5) determined by the interpretations of entities; and related to (6) entities and (7) criteria. The nature of value is of particular importance to the design community, given the emphasis on value in design and product development. In this context, a lack of clarity may be perceived in terms of when value appears, appropriate metrics, and how to add value. To provide explanations, there is a need for a theory of value in design. The presented axioms may provide the basis, as they are fundamental statements on the nature of value and not limited to a specific domain. We highlight theory requirements based on the axioms.



## Value Driven Design Revisited: Emerging Modelling Concepts And Applications

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Extended product warranties, leasing, and pay-per-use schemes are few examples of how manufacturing companies are shifting their focus from selling products to offering solutions, combining products and services to maximise customer value. The idea of optimising a system towards the best value is both "intuitive and sensible", and processes such as Value Driven Design (VDD), have been proposed to supplement traditional engineering design methodologies. Yet, value-driven initiatives struggle to communicate their benefits and to demonstrate how value models can solve actual problems. The aim of this paper is to shed light on the evolution of the VDD toolbox, mapping research clusters, applications and case studies from the perspective of how much (and how well) recent contributions have answered the five top-level questions of the VDD research agenda published in 2012. The results of the systematic literature review reveal the emergence of innovative modelling constructs, methods, and tools that help VDD in taking a leap forward in supporting organizations and teams in achieving the long-sought objective of designing for 'value'.



## Supporting early stage set-based concurrent engineering with Value Driven Design

**Alessandro Bertoni, Marco Bertoni**  
Blekinge Institute of Technology

Set-Based Concurrent Engineering is commonly adopted to drive the development of complex products and systems. However, its application requires design information about a future product that is often not mature enough in the early design stages, and that it is not encompassing a service and lifecycle-oriented perspective. There is a need for manufacturers to understand, since the early design stages, how customer value is created along the lifecycle of a product from a hardware and service perspective, and how to use such information to screen radically new technologies, trade-off promising design configurations and commit to a design concept. The paper presents an approach for the multidisciplinary value assessment of design concepts in sub-systems design, encompassing the high-level concept screening and the trade-off of different design concepts, and enabling the integration of value models results into a Set-based Concurrent Engineering process. The approach is described through its application in the case study of the development of a subsystem component for a commercial aircraft engine.





