# PROGRAMME & ABSTRACTS BOOK

ICED17

21st International Conference on Engineering Design

Vancouver, Canada 21-25 August 2017

University of British Columbia, Vancouver, BC Canada

the Design Society

THE UNIVERSITY OF BRITISH COLUMBIA

# ICED17

## 21st International Conference on Engineering Design
## Vancouver, Canada 21-25 August 2017

University of British Columbia

**Organised by**: Department of Mechanical Engineering at the University of British Columbia and the Design Society

THE UNIVERSITY OF BRITISH COLUMBIA

the Design Society

**Organising Secretariat:**
Student Housing and Hospitality Services
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The University of British Columbia | Vancouver Campus
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### Programme & Abstracts Book

**Edited by:**
Anja Maier
Stanko Škec
Chris McKesson
Mike Van der Loos

**Cover artwork credit:**
Native youth participants of the Overly Creative Minds arts studio at the Urban Native Youth Association, under the guidance of artist and OCM Coordinator Marie Wustner

**Graphics by:**
Flora Gordon

## All sessions take place at The Nest, 6133 University Blvd., Vancouver, BC.

| Time | MONDAY August 21 | TUESDAY August 22 | WEDNESDAY August 23 | THURSDAY August 24 | FRIDAY August 25 |
|---|---|---|---|---|---|
| 8:30 am to 10:30 am | **SIG Workshops** 9:30 am – 12:30 pm *W1.1 – W1.7* | **Podium Sessions** 8:30 am – 10:00 am *P1.1 – P1.8*<br>Break: 10:00 – 10:30 am | **Podium Sessions** 9:00 am – 10:30 am *P2.1 – 2.9* | **Podium Sessions** 9:00 am – 10:30 am *P3.1 – 3.8* | **Academic and Industry Tours (Optional)** 8:30 am – 5:15 pm |
| 10:30 am to 11:00 am | | **Keynote** 10:30 am – 11:15 am | Break: 10:30 – 11:00 am | Break: 10:30 – 11:00 am | |
| 11:00 am to 12:30 pm | | Break 11:15 – 11:30 am<br>**Discussion Sessions** 11:30 – 12:30 *D1.1 – 1.8* | **Keynote** 11:00 am – 11:45 am<br>**Keynote** 11:45 am – 12:30 pm | **Podium Sessions** 11:00 am – 12:30 pm *P4.1 – 4.7* | |
| 12:30 pm to 2:00 pm | Lunch Break and Meetings | | | | |
| 2:00 pm to 4:30 pm | **SIG Workshops & PhD Forum** 2:00 pm – 5:00 pm *W2.1 – W2.8* | **Discussion Sessions** 2:00 pm – 3:00 pm *D2.2 – 2.9* | **Discussion Sessions** 2:00 pm – 3:00 pm *D5.1 – 5.9* | **Discussion Sessions** 2:00 pm – 3:00 pm *D7.1 – 7.8* | |
| | | Break: 3:00 – 3:15 pm | | | |
| | | **Discussion Sessions** 3:15 pm – 4:15 pm *D3.2 – 3.9* | **Discussion Sessions** 3:15 pm – 4:15 pm *D6.1 – 6.9* | **Discussion Sessions** 3:15 pm – 4:15 pm *D8.1 – 8.8* | |
| | | Break: 4:15 – 4:30 pm | | | |
| 4:30 pm to 6:45 pm | Break: 5:00 – 5:15 pm<br>**Opening of ICED17** 5:15 – 6:00 pm<br>**Keynote** 6:00 pm – 6:45 pm | **Discussion Sessions & Student Design Fair** 4:30 pm – 5:30 pm *D4.2 – 4.9*<br>Break: 5:30 – 5:45 pm<br>**Keynote** 5:45 pm – 6:30 pm<br>Break: 6:30 – 6:45 pm | **Design Society General Meeting** 4:30 pm – 5:30 pm | **Keynote** 4:30 pm – 5:15 pm<br>**Closing of ICED17** 5:15 pm – 6:00 pm | |
| 6:45 pm to 10:00 pm | **Welcome Reception** 6:45 pm – 8:45 pm | **Young Members Event** 6:45 pm – 8:45 pm | **Gala Dinner** 6:30 pm – 10:00 pm Museum of Anthropology | **Farewell Reception** 6:00 pm – 8:30 pm | |

**Legend:** Plenary Sessions; Podium Sessions; Discussion Sessions; Workshops; Design Society Event; Special and Social Events

# WELCOME BY THE CONFERENCE CHAIRS

Mike Van der Loos
***Conference Chair***

Filippo Salustri
***Assistant Conference Chair***

Antony Hodgson
***Assistant Conference Chair***

Welcome to Vancouver, Canada! The Organizing Committee of the 21st International Conference on Engineering Design (ICED17) is honoured to bring this premier Design conference to Canada for the first time in the history of the Design Society.

If you are reading this at the conference venue on the University of British Columbia campus, then you can readily see why UBC is considered one of the most stunning university settings in Canada, and indeed the world. Overlooking Vancouver Island to the west, and the wooded and craggy Coast Mountains to the north towards Whistler, you can readily appreciate why we chose "**Resource-Sensitive Design**" as the conference theme. Beyond the beauty of the setting, Vancouver is also home to vibrant forestry, natural resource, electronic media, biotech and transportation sector industries, and is a magnet for foreign engineers and students from all corners of the globe. These strong factors, along with the powerful First Nations presence in this region, underpin the conference's three subthemes: *design for resource-limited societies, design to protect critical resources,* and *design to embrace resource limitations*. We sincerely hope you will join in celebrating this conference theme and, leave Vancouver with a renewed appreciation of the professional responsibility held by the membership of the Society to design our way to a better planet.

Beyond the conference theme, returning ICED attendees will see many familiar topics and will also see how these fields have evolved since the last ICED, joined by several new topics as well. The main Podium- and Discussion-format sessions are preceded by the more cutting-edge Monday Workshops organized by the Design Society's Special Interest Groups: together these sessions are designed to provide attendees with ample opportunity to present, discuss, reflect on and contribute to the advancement of ideas in a wide variety of engineering design fields.

As in the past, ICED17 keynote lectures will unify the meeting, giving experts in the field the opportunity to communicate their visions for the future of the world in apposition to the themes of the conference. The six keynote speakers span the Design sector: from architecture to biotech, from materials to creativity, from regulatory agencies and government to engineering practice in society. We will all be wiser after hearing their reflections.

The Organizing Committee has created a conference that is rich in opportunity and nurturing in comforts – culinary, cultural and climate. We wish ICED17 attendees a most enjoyable experience in each other's company and in fruitful scientific exchange.

# PREFACE BY THE PROGRAMME CHAIRS

Dear Reader,

Welcome to the proceedings of the 21st International Conference on Engineering Design (ICED17). Each of the 413 manuscripts provides its own contribution to the vibrant community of design researchers and practitioners. The individual contributions come together to make a significant collective impact on this year's conference theme: Resource-Sensitive Design.

We are delighted to present an exciting scientific programme that acknowledges the rich tradition of the ICED conference series, manifests the collective creation of bodies of insights, connects across topics, and provides vantage points for the role and importance of designing emergent futures.

We placed particular emphasis on the young by introducing a design competition in form of a High-School Student Design Fair, by opening the conference also to the wider public that afternoon, by fostering research talent in the PhD Forum, and by providing a platform for visions and dreams of and for the Design World to come through the Young Members' Event.

Reviews have been invaluable for the ICED17 programme team in making their final acceptance decisions, grouping papers into the conference topics, and connecting to the conference theme. As a result, resource-sensitive design, design processes, design organisation and management, design research applications and case studies, product, services and systems design, design methods and tools, design for X / design to X, design information and knowledge, design theory and research methodology, human behaviour in design, and design education are all well represented in podium and discussion sessions. The attentive observer will also pick up weak signals of upcoming trends through the papers and presentation sessions. We trust that the careful selection of session chairs will amplify these signals.

The papers have been collated into a multiple range of formats: a programme and abstracts book, a memory stick of full proceedings, and nine volumes of proceedings, available for download from the Design Society website. These have been numbered against both Design Society and ISSN/ISBN referencing. The ICED conference proceedings are included in the Thomson Reuters Conference Proceedings Citation Index. This will enable more extensive access and increase citations.

We hope that you will enjoy the programme, and that you will participate actively in what is arguably the premier engineering design research conference in the world. We also hope that you will find the time to enjoy Vancouver, catch up with old friends and make some new ones.

Anja M. Maier
***Programme Committee Chair***

Stanko Škec
***Assistant Programme Chair***

Harrison Kim
*Programme Chair*

Michael Kokkolaras
*Programme Chair*

Josef Oehmen
*Programme Chair*

# PREFACE BY THE DESIGN SOCIETY PRESIDENT

Dorian Marjanović
***The Design Society President***

Design thinking involves sensitivity for the past and the legacy that belongs to all, awareness of the present and current needs, envisioning of the future and the implications created by design. The ICED17 conference theme "Resource - Sensitive design" reflects these aspects: the local heritage, contemporary living and strivings as well as The Design Society goals and mission: "…to contribute to the broad and established understanding of all aspects of design and to promote the use of design to the betterment of humanity".

ICED17 participants have a chance to experience the dynamics of the UBC campus and Vancouver that reflects all of the design dichotomies the old and new, the art and technology, the research and practice, the chaotic and systematic.

Since the first ICED conference held in Rome in 1981, the conference has become the event where the variety of design research from all the continents is presented, and all aspects of design explored. Design as a field has expanded tremendously, and the conference programme has become more interactive and involved, opening new opportunities and challenges.

Organising a conference with such a history takes an enormous amount of work and attention to details. The programme of ICED17 is the result of a joint effort from great teams that have been working together since the last ICED conference in Milan. ICED17 schedule is the result of continuous improvements in every aspect of conference organisation. These efforts provided an exciting opportunity for all the participants to learn about the latest developments in design research and practice.

On behalf of The Design Society, I would like to express sincere thanks to Organising Committee Chair Mike Van der Loos and all the colleagues in the Organising Committee and the team of The University of British Columbia who have made this conference happen.

Special thanks also to Programme Committee Chair Anja Maier, Assistant Programme Chair Stanko Škec and all the members of Programme Committee for their tremendous work in creating an exciting programme and for ensuring the high quality of the conference.

Finally, thank you to all the participants whose attendance and input are a constant sign that ICED conference and design as a field are going in the right direction. The Society extends its gratitude to all the authors who have submitted their contributions and all the reviewers who have helped to select papers ensuring an outstanding conference experience for all participants. A special thank you goes to all the presenters and Session Chairs who will make this experience possible.

The ICED17 conference continues the efforts and intention of The Design Society to foster design research in all the design facets.

# Design Society?
# Why join?

Belong to a worldwide design community

Enjoy reduced personal subscription fees and Article Publishing Charges for key journals

Develop networking opportunities and form lifelong friendships

Attend regular events for young members

Participate in Special Interest Groups (SIGs) on current topics

Get known for your contributions to Design

Have exclusive access to recently cited research papers and over 200 theses

Receive discounts on endorsed or hosted international conferences and events

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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; look out for the following emblem throughout:

**Monday, August 21 (6:45 pm – 8:45 pm)**
**Welcome Reception**
**Great Hall & Foyer**

Immediately following Keynote Speaker Peter Busby, refreshments will be served in the Great Hall & Foyer. We welcome you to stay and mingle with Engineering Design colleagues from around the world.

**Wednesday, August 23 (6:30 pm – 10:00 pm)**
**Gala Dinner at Museum of Anthropology**

We have designed an evening for you to experience west coast heritage and culture, and hope you take time to explore all activities. There is no structured meal time. Rather, we encourage you to move through the various areas to explore at your leisure.

This world class museum is open exclusively for ICED17 delegates and their guests. Stroll through the museum at your leisure, exploring over 40,000 artifacts. Docents are on hand to answer your questions or explain key artworks.

Outside, there will be a dance performance by Git Hayetsk Dancers at 7:30. Don't miss this memorable performance in a stunning setting.

Haida House is the place to enjoy a beverage and light refreshment. Sit for a while and experience the history of this dwelling, constructed by world renowned Haida artist Bill Reid.

Cross the reflecting pond and travel up the short trail to the event tent, where you can enjoy a variety of dishes at different stations and bars. Along the way, you will pass majestic totem poles and enjoy beautiful views of the mountains and sea. Dessert and coffee is served in the Museum Café and Courtyard.

The Museum Shop is open for those who would like to purchase a memento to take home.

Please note – there is no smoking on museum grounds. We suggest you wear flat shoes for walking outside.

**Thursday, August 24 (6:00 pm – 8:30 pm)**
**Farewell Reception**
**Great Hall & Foyer**

Join us for light refreshments and a chance to visit with friend and colleagues before departing.

Please note: name badges are required to access all Social Activities. Your registration includes one drink ticket for each Social Activity. There are also cash bars at each.

# PROGRAMME & ABSTRACTS BOOK LAYOUT


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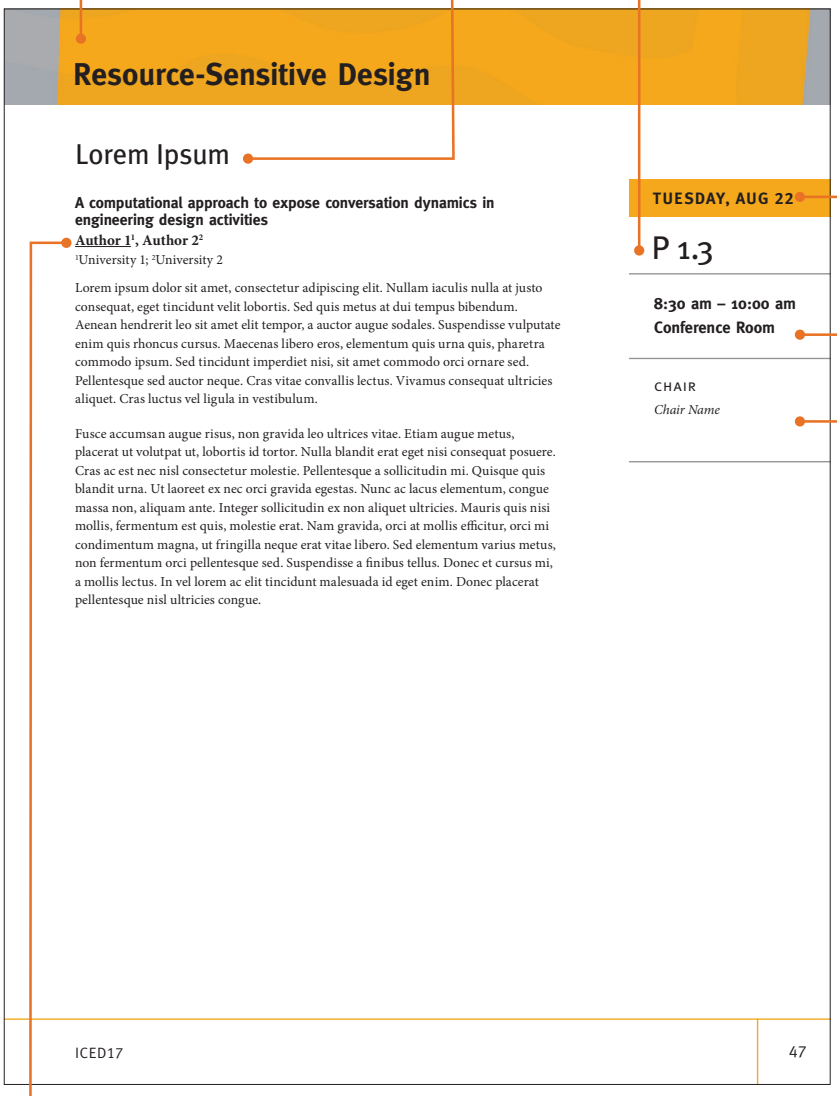
Overall theme of podium session, discussion or workshop

Specific title of podium session, discussion or workshop

**P** = podium session
**D** = discussion session
**W**= workshop

*Sequential numbering of sessions. The second digit is the parallel track number within each session.*




Coloured tabs indicate day of session. They are visible from the outside of the book.

Location. See page 284 for venue map

Session chair(s)

Presenting author's name is underlined

# MONDAY AT A GLANCE

| Location | 9:30 am – 12:30 pm | 2:00 pm – 5:00 pm | 5:15 pm – 6:00 pm | 6:00 pm – 6:45 pm | 6:45 pm – 8:45 pm |
|---|---|---|---|---|---|
| **Great Hall & Foyer** | | | **Opening Session** | **Keynote Peter Busby** | **Welcome Reception** |
| **Performance Theatre** | **W1.1:** Emotional Engineering SIG: Multisensory Engineering and Emotion | **W2.1:** Design Theory SIG: Design theory and its impact in several disciplines | | | |
| **2301** | **W1.2:** Design Education SIG: Implications for Engineering Design Education of Industry 4.0 | **W2.2:** Sustainable Design SIG: Dissemination and Implementation of Sustainable Design Tools | | | |
| **2306** | | **W2.3:** Design Creativity SIG: Developing design creativity research | | | |
| **2309** | **W1.3:** Modelling & Management of Engineering Processes SIG: Organizing innovation | **W2.4:** Design Practice SIG: Kick-off Workshop – Tackling Tough Design Challenges Together | | | |
| **2311** | **W1.4:** Design for Additive Manufacturing SIG: Strategies for Effectively Teaching Design for Additive Manufacturing (AM) and Infusing AM into the Design Classroom | **W2.5:** PhD Forum | | | |
| **2314** | **W1.5:** Collaborative Design SIG: The changing innovation landscape: Challenges for Collaboration Design | **W2.6:** Collaborative Design SIG and Design Education SIG: Collaborative Design Education | | | |
| **2504** | **W1.6:** Decision Making SIG: The new WeDecide App to support collaborative decision making in engineering design | **W2.7:** Human Behaviour in Design SIG: User in the design process | | | |
| **2506** | **W1.7:** Risk Management Processes and Methods in Design SIG: Risk Identification, Assessment and Mitigation in Design | **W2.8:** Robust Design SIG: A Robust Design Research Landscape – Clarifying the potential of RD principles and indicators | | | |

MONDAY, AUG 21

# Multisensory Engineering and Emotion

## W1.1

**9:30 am – 12:30 pm**
**Performance Theatre**

CHAIRS

*Monica Bordegoni*

*Shuichi Fukuda*

Multisensory information is attracting wide attention these days. Information from the different sensory modalities, such as sight, sound, touch, smell, taste and self-motion, may be integrated to allow humans to fully understand and experience situations.

Multisensory information is deeply associated with our perception, cognition and decision-making. The importance of perception and cognition is rapidly increasing to cope with the changes in our environments and contexts, which occur very frequently and extensively. Emotions play a crucial role in making decisions on how humans respond to these changes. As an example, if we consider the marketing sector, emotions correlated with multisensory information contribute to motivating customers to buy products.

Multisensory environments, where multisensory stimuli are computer-generated, play a key role in education and rehabilitation. Additionally, it should also be emphasized that multisensory information plays an important role in emotional communication. For example, NUI (Natural User Interface) will change our way of interacting with machines, and it is expected it will create another new value, which is more process-focused. In this context, multisensory technology allows us to study the human experience, consisting of sensors detecting data from the environment, from the context and also from the humans.

In this workshop, talks on emotional engineering with special attention to multisensory engineering are invited for discussion. Other talks on emotional engineering are also welcome. In particular, we invite young researchers and PhD students to participate in the workshop and present Emotional Engineering approach to product design, especially through case studies and demonstrations.

MONDAY, AUG 21

## W1.2

**9:30 am – 12:30 pm**

**2301**

CHAIRS

*Bryan Howell*

*Dorothy Evans*

# Implications for Engineering Design Education of Industry 4.0

The Fourth Industrial Revolution urges us to think creatively about the manufacturing process, value chain, distribution and customer service processes. In the meanwhile, the future of education emphasises the immense need to look beyond these areas and strategically utilise the "Internet of Things" to prepare the coming workforce for the challenges ahead. Universities emphasise their role in shaping future technology by being the testbeds for innovation and educating future generations. Traditional education has contributed greatly to the current levels of industrial evolution and technological advancement. However, in order for higher education to deliver future generations with the right set of skills and knowledge; an imperative question has to be asked regarding how higher education institutes would be affected by the Fourth Industrial Revolution and how the delivery of education will be transformed.

Altering higher education is more necessary than ever before. However, the challenges ahead have to be considered in order to ensure effective and immediate transformation. With the reduced public financial support for higher education; universities need to think strategically regarding methods to utilise their experience in credentials, trust and identity to offer new services. Furthermore, higher education leadership needs to be less risk averse especially in this world of disruptive change. It is no longer an option to keep doing things the old way; innovation and accepting change are now prerequisite for survival.

This is the time to ask whether the global higher education community will only react to how the business world is shaping the Fourth Industrial Revolution or if it will be among the key players of shaping the Fourth Industrial Revolution!

The workshop aim is to identify the key enhancements to engineering design UG and PG educational programmes to ensure that graduates are ready to work in an Industry 4.0 enabled environment

The workshop output will be information for a DESIGN position paper on 'Industry 4.0 enabled design education'. The paper will identify the key enhancement and changes in emphasis required to meet future industry design needs.

The workshop will also inspire future work and information gathering around the topic — all of which will feed into the position paper. It is also anticipated that the workshop will result in papers for EPDE and Design Science, both intended to enhance dissemination of the outcomes.

# Organizing Innovation

## W1.3

**9:30 am – 12:30 pm**

**2309**

CHAIRS

*Bernard Yannou*

*Claudia Eckert*

*Kilian Gericke*

The Modelling and Managing of Engineering Processes Special Interest Group aims to support industry in understanding, modelling and running design processes by bringing together a community of design researchers and interacting with industry by identifying research challenges and working together to resolve them.

The product development process of complex engineering products typically involves the collaboration of hundreds of experts often located across the world over a period of several months or years. Delivering these products depends on effective and efficient product development processes.

Product development projects are interdisciplinary endeavours involving different business functions and departments. Thus, a design process interacts with other processes within a company.

Innovation projects, as well as product development projects, need to be planned, monitored and need to create value for a company. Therefore, Chief Innovation Officers (CIOs) are in charge of organizing numerous facets of innovation such as:

- Research, technology and market roadmapping
- Innovation governance (human resources, activities, budgets)
- Organizing and supporting disruptive innovation projects for avoiding siloing business groups
- Organizing open innovation (screening interesting start-ups, capturing lead users' opinion)
- Articulating research activity (augmenting technology maturity), innovation projects (leading to convincing POCs), and development and launch of new products or product lines.

This workshop focusses on the interplay between innovation processes and the design process. It will explore how to organize innovation in a company as an extension of development processes and design approaches.

The management of innovation projects and product development projects are researched by different communities and publications seem often to be disconnected. Therefore, this workshop aims to start a discussion on how to transfer knowledge between the different areas and aims to identify challenges at the interface of both areas that need further investigation.

A possible outcome of this workshop is the opening of a Thematic Collection on "Organizing Innovation" in the *Design Science Journal*. Therefore, we will discuss with the participants:

- Their interest in contributing to such a thematic collection.
- Is the subject large and relevant enough?
- Is our community the best adapted for this?

**MONDAY, AUG 21**

## W1.4

**9:30 am – 12:30 pm**
**2311**

CHAIR
*Georges Fadel*

# Strategies for Effectively Teaching Design for Additive Manufacturing (AM) and Infusing AM into the Design Classroom

Additive manufacturing (AM) is rapidly changing the way we fabricate parts and introducing a complex new design space to be explored. In keeping with this trend, there is growing interest in teaching classes that focus not only on AM but also on "Design for AM."

In this workshop, participants and facilitators will share best practices and ideate additional strategies for teaching "Design for AM" classes.

Participants and facilitators will also identify opportunities for infusing AM into broader design curricula to reinforce topics as broad as prototyping, ideation, DfM, experimentation, and optimization.

This workshop is intended to be highly interactive. It will begin with short lightning talks that highlight best practices in Design for AM education and stimulate discussion, followed by small group ideation sessions in which participants design forward-thinking Design for AM modules and assignments and brainstorm opportunities for using AM strategically to reinforce concepts in conventional design classes.

A special emphasis will be placed on sharing AM case studies that can be used in the classroom.

MONDAY, AUG 21

# The changing innovation landscape: Challenges for Collaboration Design

## W1.5

**9:30 am – 12:30 pm**

**2314**

CHAIRS

*Robert Ian Whitfield*

*Avril Thomson*

New innovation landscapes have radically changed and advanced collaborative practices in order to develop more user-centred, innovative and customised products in a timelier manner. This has in turn prompted a motivation for industry to adapt their organisational practices in order to remain competitive.

This innovation landscape is characterised by the use of information systems throughout the innovation process to support stakeholders in manifesting and brokering product development knowledge. The innovation process is discontinuous, dispersed and open which in turn creates opportunities for new business models and markets. The product development process is democratised and adopts dynamic capabilities to radically innovative and sustain competitive advantage. Cloud-based methods, redistributed manufacturing, Industry 4.0, and Open Innovation are representative of the methods used to drive research within this innovation landscape.

These characteristics present complex challenges to conventional industrial practice and confounds the benefits gained from wide-spread implementation. These challenges could for example relate to the complexities of extending knowledge management practices beyond the boundaries of the organisation and the subsequent manipulation of this knowledge; the operation of formal and informal collaborative networks that manages ambiguity, equivocality, and conflicting constraints; the adaptation of organisational structures to become more flexible, agile and open; and the ownership of the product development process.

This workshop will bring together collaborative design and innovation researchers with the aim of creating a coherent, integrated, and more holistic picture of the collaboration challenges within this open innovation landscape.

The workshop is aimed at industrial and academic researchers and practitioners with an interest in Collaborative Design and Innovation. The outcome of the workshop will benefit both domains of researchers by forming the foundation for establishing international relationships.

This workshop will aim to answer the questions:

- How is this changing innovation landscape characterised, and what are the benefits to industry of adopting these innovation practices?
- What are the challenges and contradictions that confront industry in adopting these practices?
- Can these challenges be consolidated into research themes, and what pockets of research should be integrated into these themes?

**MONDAY, AUG 21**

## W1.6

**9:30 am – 12:30 pm**
**2504**

CHAIRS
*Sandro Wartzack*
*Thomas Luft*
*Julie Stal-Le Cardinal*

# The new WeDecide App to support collaborative decision making in engineering design

The research activities of the SIG DM contribute to the field of engineering design research particularly in the development of methodologies and tools in order to support the decision maker. The selection of promising ideas or first product concepts represents a decision making process which can be characterized as complex, dynamic and multi-staged process which has multiple and often conflicting objectives as well as involves different groups of decision makers. Due to the complexity of product development process, the task of the decision making needs to be supported not only methodologically but also through the use of IT tools, like an app.

Thus, during last ICED 2015 in Milano, participants of the SIG DM discussed about decision making models as a basis for iDecide App, the new Decision Making App. The main output (e.g. first concepts for an decision making app) and some further research work is summarized in our paper with the title "A Business Model Canvas for idecide – How to design a new decision making app?".

This paper was presented by Thomas Luft at the beginning of our last workshop during the DESIGN 2016. Thereafter, we motivated our participants of the workshop by presenting them the concept of our new smartphone app to support decision making in the context of engineering design. Afterwards, we also presented a first prototype of this decision making app. Then, the participants had the opportunity to use this prototype app in the workshop to find good decisions in three different case studies.

Based on the feedback from the workshop, the app was then further developed by us. We presented this revised app in the workshop during the ICoRD 2017. This further developed app has been applied at the workshop by the participants for different case studies. More information regarding our app has been summarized in the ICED 2017 Paper with the title "A concept and prototype for a new app to support collaborative and multi-criteria decision making in product development". The gained feedback will be used for a significant revision and enhancement of the WeDecide App.

Based on the feedback from the previous workshops, we have continued to develop the prototype of our WeDecide App. We have taken into account many different factors during the improvement of the prototype. At the beginning we will present the current version of the app.

The participants will have the opportunity to use an advanced prototype of the app during the group work of the workshop. Therefore, all participants should have a notebook. The feedback we will get during different group works in the workshop, would be very useful for the further development of the app and for further research within the SIG.

MONDAY, AUG 21

# Risk Identification, Assessment and Mitigation in Design

## W1.7

**9:30 am – 12:30 pm**
**2506**

CHAIR
*Jeffrey Herrmann*

Conducting a design process requires managing many types of uncertainty. One can even view product design and development itself as a risk management process that reduces uncertainty in a structured manner from the step of generating the first product idea to launch of a product in the market. The Risk Management Processes and Methods in Design SIG (Risk SIG) studies design processes through the lens of risk management.

This workshop will focus on three key risk management activities:
1. risk identification (what are the potential problems)
2. risk assessment (how to estimate the likelihood and consequences)
3. risk mitigation (how to reduce the risk).

The workshop will be divided into three discussions (one for each activity). Each discussion will begin with a brief presentation on the activity that reviews the fundamentals and the state-of-the-art in relevant research (including a bibliography). The participants will also contribute their expertise and ideas to the discussion, and each discussion will yield an outline of the critical concepts and techniques relevant to that activity.

Participants will be invited to contribute to revising the outlines and drafting a technical report that documents the workshop results.

MONDAY, AUG 21

## W2.1

**2:00 pm – 5:00 pm**
**Performance Theatre**

CHAIRS
*Pascal Le Masson*
*Akin Kazakçi*
*Eswaran Subrahmanian*

# Design theory and its impact in several disciplines

In 2017, the Design Theory SIG had its 10th workshop — the symposium at ICED 2017 will present an overview and history of design theory.

In the last 10 years, a large variety of models and formalisms have led to significant advances on the deep logic of generativity and unknownness that is central to design.

Design theory deepens the scientific foundations of design and engineering; it bridges the gap with other design professions (such as industrial design) and helps in addressing critical, contemporary innovation issues.

These advancements provide the opportunity to explore new fruitful relations between design research and design theory. Design theory paves the way to extend decision science and supports new perspectives in its growth and organization.

This symposium will be conducted two parts:

**Part 1:** Overview and history of design theory
- Design theory, decision making and problem solving
- Historical roots of systematic design
- Formal models (GDT, AD, CDP, ID, CK)
- Future efforts in design theory

**Part 2:** Researchers will share their experience on the use of Design Theory to contribute to innovative results in different fields including
- Design Theory and cognition
- Design Theory and data science
- Design Theory and project Management
- Design Theory and creativity
- Design Theory and conceptual design methods
- Design Theory and engineering science
- Design Theory and the design of scientific instruments

MONDAY, AUG 21

# Dissemination and Implementation of Sustainable Design Tools

## W2.2

**2:00 pm – 5:00 pm**

**2301**

CHAIR

*Daniela Pigosso*

Many methods and tools have been developed over the last decades to support industry in the development of more sustainable products and services. Covering different phases of the product development process, and sustainability aspects, the developed methods and tools can be used to support a set of different activities: from requirements specification and conceptualization, to screening of candidate solutions and product evaluation. Nevertheless, their uptake by industry is surprisingly low. How to enhance the implementation and dissemination of the Sustainable Design tools?

With this key question in mind, we have structured the workshop in order to:

- provide an overview of existing tools for Sustainable Design, with try-out of selected tools
- discuss success factors, challenges and opportunities for disseminating and implementing sustainable design tools in industry – discuss strategies for ensuring a higher dissemination of Sustainable Design tools in industry

During the workshop, new trends and approaches for Sustainable Design Tools and their uptake by industry will be discussed. By means of hands-on activities and role-play discussions, we will challenge the participants to find new ways for tools development and dissemination, in a way to enhance the impact of Sustainable Design Tools in industry.

Join our Ecodesign SIG group at LinkedIn to be part of an exchange of ideas and a discussion of Sustainable Design before and after the workshop. It is a great opportunity to share knowledge with other scientists worldwide as well as to receive the latest news of the SIG Sustainable Design.

**MONDAY, AUG 21**

## W2.3

**2:00 pm – 5:00 pm**
**2306**

CHAIRS

*Yukari Nagai*
*Amaresh Chakrabarti*
*Gaetano Cascini*

# Developing design creativity research

In this workshop, we discuss how to empower our ability to design toward social innovation. According to the main theme of "how do we develop design creativity research", we will focus on three sub-topics: co-creativity, design creativity metrics, and design creativity with psychology and neuroscience. We invite keynotes to introduce the latest knowledge and issues about those topics.

The Design Creativity SIG will be introduced by the chairs, followed by three keynote speakers on the topics mentioned above. This will be followed by discussions in parallel working groups, report-out and finally integration of these discussions. The workshop will conclude with an announcement regarding the ICDC2018 conference.

MONDAY, AUG 21

# Design Practice SIG Kickoff – Tackling Tough Design Challenges Together

W2.4

**2:00 pm – 5:00 pm**

**2309**

CHAIRS

*Oscar Nespoli*

*Ola Isaksson*

A Special Interest Group (SIG) entitled 'Design Practice' has been formed with the broad objective to capture, study, and communicate authentic, relevant and current design problems in their contexts, from all areas of engineering practice, including industry, government/ healthcare, academia.

More specifically, this SIG aims to:
- Encourage practitioners to challenge researchers
- Encourage academics to understand design practice
- Express the value of design research
- Increase awareness to industry and other sectors of the availability of practical design methods, 'theory' and tools

The workshop will allow interested conference participants to formulate and solve a real design problem sourced from engineering practice, in order to achieve the goals above.

Academics, practitioners, students (PhD, undergraduate) and others can come together to learn from each other, with the catalyst being the design problem and workshop facilitation.

The workshop will be moderated and facilitated by the proposed Design Practice SIG. A call for problems will be issued not unlike the World Open Innovation Conference call, screened and invited presenters prepared for the workshop. Problems may be formatted in the form of a case study with video exhibits. Three or four problems will be available for the workshop attendees to address. The attendees will be in groups mixed by profession (i.e. academics, practitioners, students, other).

## W2.5

**2:00 pm – 5:00 pm**

**2311**

CHAIRS

*Philip Cash*

*Kilian Gericke*

# PhD Forum

The PhD Forum is now in its fifth year and gives PhD students the opportunity to discuss their work, as well as ask for feedback on more specific issues or challenges. This is framed in a group discussion, giving participants' insight into how others are approaching related topics.

Feedback is provided by experienced scholars as well as by the participant's peers. This is all combined into a vibrant workshop where participants can explore their subject and network with other young researchers.

Aims:

- To foster the exchange of ideas and research approaches between younger researchers.
- To provide opportunities for discussing personal research topics, methodologies and potential problems with experienced scholar.
- To enhance networking and collaboration.

# Collaborative Design Education

## w2.6

**2:00 pm – 5:00 pm**

**2314**

CHAIRS

*Ross Brisco*

*Bryan Howell*

Collaborative design education requires students to work together in teams on design projects to tackle problem solving tasks. This pedagogical practice acknowledges that learning is a social activity during which students will be able to improve their engineering design skills. This has many advantages for improving students' academic learning and team working as well as social integration with their peers. However, the nature of the work and how this work is shared can make it difficult to ensure that individual team members learning benefited from participating in this learning environment.

From a pedagogical perspective this raises interesting questions regarding how we should engage our students both in terms of solving problems and the collaborative process, as well as the associated assessment of group project work. To ensure all students benefit we should ask; what might be appropriate learning outcomes and assessments to support students' learning? What range of practices academics could implement in prior and during the collaborative design student's projects?

This cross-SIG workshop will provide a novel forum for Collaborative Design and Design Education researchers to come together and discuss the context of their research, and exchange ideas relating to different experiences preparing and conducting collaborative project based learning classes. The workshop will be beneficial to researchers at all stages of their investigations.

The workshop will last for two hours and will be formatted as follows:

- An introduction will be delivered on the challenges of ensuring fairness in collaborative project work and then groups will be formed to discuss the workshop questions.
- Participants in the workshop will engage in discussion about the benefits and challenges associated with collaborative design education and how we might improve the practice in the future.
- Participants will be asked to share the findings of their group so that all who attend can benefit from the findings and might take away some knowledge to implement in their teaching and research.

This workshop will aim to answer the questions:

- What are the benefits of collaborative project based learning in engineering design education?
- What are the challenges in implementing collaborative design education?
- What pedagogical elements can encourage student's collaborative design process?
- What approaches can be used to support learning from all the participating students on a collaborative engineering design project?

**MONDAY, AUG 21**

## W2.7

**2:00 pm – 5:00 pm**

**2504**

CHAIR

*Kristin Paetzold*

# User in the design process

The HBiD SIG addresses researchers who are studying human behavior in the field of design. Both topics are addressed, the applied processes in industry related fields as well as fundamental research related to this topics. The SIG provides a forum to present and learn about current research in the field. The SIG is focusing on the transfer of research methods from the field of behavioral and cognitive science and discussing the applicability in the context of engineering design.

The SIG aims to support and improve thinking and acting processes in design by:

- developing research approaches to understand human behavior in design based on problem solving and methods based on physiological measurements
- Development and integration of ways us views of human being (as designer as well as user) to explain the product purpose resp. the product functionality

Activities of the SIG HBiD in the past have been on discussing systematic approaches to develop better products based on physiological measurements with main focus on Eye-Tracking. Based on this the identification, description and modelling of use cases, as well as aspects of need finding were picked out.

Starting from the term Human Behavior in Design (HBiD) the human being can take at least two main directions, or two main roles, designer or user but often there is a mutual ignorance between user and designer. One of the main findings in the work of the SIG HBiD is, that it needs a kind of transformation process to convert user needs and wishes in goal-systems for product development respectively into functionality, requirements and technical parameters. Based on these results the focus of the upcoming research topics will be discussed in the next future of the SiG:

- Analysis of the main influences in the relationship of designer and user which are relevant to align the transformation processes between these two groups and how can a mutual or shared understanding be supported
- How can we build references to understand different users in using products

For the next two years we will focus on how the information is generated using these methods, how the information can be integrated in the design process and how successful approaches of designers can be transferred to other designers.

MONDAY, AUG 21

# A Robust Design Research Landscape – Clarifying the potential of RD principles and indicators

## W2.8

**2:00 pm – 5:00 pm**

**2506**

CHAIRS

*Tobias Eifler*

*Alexander Aschenbrenner*

This year's SIG workshop aims at creating a landscape of research in Robust Design (RD) within the Design Society (including related topic areas such as Design for Reliability, Tolerancing, Embodiment Design, etc.) in order to initiate a discussion on the value/limits of early stage robustness indicators, as well as on future topics and SIG activities in research and education.

Traditionally focusing on an improvement of robustness via (computational) expensive virtual/physical experiments and the corresponding statistical analyses, RD has been often criticized for not offering enough guidance and support in early phases of development. In a new direction, the RD SIG would therefore like to bring RD thinking and research into earlier stages of development, including more pragmatic tools, which are also applicable in short iteration cycles. The SIG's key objectives are to:

- propose and debate a coherent RD toolbox as well as a Robust Design process.
- test out robust design tools, methods and theory on real case studies in a workshop format.
- stimulate a discussion on utility and/or potential limits of early RD consideration (as Robustness is, beyond doubt, in many cases influenced by embodiment rather than conceptual decisions).

In line with these overall objectives, this year's workshop focuses on an overview of Robust Design (related) research within the Design Society, and raises the question of suitable RD principles and indicators for an early evaluation of product robustness. Built around research on the importance/value of Robustness indicators, such as part count, functional couplings and contradictions, the attendees will be given an active role in guided tutorials and will be challenged to analyse/evaluate the robustness of a case example.

Given the organisers role as interim chairs of the RD SIG, this year's RD Workshop is structured into two subsequent parts.

1. After a short introduction, the participants are provided with an overview of RD related research topics in the Design Society, (DTU, FAU, etc., all attendees are invited to submit additional contributions!) including an introduction to Robustness indicators such as part count, functional couplings and contradictions metric. Afterwards, the attendees will be given an active role in analysing the robustness of a case example to discuss the corresponding benefits/limits of available methods, principles and indicators.
2. Based on this hands-on experience, the second part of the workshop is then dedicated to summarise the current RD research landscape within the Design Society and to discuss potential new directions for future RD research as well as future activities and the set-up of the RD SIG.

# ICED17 Opening Ceremony & Keynote

**5:15 pm – 6:45 pm Great Hall & Foyer**

**James Olson**
Dean, Faculty of Applied Science
The University of British Columbia

**Dorian Marjanović**
President of the Design Society

**Mike Van der Loos**
Conference Chair

**Anja Maier**
Programme Committee Chair

**Mike Van der Loos**
Introduction of the Keynote Speaker

**Peter Busby**
Opening Keynote Lecture

# Welcome Reception

**6:45 pm – 8:45 pm Great Hall & Foyer**

Join us at the Welcome Reception to kick-off the conference! There will be delicious food and drinks and plenty of time to mingle.

# NOTES

**MONDAY, AUG 21**

**6:00 pm – 6:45 pm**
**Great Hall & Foyer**

CHAIR
*Mike Van der Loos*

# Peter Busby

## C.M., FRAIC, MAIBC, LEED® Fellow; Managing Director, Principal: Perkins+Will

**Biography:** Internationally recognized for his contributions to architecture and planning, Peter Busby's award-winning portfolio embodies his philosophy of social responsibility and commitment to sustainable design. Since opening his Vancouver practice in 1984, Peter's body of work has gained a reputation for design excellence and innovation, becoming a powerful catalyst in the growth of the green architecture movement in North America and abroad. After merging his firm with Perkins+Will in 2004, Peter became a driving force across the company, compelling its industry-leading sustainable design initiatives. In 2012, Peter relocated to be the Managing Director of Perkins+Will's San Francisco office, bringing his focus on sustainable communities and regenerative design to all of Perkins+Will's West Coast offices, directing teams working on projects locally and internationally. Peter's dedication to design advocacy remains steadfast; he lectures frequently at academic institutions and professional engagements around the world. Peter's latest book, published in spring 2015, is titled Busby: Architecture's New Edges.

# Exploring Architecture's New Edges

Rapid technological advances and meaningful cultural shifts have brought architects into a new era of sustainable design.

In this presentation Peter Busby, deep green architect, broadens the boundaries of the sustainability discussion to explore "Architecture's New Edges," a more inclusive understanding of high-performance design.

**6:00 pm – 6:45 pm**
**Great Hall & Foyer**

CHAIR

*Mike Van der Loos*

Through case studies drawn from his latest publication, *Busby: Architecture's New Edges*, Peter leads an exploration of architecture's new boundaries. These "edges" are the new facets of resource-sensitive design that go beyond traditional conservation measures to highlight the opportunities to create vibrant communities, regenerate natural ecosystems, and foster a culture of design innovation.

# TUESDAY AT A GLANCE

| Location | 8:30 am – 10:00 am | 10:30 am – 11:15 am | 11:30 am – 12:30 pm | 2:00 pm – 3:00 pm | 3:15 pm – 4:15 pm | 4:30 pm – 5:30 pm | 5:45 pm – 6:30 pm | 6:45 pm – 8:45 pm |
|---|---|---|---|---|---|---|---|---|
| Great Hall & Foyer | | **Keynote Yukari Nagai** | | | | | **Keynote P. John Clarkson** | **Young Members Event** |
| Performance Theatre | **P1.1:** Design for Additive Manufacturing 1 | | **D1.1:** Design for Additive Manufacturing 2 | | | | | |
| Art Gallery | **P1.2:** Creativity Strategies | | **D1.2:** Creativity Methods | **D2.2:** Co-Creation | **D3.2:** Collaborative Design 1 | **D4.2:** Collaborative Design 2 | | |
| 2301 | **P1.3:** Design Process Analysis | | **D1.3:** Design Processes | **D2.3:** Design Theories and Frameworks | **D3.3:** Data-Driven Design Approaches | **D4.3:** Cyber-physical systems and Digitalization | | |
| 2306 / 2309 | **P1.4:** Strategic Management and Design | | **D1.4:** Project Management and Design | **D2.4:** Complex Product Development | **D3.4:** Organizational Process and Management in Design | **D4.4:** Agile Design Approaches | | |
| 2311 | **P1.5:** Research Applications – User-Focused Design | | **D1.5:** Methods for Early Design Stages | **D2.5:** Function-Oriented Modeling and QFD Applications | **D3.5:** Design Representations | **D4.5:** Computational Conceptual Design | | |
| 2314 | **P1.6:** Resource-Limited Societies: Frameworks | | **D1.6:** Resource-Limited Societies: Applications | **D2.6:** Design for Emotion | **D3.6:** Experience Design | **D4.6:** Design Ergonomics | | |
| 2504 | **P1.7:** Systems Engineering | | **D1.7:** New Approaches in Systems Engineering | **D2.7:** Model-Based Systems Engineering (MBSE) | **D3.7:** Product Service Systems 1 | **D4.7:** Product Service Systems 2 | | |
| 2506 | **P1.8:** Information and Knowledge Management – Approaches | | **D1.8:** Information and Knowledge Management – Applications | **D2.8:** Knowledge Intensive Design | **D3.8:** Analysis and Capture of Design Rationale | **D4.8:** Reuse and Classification of Information and Knowledge | | |
| 2514 | | | | **D2.9:** Improving Learning Experience | **D3.9:** Virtual Design Teams/Project-Based Learning | **D4.9:** Design Education – Assessment Tools | | |
| Atrium Lower Level | | | | | | **Student Design Fair** | | |



**Legend:** Plenary Sessions; Podium Sessions; Discussion Sessions; Workshops; Design Society Event; Special and Social Events

# Design for Additive Manufacturing 1

TUESDAY, AUG 22

P1.1

8:30 am – 10:00 am
Performance Theatre

CHAIR
*Georges Fadel*

## Assessing the performance of additive manufacturing applications

**Daniel-Alexander Türk[1], Filippo Fontana[1], Fabian Rüegg[1], Rajan Joshua Gill[2], Mirko Meboldt[1]**
[1]ETH Zurich, Institute of Design, Materials, and Fabrication, Switzerland; [2]ETH Zurich, Institute for Dynamic Systems and Control, Switzerland

Additive manufacturing offers vast potentials in the development of competitive products. As technological readiness level increases and novel software solutions arise, engineers can fully exploit the design advantages AM has to offer, namely design freedom. To successfully implement AM products in industry, decision makers must see a clear advantage in producing a design additively, that is a trade-off of AM costs and benefits. AM parts can improve product performance, e.g. weight savings, or improve processing, e.g. manufacturing objectives. AM has the potential to create value on both dimensions, but many studies consider exclusively either the product- or the process performance by assessing the costs of an isolated part. To close this gap, this work presents a framework for evaluating the value of additive and conventionally manufactured products by comparing the product-related to the process-related performance. The framework is applied to a case study consisting of a flying vehicle with an annular wing. Results show that AM products can be competitive if design advantages are used to leverage both, the product- and the process-related performance.

## A framework for designing end use products for direct manufacturing using additive manufacturing technologies

**Zicheng Zhu[1], Patrick Pradel[2], Richard Bibb[2], James Moultrie[1]**
[1]University of Cambridge, United Kingdom; [2]Loughborough University, United Kingdom

Additive Manufacturing (AM) has enjoyed rapid development over the past decade and improved process capability brings attractive potentials for direct manufacturing of end use components and products. This opens a new avenue for designers to design a much wider variety of products in a more time and cost effective way. A new research field — design for AM — is emerging, exploring new design principles, methods and rules. However, the vast majority of the methods and rules presented to date focus on the feature level, which are specifically applied at the detail design stage to ensure the manufacturability of the features for a given AM process. This does not enable designers to fully benefit from unique AM capabilities. Therefore, this paper proposes a framework that holistically considers design freedoms, AM advantages and limitations for designing end use products, providing guidance throughout process selection and different design stages. The major considerations in the design process are addressed, showing effective ways of making use of AM. Process characteristics, design rules and implications of using AM on product shape, quality and economic viability are also described.

# Design for Additive Manufacturing 1, cont'd

**TUESDAY, AUG 22**

**P1.1**

**8:30 am – 10:00 am**
**Performance Theatre**

CHAIR
*Georges Fadel*

### Realisation of self-replicating production resources through tight coupling of manufacturing technologies

**Mark Goudswaard, Ben Hicks, Aydin Nassehi, David Mathias**
University of Bristol, United Kingdom

The purpose of this paper is to explore the implications of the tight coupling of manufacturing technologies and the extent to which it can facilitate the realisation of self-replicating production resources. This was explored through a three year programme of development projects where multiple 3D printing and milling machines were designed, built and evaluated with respect to their manufacturing capabilities and self-replicability. It was found that this tight coupling of processes increased functionality, self-replicability and consequentially utility of these machines. The project specifications were used to identify conflicting requirements and qualitatively assess their interrelationships. Further work will see this expanded into a quantitative model to identify where design effort should be focused and also theoretical limits of self-replicability. The principal social implication of this work is that non-autotrophic self-replication, upon which the RepRap philosophy is based, is largely dependent upon locally available technology and resources. Self-replication therefore becomes an affordance of not solely machine but also of environment.

### Towards a top-down design methodology for 4D printing

**Germain Sossou, Frédéric Demoly, Ghislain Montavon, Samuel Gomes**
University of Burgundy, France

An innovative trend promoted by the unique capabilities of additive manufacturing techniques is about the 4D Printing concept. It is the process by which parts embodying smart materials are printed, they are therefore able to react to changes in their environment. As a new way of thinking and manufacturing method, few is known about how to systematically bring such smart products ideas into reality. This paper discusses a general framework for designing 4D printed products. It delineates the research effort to be made so that designers are sufficiently empowered to design this new type of products. A methodology facilitating the consideration of smart materials is considered.

# Creativity Strategies

TUESDAY, AUG 22

P1.2

8:30 am – 10:00 am
Art Gallery

CHAIR
*Carlos Coimbra Cardoso*

## Creativity as a way to innovate successfully

**Agnes Guenther[1], Boris Eisenbart[1], Andy Dong[2]**
[1]Delft University of Technology, The Netherlands; [2]The University of Sydney, Australia

Selecting innovative design concepts for further development entails decision making under conditions of sometimes extreme uncertainty pertaining to technical feasibility and market potential. In such situations, decision makers all too often become risk averse and reliant on known metrics that are inherently based on deductive and inductive logics. In prior research, however, good decision making on innovation has been linked with the complementary use of another form of logic: abductive reasoning. Abductive reasoning changes the mind-set of decision makers to become intrinsically forward thinking and explorative towards innovation opportunity. In this paper, we present an experimental study suggesting that the cognitive, creative capabilities of humans correlate positively with their use of abductive reasoning in decision making. We are further able to show that a higher level of abductive reasoning leads to significantly better, i.e. more accurate, decisions in selecting successful innovation concepts. These findings have strong implications for companies seeking to improve their innovative performance, specifically, how and by whom decisions on innovation should be made.

## Three driven approaches to combinational creativity

**Ji Han, Dongmyung Park, Feng Shi, Liuqing Chen, Peter R. N. Childs**
Imperial College London, United Kingdom

Creativity is a crucial element of design, and a human attribute that has aroused significant attention. However, few studies have focused on the factors and motivations that drive creativity. The aim of the study is to investigate the driving forces behind combinational creativity for developing original creative products. We propose three driven approaches to combinational creativity, the problem-driven approach, the common-driven approach, and the inspiration-driven approach, based on previous research projects on design process, design strategy, and design cognition. A test involving two-hundred practical products has been conducted to validate the three approaches by means of expert evaluation. The test results have indicated the validity of the three driven approaches. The three approaches proposed in this study have provided an understanding of how combinational creativity is driven in design, which could lead to a better comprehension of human creativity in design. The study enables indication that the three approaches can be applied by designers to aid in the production of creative designs for and in resource-limited societies.

# Creativity Strategies, cont'd

**TUESDAY, AUG 22**

**P1.2**

**8:30 am – 10:00 am**
**Art Gallery**

CHAIR
*Carlos Coimbra Cardoso*

### Business game and its relationship with creativity: A systematic literature review

**Marcela Rosa, Mario González, Ana Cláudia Costa de Araújo, George Santiago**
UFRN Federal University of Rio Grande do Norte, Brazil

This paper aims to analyze the relationship between the development of creative potential and business game. For this, we carried out a systematic bibliographical review of 157 articles hosted on the Scopus and Web of Science platforms and published between 1970 and 2016. The results present in the same scope the analysis of publications with different research approaches on the theme, connecting authors' studies which, until then, had not been interconnected; The use of business games as a positive return factor for the environment; The intrinsic relationship between creativity techniques and business games. We also found business games main objectives are the encouragement of collaboration skills development, the elaboration of strategic plans and the simulation of specific realities. Regarding the development of creative potential, the business games analyzed in the articles consider it as a secondary factor that manifests itself during the game.

### Heterogeneous engineering: Essential bridge implementing creative design

**Smulders, Frido, Frédéric Demoly, Ghislain Montavon, Samuel Gomes**
Delft University of Technology, The Netherlands

This paper connects design creativity to engineering activities as means for smooth implementation of creative concepts. It applies C-K design theory and the IDER-innovation model as lenses to investigate three case studies. The results point to engineering activities as operators to transform the undecidable concepts in the C-space to objects with a logical status in the K-space. Engineering (E) knowledge as validated objects in the K-space supports the transformation process. If existing E-knowledge is sufficient, then this resembles single loop learning. If concepts in the C-space are too different from earlier concepts, then new E-knowledge needs to be developed which resembles double loop learning. The research for developing new E-knowledge unfolds in a similar fashion. Tentative theoretical insights in the C-space are 'engineered' by validated research methods from the K-space. Further research needs to address the complexity of real-life socio-interactive situations. The paper shows that the engineering act in a heterogeneous manner is at least of equal importance for innovation as the creative design act.

### The best of three worlds – The creation of InnoDev a software development approach that integrates Design Thinking, Scrum and Lean Startup

**Franziska Dobrigkeit**[1], **Danielly de Paula**[2]
[1]Hasso-Plattner-Institut, Germany; [2]National University of Ireland Galway, Ireland

Agile development has been important to software engineering for decades. However, limitations in existing agile methods such as Scrum and eXtreme Programming still persist and have given rise to efforts aiming to integrate agile software development with other iterative and innovative practices such as Deisgn Thinking or Lean Startup. This paper aims to identify best practices and valuable proposals from such integration efforts, in order to create a new process model, which aggregates the core elements and key aspects of the former works. The research is based on a literature review and a cross-case analysis of two already existing models, MoIT and DT@Scrum. Relevant aspects of both models are presented and discussed in relation to other relevant research in this area. The analysis shows that an integration of Scrum practices with Design Thinking and Lean Startup could be favorable. Furthermore, the combined process model InnoDev is presented.

# Design Process Analysis

**TUESDAY, AUG 22**

P1.3

**8:30 am – 10:00 am**

**2301**

CHAIR

*Eric Blanco*

## A computational approach to expose conversation dynamics in engineering design activities

**Andreas Wulvik[1], Axel Menning[2], Martin Steinert[1]**

[1]Norwegian University of Science and Technology, Norway; [2]Hasso-Plattner-Institut, Germany

This paper presents work in the field of using computational tools to expose conversation dynamics in design activities. We are considering quantitatively how designers engage in design conversations as opposed to the semantic content they provide to the discussion. The latter has been explored extensively through Protocol Analysis and Conversation Analysis, while the former is a relatively new field of study. This work presents the process of applying Temporal Static Visualisations to transcript data. In addition application of the approach is shown in a case study consisting of two sessions comprising 300 lines of text each. The results of the analysis reflect the task structure of the sessions.

## Using data- and network science to reveal iterations and phase-transitions in the design process

**Sebastiano Piccolo[1], Sune Lehmann[2], Anja Maier[1]**

[1]Technical University of Denmark, DTU Management Engineering, Denmark; [2]Technical University of Denmark, DTU Compute, Denmark

Understanding the role of iterations is a prevalent topic in both design research and design practice. Furthermore, the increasing amount of data produced and stored by companies leaves traces and enables the application of data science to learn from past design processes. In this article, we analyse a document-log to show the temporal evolution of a real design process of a power plant by using exploratory data analysis and network analysis. We show how the iterative nature of the design process is reflected in archival data and how one might re-construct the design process, involving iterations between many parties, including the client, external consultants, suppliers, and designers. We also show how people use different representations during the design process and how this is associated with a design phase-transition in the process. Finally, we relate our findings with the literature on iterations and discuss implications for research and practice with application to project management and process modelling.

### Eliciting configuration design heuristics with hidden Markov models

**Christopher McComb, Jonathan Cagan, Kenneth Kotovsky**
Carnegie Mellon University, United States of America

Configuration design problems, characterized by the selection and assembly of components into a final desired solution, are common in engineering design. Although a variety of theoretical approaches to solving configuration design problems have been developed, little research has been conducted to observe how humans naturally attempt to solve such problems. This work mines the data from a cognitive study of configuration design to extract helpful design heuristics. The extraction of these heuristics is automated through the application of hidden Markov models. Results show that, for a truss configuration problem, designers proceed through four procedural states in solving configuration design problems, transitioning from topology design to shape and parameter design. High-performing designers are distinguished by their opportunistic tuning of parameters early in the process, enabling a heuristic search process similar to the A* search algorithm.

### Modelling the design parameters dynamics with Petri nets

**Jasmin Juranic[1], Neven Pavkovic[1], Thomas Naumann[2], Dorian Marjanović[1]**
[1]University of Zagreb, Croatia; [2]Daimler AG, Germany

The aim of the presented research is to develop methods and tools which would enable consistent dynamic updating and propagation of updated design information in teamwork in a manner that will not generate additional tasks for designers. The research has been focused on management of design parameters, especially to issues that occur in collaborative teamwork when several designers work on a group of coupled parameters. An example of a complex assembly design process has been analysed to demonstrate the suitability of Coloured Petri nets for modelling dynamics of design parameters. Based on initial results authors believe that it is worthwhile to continue with the approach where repetitive patterns of communication situations and parts of the design process will be extracted and modelled with Coloured Petri nets in form of generic templates. The implementation of the proposed model should be able to suggest and approve the automatic launch of small parts (sequences) of the process with the aim of gradual automatization of recognised information processing and information transferring activities.

# Design Process Analysis, cont'd

**TUESDAY, AUG 22**

P1.3

**8:30 am – 10:00 am**

**2301**

CHAIR

*Eric Blanco*

## Using clustering algorithms to identify subproblems in design processes

**Michael Morency[1], Azrah Anparasan[2], Jeffrey Herrmann[1], Erica Gralla[2]**

[1]University of Maryland, United States of America; [2]George Washington University, United States of America

Designers work in teams to design complex systems. They separate the design problem into subproblems and solve the smaller, more manageable subproblems. Because this affects the overall quality of their design, it is important to understand how teams decompose system design problems, which will ultimately enable future research on how to design better design processes. We studied teams of experts solving two different facility design problems. We developed a novel approach that combines qualitative and quantitative techniques. It records a team's discussion, identifies the design variables using qualitative coding techniques, and groups these variables into subproblems. A subproblem is a set of variables that are considered together. We evaluated four clustering algorithms that group the coded variables into subproblems. This paper discusses the data collection, the clustering algorithms, and the evaluation techniques. The the algorithms generated similar but not identical clusters, and no algorithm's clusters consistently out-performed the others on quantitative measures of cluster quality. The clusters do provide insights into the subproblems that the design team solved.

# Strategic Management and Design

TUESDAY, AUG 22

P1.4

8:30 am – 10:00 am
2306/2309

CHAIR
*Anna Öhrwall Rönnbäck*

### Connecting strategy and execution in global R&D

**Federico Sbernini, Nicola Granini, Zaza Nadja Lee Hansen**
Technical University of Denmark, Denmark

The paper investigates the relationship between global product development strategic decisions, which include outsourcing, offshoring practices as well as strategic alliances, and their impact on the day-to-day business in a global and open innovation context. By adopting an exploratory inductive research, founded on core literature in the area and using empirical data from four companies in different industries, the study intends to understand the interconnection between the shift toward a global R&D strategy, and the dependent changes at the operational and managerial level. The series of changes in the innovation network are strictly connected with the company's source of competitive advantage, their internationalisation drivers, the internationalisation practices adopted, and the series of organisational capabilities needed to support the internationalization as well as externalization of innovation sources.

### Lean assessment and transformation strategies in product development: A longitudinal study

**Torgeir Welo, Geir Ringen**
Norwegian University of Science and Technology, Norway

Maintaining simultaneous focus on efficiency and effectiveness is a difficult yet necessary strategy to deliver commercially viable products in today's global world of competition. As a result, manufacturing companies aim to shift from a modus of operandi dominated by removing waste at the factory floor to leveraging value creation in all direct or indirect activities within the product value stream. One of the most popular strategies in this regard is to apply the Lean concept in product development (PD). This paper researches to which degree PD practices in a Scandinavian design and manufacturing company comply with Lean in its own context. A capability maturity tool has been developed, piloted and followed-up in the case company to identify gaps and improvement potentials. A capability maturity assessment has been conducted twice, with a time span of seven years. This longitudinal study shows that the PD team rate their performance surprisingly identical from 2009 to 2016, reflecting that an increased Lean PD awareness has brought new challenges to the surface — ones that were hidden by more obvious issues in the past.

# Strategic Management and Design, cont'd

**TUESDAY, AUG 22**

## P1.4

**8:30 am – 10:00 am**
**2306/2309**

CHAIR
*Anna Öhrwall Rönnbäck*

### Fitting squares into round holes: Enabling innovation, creativity, and entrepreneurship through corporate Fab Labs

**Matt Fuller**
Université Paris-Dauphine, France

Acting on personal convictions that a large automobile maker's ability to innovate was too closed-off and poorly suited for breakthrough innovation, a small team at the main R&D campus decided in late 2013 to create a corporate Fab Lab. Building upon what started as a MIT outreach program called Fab Labs, these spaces, present in over twenty large multi-national firms since 2009, are seen by their creators as an opportunity to increase employees' ability to innovate. Although innovation is a strategic priority in most firms, the creators of these spaces encountered substantial institutional resistance early on due to the different nature of Fab Labs, or in their words trying to fit a "square in a round hole." This paper presents corporate Fab Labs to scientific literature. It proposes a theoretical foundation building on established fields of research in managing innovation capabilities and institutional entrepreneurship. Empirical data collected from the founders of ten Labs in France, Japan, and South Korea is analyzed to test this framework. Findings include unique contributions made by Fab Labs to a firm's innovation capabilities and proposals of complementary research paths.

### Improving exploration capability by interacting with start-ups

**Lennart Sebastian Buck, Susanne Nilsson, Sofia Ritzén**
KTH Royal Institute of Technology, Sweden

This paper describes and analyses an exploration-capability model that is currently being introduced in an automotive OEM. An increasingly high environmental dynamism as well as a new level of competition in the automotive industry call for an improved capability to explore and realise more radical innovations to complement the established OEMs exploitation skills and present focus on incremental innovation. The model that is target for the study offers the employees in the OEM five different forms of interactions with start-ups as a way to develop the capability to explore. The different forms of interaction are found to make use of different modes of balancing ambidexterity and to introduce different means to improve and establish individual, entrepreneurial skills, as well as influence the innovation culture of the OEM. The paper lays the foundation for future research by describing how and why an OEM is designing a new model to develop its exploration capability through interacting with start-ups by analysing the model in relation to theory, and presenting propositions that will act as a baseline for further studies.

## Proposition of a tools selection method to support and favour innovation for a manufacturing company

**Pauline Lacom[1,2], Florence Bazzaro[1], Jean-Claude Sagot[1]**

[1]Université Technologie Belfort Montbéliard, France; [2]Lisi Automotive, France

Nowadays, companies have to innovate in order to cope with competition, and to ensure the durability of their activities. Innovation is more and more perceived as a result. Users can be involved in this process to diversify the types of innovation. However, it can be difficult for companies which are novice at the subject to set-up an innovation process. This is especially true for manufacturing companies operating on a B2B market. As far as we know, the specific features of innovation in such companies have not been studied a lot. In this context, we will try in our paper to define which are the first steps of the innovation process that could be set up by such companies. Then, we will try to determine tools, techniques and/or methods for each step of our innovation process. After that, we will do a proposition of a tools selection method, to determine the best tools for each step. This selection of best tools will be applied in a manufacturing company operating on a B2B market. A study in a manufacturing company enables to validate the pertinence of our proposition.

**TUESDAY, AUG 22**

P1.5

**8:30 am – 10:00 am**

**2311**

CHAIR

*Kristin Paetzold*

# Research Applications – User-Focused Design

### A design case study: Transferring design processes and prototyping principles into industry for rapid response and user impact

**Karen Hui En Sng, Sujithra Raviselvam, David Anderson, Lucienne Blessing, Bradley Adam Camburn, Kristin Wood**

Singapore University of Technology and Design, Singapore

Process models and design principles play a major role in the development of a product. With every process and principle having their own benefits, deciding the right combination is a challenging task. In this case study, existing design methods and design principles were tailored through a Design Innovation (DI) process to achieve rapid response system critical for project completion. This paper explores in detail how the DI process was formally made instrumental for an industrial development. Pohlmeyer's ContinUE model was used as a systematic guide on the critical stages along the DI process to capture user needs. The success of the project and implementation of the DI process was tested via the user satisfaction recorded towards the end of the process. With a total of 326 target users, the analysis showed that the diverse user needs identification methods results in different insights. Design theory and other methodologies such as prototyping principles were also demonstrated to be valuable and practical in developing and delivering design solutions. The combination of design theories and process can lead to successful implementation at a industrial level.

### Design of human-powered hybrid electric-power shovel for deep excavation

**Naoki Matsuura, Yuji Hatano, Teppei Iizuka, Tatsuro Fujisawa, Shigeru Wesugi**

Waseda University, Japan

There are still a lot of high-load physical works which can't be substituted by machine, such as clearing snow, removing sediment under floor and volcanic ashes, where a large-sized machine cannot be used or where human resources and electric power were short on occasions of emergency. Therefore, authors address to design a device for those situation. Authors focus on unique approach of "human-powered hybrid" method combining merits of human-power and machine-power. In this paper, we made this approach clear as a design method, which suggest 3 policies: choose a heavy equipment suitable to targeted work, apply human-power to each work process, and consider usability. And we apply these policies to new device for removing earth-and-sand under floor as a specific situation. Then we designed and constructed it that can excavate while switching human-power or machine-power. Users can operate it semi-automatically without pre-training, and can operate it in safety not to fall over by incorporating mechanical and electrical structures. Finally, we conducted performance experiments and confirmed that the device could work efficiently not only with human-power but also with machine-power.

### Improving inclusive design practice – transferring knowledge from sports design practice

**Nicky Wilson[1], Avril Thomson[1], Philip Riches[2]**

[1]University of Strathclyde, Design, Manufacture and Engineering Management, United Kingdom; [2]University of Strathclyde, Department of Biomedical Engineering, United Kingdom

Despite the existence of many design tools to educate and assist the designer in implementing inclusive design, there is still a lack of inclusive design uptake in industry. The client is often cited as a barrier to inclusive design uptake, therefore it is important that this issue is addressed if inclusive design uptake is to be increased. Sports design is a highly user focused discipline, therefore it is anticipated that there is scope for inclusive design to learn from this user centred discipline. This research aims to investigate the potential of applying the sports design process within an inclusive design context to increase inclusive design uptake in industry. The paper reports on a practical study, which interviewed practising industry designers and designers from a UK centre specialising in inclusive design. The outcome is a set of recommendations from designers on how the sports design process model can be developed to facilitate inclusive design uptake in industry.

### The frame network of interdisciplinary stakeholder compositions in the early phases of new product development

**Alexander Kjær Andersen, Nadiim Nafei, Michael Planck, Louise Møller Nielsen**

Aalborg University, Denmark

New Product Development (NPD) projects have continually become more complex over the years and now involve a diverse range of stakeholders, who have different disciplinary backgrounds, values, objectives, and experience. This makes them create different 'frames', which may represent conflicting perspectives. This might create challenges or bring the process to a standstill ultimately wasting resources. By analysing case studies from three different Scandinavian product development companies: LEGO, LEO Pharma, and Zenit Design, this paper investigates the characteristics of the framing process in the early phases of NPD projects involving interdisciplinary stakeholders in organisational settings. The study indicates that stakeholders create isolated aspired values and working principles and from these form a 'network' of 'partial frames' before connecting them into 'fully defined frames'. The study also identifies core activities and events of the framing process and propose a model describing an iterative cycle of six phases that stakeholders in New Product Development go through, which we in this article call 'The Interdisciplinary Framing Loop'.

# Research Applications – User-Focused Design, cont'd

**TUESDAY, AUG 22**

## P1.5

**8:30 am – 10:00 am**

**2311**

CHAIR

*Kristin Paetzold*

### Value-driven engineering design: Lessons learned from the road construction equipment industry

**Marco Bertoni[1], Massimo Panarotto[1,2], Pontus Jonsson[3]**

[1]Blekinge Institute of Technology, Sweden; [2]Chalmers University of Technology, Sweden; [3]Dynapac Compaction Equipment AB, Sweden

Value models, in form of economical optimization functions, are often proposed to frontload engineering design activities. However, literature argues that, when qualitative data and assumptions prevail, a qualitative assessment of the 'goodness' of a design is preferable against a numerical (and monetary-based) encoding of preferences. This paper explores how a model-based approach can support deliberation about value in cross-functional design teams. Emerging from case studies in the road compaction equipment industry, the paper analyzes preferences for value modelling support when it comes to iteratively translate customer desires into terms meaningful for engineering design decision-making. It further prescribes a framework for value-driven engineering design that considers the need to update the value model definition as far as new information become available in the process, moving from qualitative to quantitative. The findings highlight the role the proposed chain of value models plays in terms of providing a shared reference to stimulate value discussions across functions and organizational roles, which is something that does not naturally happen in the organization today.

# Resource-Limited Societies: Frameworks

TUESDAY, AUG 22

P1.6

8:30 am – 10:00 am

2314

CHAIR

*Mike Van der Loos*

## Economic development as design: Insight and guidance through the PSI framework

**Eswaran Subrahmanian[1], Claudia Eckert[2], Christopher McMahon[3,4], Yoram Reich[5]**

[1]Carnegie Mellon University, United States of America; [2]The Open University, United Kingdom; [3]University of Bristol, United Kingdom; [4]Technical University of Denmark, Denmark; [5]Tel Aviv University, Israel

Economic development is aimed at improving the lives of people in the developing world, and needs to be carried out with design at its heart, but this has often not been the case. This paper first reviews dominant approaches to economic development including the use of subsidies or the creation of markets and demand and the testing of initiatives using randomized control trials. It then introduces 'development engineering' as a representative engineering design approach to engineering and technology in development before presenting the view that successful development needs to involve continual learning through innovation in context. The PSI (problem social institutional) framework is presented as a basis for guiding such development as a design activity, and its application is illustrated using examples from India of the unsuccessful introduction of new cooking stoves and then both successful and unsuccessful approaches to rural electrification. A 2-level approach to PSI is taken, in which the lower level represents daily operation of communities and the 2nd level represents the development project including addressing misalignments between the different PSI spaces and levels.

## Design for resource-limited societies: Informational behaviour of designers

**Santosh Jagtap[1], Andreas Larsson[1], Anders Warell[2]**

[1]Blekinge Institute of Technology, Sweden; [2]Lund University, Sweden

There is a sharp contrast between High Resource Settings (HRSs), commonly seen in developed countries and Low Resource Settings (LRSs), typically found in the marginalised sections of societies around the world. Product design for LRSs is crucial to satisfy unmet or under-served needs of the people living in LRSs. Supporting designers to develop successful products for LRSs demands developing an in-depth understanding of their design process, including their informational behaviour. In this research, using think aloud protocol analysis, we compared the designers' informational behaviour in designing products for LRSs and HRSs, where HRSs is considered a baseline. The findings indicate that designing products for LRSs is more information intensive, and that it influences the informational activities of designers, thus indicating potential impact of a resource-setting on the way designers deal with information.

# Resource-Limited Societies: Frameworks

**TUESDAY, AUG 22**

## P1.6

**8:30 am – 10:00 am**

**2314**

CHAIR

*Mike Van der Loos*

### Co-design in Zambia – an examination of design outcomes

**Eric Reynolds Brubaker[1], Carl Jensen[2], Sunday Silungwe[2], Sheri D. Sheppard[1], Maria Yang[3]**

[1]Stanford University, United States of America; [2]Good Nature Agro, United States of America; [3]Massachusetts Institute of Technology, United States of America

After decades of limited success "designing for the developing world", it is clear that Base of the Pyramid (BoP) markets are complex and face unique challenges, such as large geographical distances between designers and users as well as poor understanding of user/customer needs. Participatory design has emerged as a strategy to improve user/customer understanding in BoP markets in hopes that it may lead to improved design outcomes. This study aims to better understand the relationship between co-design and related participatory design approaches with design outcomes. An experiment was conducted in rural Zambia in partnership with an agricultural enterprise and also at a university in the USA, and the resulting design outcomes compared with the level of end-user/customer participation. Concepts rated with the highest likelihood of adoption were generated by teams composed entirely of end-users/customers, however these were also among the least creative concepts. Teams that employed user-centered design produced concepts with mixed results, and teams that followed a co-design approach produced concepts with the greatest balance of creativity, feasibility, and meeting the need.

### Using TheDesignExchange as a knowledge platform for human-centered design-driven global development

**Julia Kramer, Danielle Poreh, Alice Agogino**

UC Berkeley, United States of America

Human-centered design, for its value in allowing design practitioners to deeply engage with and understand the manifold needs of their end-users, is often invoked to tackle challenges of poverty and development around the world. TheDesignExchange is the largest comprehensive database of human-centered design methods and has been built to support designers working in a broad range of project and topic areas. Given the burgeoning interest in leveraging human-centered design methods to address challenges in resource-limited settings, theDesignExchange has begun building out case studies to support a network of designers around the world in addressing complex challenges of poverty and development using a human-centered design process.

## A tool for assessing customers' barriers for consuming remanufactured products

**Lars Almefelt, Oskar Rexfelt**

Chalmers University of Technology, Sweden

One opportunity to address our world's environmental challenges is to change our patterns of consumption towards more sustainable ones, e.g. buying used products, renting products, and joining pools for co-consumption. All of these patterns share at least one point of departure: They imply that people use products that other people have used before. In this context, remanufacturing is a particular opportunity. In principle, remanufacturing means that a used product is industrially renovated in order to assure quality. However, remanufacturing is still just a niche, and the established pattern of consumption and production — involving new products — is very dominant. Reflecting this, there is a need to better understand how to gain acceptance for remanufactured products, and in particular to understand customers' barriers and drivers for consuming used and remanufactured products. Reflecting this background, the tool presented in this paper is aiming to support remanufacturing organisations to get a better understanding about the customers and their possible ways of reasoning when they approach an offer based on a remanufactured product.

# Systems Engineering

**TUESDAY, AUG 22**

**P1.7**

**8:30 am – 10:00 am**

**2504**

CHAIR

*François Patou*

## Estimating the impact of systems engineers on systems design processes

**Arianne Collopy, Melissa Greene, Eytan Adar, Panos Papalambros**
University of Michigan, United States of America

In this work we develop an understanding of how systems engineers or system integrators can mediate communication channels within a design organization, leading to increased technical success where otherwise no coordination is observed. The models developed here are offered as alternative explanations for observed communication or coordination gaps between design groups working on connected technical subsystems. The results of analysis of simulated organizational network data indicate that systems engineers in mediating roles can improve the probability of technical success as estimated by communication path length within the organizational network. This suggests that roles beyond those directly involved in design tasks should be considered in organizational models used to predict technical system performance.

## Using TRLs and system architecture to estimate technology integration risk

**Tushar Garg, Steven Eppinger, Nitin Joglekar, Alison Olechowski**
Massachusetts Institute of Technology, United States of America

Risk estimation is a key activity for product development and technology integration programs. There are a number of decision support tools that help project managers identify and mitigate risks in a project, however few explicitly consider the effects of architecture on risk. We propose a novel risk estimation framework that includes considerations of the system architecture. By starting with traditional project management literature, we define risk as a combination of likelihood and impact. We use Technology Readiness Levels as our measure for likelihood, and given that change propagates through interfaces, we used measures that relate to connectivity to estimate impact. This framework is applied to an industry example and we visualize the data in different formats to aid in analysis. The insights gained from this analysis are discussed, and we conclude that the risk estimation framework provides estimates that are in line with the experience of engineers at the company.

## Integrating product development models and "in-product models"

**Gert Aßmann[1], Ralf Stetter[2]**
[1]Knorr Bremse, Systeme für Schienenfahrzeuge, Germany; [2]University of Applied Sciences Ravensburg-Weingarten, Germany

Current complex products such as transportation systems usually dispose of an elaborate monitoring, control and diagnosis system. Very often such intelligent systems rely on models of the product (e.g. mathematical models). Such models are stored in the control units, in diagnosis and/or safety systems of the product and can therefore be referred to as "in-product models". It is important to note that several models of the product are generated during the product development of this system. One example for an in-product model might be a monitoring system for condition based service. Such systems rely on sensory information such as from vibration sensors and need to determine when service is necessary. Similarly, in product development engineers investigate vibrations of the product and need to determine how much vibration is admissible. Today, the generation of the two kinds of models is frequently done in separate departments and is usually not connected in a systematic manner. This paper discusses possibilities to integrate the generation of product development models and "in-product models" using the product example oil free compressor for braking systems of trains.

## Design prototyping of systems

**Bradley Adam Camburn[1],[2], Ryan Arlitt[1], K. Blake Perez[1], David Anderson[1], Pui Kun Choo[1], Terry Lim[2], Adam Gilmour[2], Kristin Wood[1]**
[1]Singapore University of Technology and Design, Singapore; [2]Gilmour Space Technologies, Singapore

In recent years, groundbreaking work in design science has identified that prototyping is one of the most critical factors leading to successful development. Many decisions regarding the detail of a design and the allocation of resources are made during design prototyping. Extant studies provide foundational insights in strategic prototyping. This work explores prototypes for developing services and systems that are complex. A framework is proposed to visualise strategic prototyping to search design spaces that span multiple domains. We define three phases of system prototyping: partitioning, search, and implementation. The framework illustrates the relationship between individual techniques and associated cost versus performance outcome. This new framework is supported through two commercial development case studies that demonstrate the approach. The first is a subsystem from a hybrid launch vehicle development effort at Gilmour Space Technologies, the second is a service centre design case from the SUTD-MIT International Design Centre.

# Systems Engineering, cont'd

**TUESDAY, AUG 22**

P1.7

**8:30 am – 10:00 am**

**2504**

CHAIR

*François Patou*

### Trends, observations and drivers for change in systems engineering design

**Ola Isaksson[1], Ívar Arnarsson[2], Dag Bergsjö1, Amer Catic1[3], Göran Gustafsson[1], Onur Kaya[1], Jonas Landahl[1], Christoffer Levandowski[1], Johan Malmqvist[1], Jakob Müller[1], Visakha Raja[4], Dag S. Raudberget[1], Daniel Stenholm[1], Mikael Ström[5]**

[1]Chalmers University of Technology, Sweden; [2]Volvo Trucks, Sweden; [3]Volvo Group Trucks Technology, Sweden; [4]GKN Aerospace Sweden, Sweden; [5]Swerea, Sweden

Manufactures, developing products, need to adapt and improve their practices taking advantage of technology advancements and simultaneously develop products and solutions to fit a new world. This paper discusses how societal and technological trends drive the need for change and evolution in what is called Systems Engineering Design (SED), indicating a systems view on engineering design. Through an analysis and selected examples it is argued that SED capabilities need to better address the width and complexity of design problem, takes advantages of increased computational power and sensing technologies to master future challenges. An important factor for successful deployment and change in industrial context, is the need for interactive and visual aids and easily accessible support methods. This can pave the way also for advanced SED support.

# Information and Knowledge Management – Approaches

**TUESDAY, AUG 22**

**P1.8**

**8:30 am – 10:00 am**
**2506**

CHAIR
*Mickael Gardoni*

### Towards robust inter-organizational synergy: Perceived quality knowledge transfer in the automotive industry

**Daniel Stenholm, Konstantinos Stylidis, Dag Bergsjö, Rikard Söderberg**
Chalmers University of Technology, Sweden

With the highly competitive market environment, organizations which want to promote innovation are imposed to create strategic alliances. In this situation involved parties have to exchange knowledge at all stages of product development to support the product development process. At the same moment manufacturers have a constant pressure of balancing costs, quality and production cycles shortening. In this paper, authors identified challenges for knowledge exchange in collaboration between competitive organizations. With the example of five European automotive OEMs exchanging knowledge regarding perceived quality. This paper presents a framework for successful knowledge exchange between organizations. It proposes the methodology for the knowledge taxonomy and establishment of the synergistic knowledge network.

### Maturity of models in a multi-model decision support system

**Christian Johansson[1], Johan Wall[1], Massimo Panarotto[1,2]**
[1]Blekinge Institute of Technology, Sweden; [2]Chalmers University of Technology, Sweden

To reduce uncertainty in decisions, engineers experiment with models, such as, exploring what-if scenarios, and thus increase knowledge. Still, because modelling is an idealisation of reality, there is often substantial uncertainty involved, and this decision makers less confident to lean onto models alone when making decisions. The aim of this paper is to conceptualize a design support for improving confidence and validity in models, by communicating uncertainties from modelling and simulation to relevant stakeholders. The paper reports on empirical data from a research profile workshop. The findings illustrate the importance of communicating uncertainties from models between relevant stakeholders in order to drive action. The paper then presents an approach to visualize model maturity levels as well as impact levels in relation to one or several aggregated models. With this approach, focus can move to discuss the knowledge about the knowledge that is created from modelling, and to facilitate discussions on a meta-level about the modelling and simulation. This is exemplified by a test scenario where a multi-disciplinary modelling and simulation of an asphalt roller is presented.

# Information and Knowledge Management – Approaches, cont'd

**TUESDAY, AUG 22**

**P1.8**

**8:30 am – 10:00 am**
**2506**

CHAIR
*Mickael Gardoni*

## Improved codification and transfer of engineering knowledge through human intermediaries

**Tobias Ruck, Albert Albers, Nicolas Reiß**
Karlsruhe Institute of Technology (KIT), Germany

In multi-domain product development and companies with a high division of expertise, there is a permanent need to transfer expert knowledge to mechanical designers. Especially in large distributed organizations, the "people-to-documents" approach plays an important role since experts are often temporarily or locally not available. However, experts face several problems when they independently codify their knowledge for mechanical designers into a computer-based knowledge system. Difficulties are resulting from the characteristics of expert-layperson communication or from cognitive and motivational barriers. In order to overcome the problems, an intermediary is suggested as a medium to reduce the experts' effort and support them in anticipating designers' knowledge needs. For this purpose, an intermediary based knowledge codification method has been applied in a case study in the German automotive supplier industry. Thereafter, the method was evaluated by interviews with experts who have participated in that process.

## Modeling product co-consideration relations: A comparative study of two network models

**Zhenghui Sha[1], Mingxian Wang[2], Yun Huang[1], Noshir Contractor[1], Yan Fu[2], Wei Chen[1]**
[1]Northwestern University, United States of America; [2]Ford Motor Company, United States of America

Customers often compare and evaluate alternative products before making purchase decisions. Understanding customer preference is an important step for choice modeling in engineering design. This study presents a network approach to model co-consideration relations between products in supporting engineering design decisions. The network approach of co-consideration represents each product as a node, and a link between two nodes implies the two products are co-considered by customers. We compare two network-based modeling techniques — the multiple regression quadratic assignment procedure (MRQAP) and the exponential random graph model (ERGM). Using vehicle purchase data in the 2013 China market, we evaluate the goodness-of-fit of the two techniques at both network level and link level. The analysis indicates that the ERGM outperforms the MRQAP model. Specifically, the ERGM is able to characterize the interdependence of product co-considerations through various network configurations and therefore has a better fit of the data. The insights of co-consideration models help to understand market segmentation and product competitions as well as other types of product associations.

# P1.8

**8:30 am – 10:00 am**
**2506**

CHAIR
*Mickael Gardoni*

### Passive monitoring in the workplace: Design guidelines for self quantified employee feedback system

**Muhammad Tufail, Haebin Lee, Myungjin Kim, KwanMyung Kim**
UNIST Ulsan National Institute of Science and Technology, Republic of Korea

The use of online social networking services is considerably more accessible today due to advances in ICT in workplaces. Employees are spending more time on Internet engaging in non-work-related activities, such as maintaining personal networks, interacting with friends, streaming music and video, checking sports scores and following Web bookmarks by visiting various online social venues. As such, organizations are increasingly concerned about maintaining a stable workforce, and thus they make the use of monitoring systems. However, the current monitoring practices violate employees' reasonable expectation of privacy, decrease self-determination and cause employees to complain and possibly increase intent to quit jobs. We present the use of passive monitoring in the workplace as a new tool to observe employees' Internet activities with objective measures. Based on Self Quantified movement, we aim to design a system that can passively monitor employees, provide visualization feedback based on their Internet usage activities, and allow employees to understand the implications of their actions concerning the boundary between work-related and non-work related Internet activities.

## Break

**10:00 am – 10:30 am  Atrium Lower Level**

**TUESDAY, AUG 22**

**10:30 am – 11:15 am**
**Great Hall & Foyer**

CHAIR
*Josef Oehmen*

# Yukari Nagai, PhD

**Biography:** Yukari Nagai is Vice-president of Japan Advanced Institute of Science and Technology (JAIST). Dean (2014-), Professor (2011-) of School of Knowledge Science, JAIST. Director of International Research Center of Innovation Design (2016-)

She received MA from Musashino Art University, Tokyo (1990), Doctor of Philosophy from Chiba University (2002), PhD in Computing Sciences from University of Technology, Sydney (2009).

She contributes to the developing discipline of design in her capacity as Chair of Design Creativity SIG of the Design Society (2007-), Fellow of Design Research Society (2010-), and member of the Advisory Board of Design Society (2011-); she has been instrumental in organizing a community of design researchers as Editor-in-Chief of International Journal of Design Creativity and Innovation, Taylor & Francis (2013-); she served as Guest Editor on the special issue of Artifact(2008) on Design Research Methods; she edited the special issue of Journal of Engineering Design (2010) on Design Creativity, held the position of Co-Chair of the ACM Creativity and Cognition Conference (2013) and Vice-Chair of the International Conference of Design Creativity (2012, 2015, 2016).

# Creativity, Design, and Innovation

Design thinking has attracted interest in various fields as the ability to characterize humans. It forms a certain but pliable base for multiple disciplines featuring art, engineering, and science. The 21st century has recognized the importance of "design creativity" modes for establishing a balanced entirety in the future society.

The power forming the core of design ability is creativity. Discussing human-specific creativity and inherited human design thinking brings about comprehensive knowledge to understand humans. In this keynote lecture, we first examine what has been studied so far from the viewpoint of human science, including cognition, development, and behavior, with regard to human creativity so that we may be able to identify its relationship with design thinking as a social activity.

Next, we shall reconsider the relationship between innovation and design thinking to identify the inherent power of creativity in the framework of a human ego-social linkage that includes motivation, organization, and ethics. Innovation contributes to revitalization of not only the worldwide market but also the entire activity of a society. Therefore, one of the aims of higher education and industry is the popular trend to groom innovative people, although our knowledge of management technology for innovation is yet uncertain. By introducing a significant program of design education, this keynote suggests new modes of design based on a tentative model of the curriculum of "innovation design." Based on the proposed model and the latest mode of life styles, we shall then discuss the essential structure of the pedagogy for "design creativity," design community for co-creative activity, and the future challenges of design creativity. In attempting to realize an ideal model of innovation design, this keynote highlights the essential issue of individual design creativity and social innovation.

**TUESDAY, AUG 22**

**10:30 am – 11:15 am**
**Great Hall & Foyer**

CHAIR
*Josef Oehmen*

**TUESDAY, AUG 22**

# Design for Additive Manufacturing 2

TUESDAY, AUG 22

D1.1

**11:30 am – 12:30 pm**
**Performance Theatre**

CHAIR
*Georges Fadel*

## The need for effective design guides in additive manufacturing

**Carolyn Conner Seepersad, Jared Allison, Conner Sharpe**
University of Texas at Austin, United States of America

As interest in additive manufacturing (AM) grows, design guides are needed for helping designers conceptualize and embody products that are suitable for AM. As these guides begin to emerge, they are focused primarily on the limitations of AM, including the types of features that can and cannot be built with a particular process and the dimensional limitations on those features. To design for AM effectively, however, designers need guides that help them understand not only the limitations of a particular AM process but also the design opportunities and freedoms afforded by the process. Furthermore, developing a basic understanding of the AM process and its relationship to those limitations and capabilities helps designers translate their knowledge to new applications. An expanded type of design guide is needed that fulfills all of these functions for the designer.

## Design heuristics for additive manufacturing

**Alexandra Blösch-Paidosh, Kristina Shea**
ETH Zurich, Switzerland

The potential benefits of additive manufacturing (AM) have been expounded upon by many in academic, industry, media, and policy circles. These potential benefits include functional integration, reduced complexity, increased robustness and increased performance. Many designers would like to take advantage of these benefits to improve their designs, but are at a loss as to how they can best incorporate AM. Existing DfAM methods are not tailored to generating the high-level concepts desired in the early stages of the design process and often require AM process-specific knowledge. Therefore, we propose to provide an AM process-independent method for transferring the high-level knowledge necessary for reasoning about functions and configurations to designers in the context of AM. The chosen method to accomplish this knowledge transfer is design heuristics for AM, which we derive from an analysis of 275 existing AM artifacts. Twenty-nine process-independent heuristics are derived, and the feasibility of the heuristics is verified with two DfAM case studies: a car door and a fighter pilot helmet to provide an initial proof of concept.

TUESDAY, AUG 22

D1.1

11:30 am – 12:30 pm
Performance Theatre

CHAIR
*Georges Fadel*

# Design for Additive Manufacturing 2, cont'd

## Implementation of lightweight design in the product development process of unmanned aerial vehicles

**Stefan Junk[1], Werner Schröder[2], Nikolai Hangst[1]**
[1]Offenburg University of Applied Sciences, Business and Engineering, Germany; [2]Offenburg University of Applied Sciences, Institute of Unmanned Aerial Systems, Germany

The development and manufacturing of unmanned aerial vehicles (UAVs) require a multitude of design rules. Thereby, additive manufacturing (AM) processes provide a number of significant advantages over conventional production methods, particularly for implementing requirements with regard to lightweight construction and sustainability. A new, promising approach is presented, with which, through the combination of very light structural elements with a ribbed construction, an attached covering by means of foil is used. This contribution develops and presents a development process that is based on various development cycles. Such cycles differ in their effort and scope within the overall development, and may only comprise one part of the development process, or the entire development process. The applicability of this development process is demonstrated within the framework of a comprehensive case study. The aim is to develop an additively manufactured product that is as light as possible in the form of a UAV, along with a sustainable manufacturing process for such product. Finally, the results of this case study are analyzed with regard to the improvement of lightweight construction.

## A design method for restriction oriented lightweight design by using selective laser melting

**Bastian Lippert, Roland Lachmayer**
Leibniz Universität Hannover, Germany

This paper describes the implementation of internal structures for mechanically loaded components to save material, and thus for a lightweight design, by using selective laser melting. Based on the analysis of structures inspired by nature and technical analogies, a design approach for the substitution of solid geometries by internal structures is investigated. Concerning a demonstrator, a stress- and manufacturing-oriented design for the integration of internal structures is analyzed. By the consideration of design guidelines and the application of Finite Element Methods, various model generations are built up iteratively and evaluated in comparison to the initial model. For the simulation, a material database is defined to involve the anisotropic material properties. The optimized model is manufactured by using AlSi10Mg powder. The deviations of the physical model from the digital model are evaluated and considered by adapting the component design according to the design approach. The final model generation enables new lightweight potentials compared to conventionally manufactured models and corresponds to the possibilities of selective laser melting.

# Creativity Methods

**TUESDAY, AUG 22**

## D1.2

**11:30 am – 12:30 pm**
**Art Gallery**

CHAIR
*Yukari Nagai*

### Design variation through richness of rules embedded in LEGO bricks

**David Mathias, Duncan Boa, Ben Hicks, Chris Snider, Peter Bennett, Colin Taylor**
University of Bristol, United Kingdom

Design rules govern the design process by imposing constraints on the development of a product. Examples of design rules include engineering standards, regulations, standard operating procedures and existing designs as protected by patents. They have the potential to over-constrain the design space and impact innovation. In this paper, an exploratory study is reported that investigates the link between richness of design rules and the resulting design variation in a LEGO model. Design rule richness describes the quantity and explicitness of constraints relating to a design. Design rules, relating to a model of a simple spaceship, were embedded in individual LEGO bricks. Twenty participants were tasked with constructing the spaceship while adhering to the set design rules. There were four levels of design rule richness and the participants constructed a model for each level. Measuring the design variation through Design Structure Matrices revealed that the richness of the design rules only had a significant effect on the design variation between the least and most rich design rules. This suggests that a point exists at which the richness of design rules limit design variation.

### Elements to the development of a creativity technique

**Kleidson Medeiros Leopoldino, Mario Aguirre González, Paula de Oliveira Ferreira, David de Melo, Rafael de Vasconcelos**
UFRN Federal University of Rio Grande do Norte, Brazil

Understood as a skill, and present at different levels in the human being, creativity can be developed spontaneously and not spontaneously. Spontaneously from the interaction between endogenous and exogenous factors. And already in its induced form, through creative techniques that aim to generate ideas to solve problems through the systematization of the creative process. The article aims to point out elements to the development of a creativity technique. To accomplish this goal, a literature review was carried out. After the analysis of the articles and with the use of affinity diagrams, fourteen elements were obtained that should be considered in the elaboration of a creativity technique. The elements identified were: time, colors, multidisciplinarity, collaborative work, playfulness, creative profiles, positive humor, intrinsic motivation, convergent and divergent thinking, incubation, nonverbal language, qualification of ideas, intergroup competition and size of groups. For future research, it is recommended the construction of controlled experiments to measure and understand the influence of each factor, indicated in this article, to stimulate non-spontaneous creativity.

# Creativity Methods, cont'd

**TUESDAY, AUG 22**

**D1.2**

**11:30 am – 12:30 pm**
**Art Gallery**

CHAIR
*Yukari Nagai*

### Necessary extension of conventional idea processes by means of a method for the identification of radical product ideas

**Thorsten Herrmann, Hansgeorg Binz, Daniel Roth**
University of Stuttgart, Germany

The high failure rate of trials for implementing radical innovations underlines a demand for supporting the development process for new radical innovations. This demand has arisen in many companies over the last few years and has also been recognized in expert interviews with industrial partners of our institute in the last few months. Our institute's research project "Handling radical innovation in the field of idea processes and product development" addresses that topic and researches methodical support to meet the described need. This paper will demonstrate the necessity of adding conventional idea processes by means of a method for the identification of radical product ideas. Furthermore, there will be discussion as to how such a method can be elaborated and what should be taken into account according to the characteristics of radical product ideas or innovations. The step of identifying radical product ideas in idea processes in order to separate them and treat them differently from incremental product ideas is seen as imperative. Additionally, the paper considers the question of how such an identification step for radical product ideas can be elaborated in future research.

### Proposing a new product creativity assessment tool and a novel methodology to investigate the effects of different types of product functionality on the underlying structure of factor analysis

**Kamyar Hazeri[1], Peter R. N. Childs[1], David Cropley[2]**
[1]Imperial College London, United Kingdom; [2]University of South Australia, Australia

The aim of study is to indicate a gap in creativity research arising from products with dissimilar capabilities requiring independent creativity indicators that are empirically formed according to their functionality. Initially, a hypothesis for a criterion-based tool comprising 9 criteria and 40 indicators is put forward for assessing functional products. Then, a novel experimental approach is presented to indicate this variation. The first experiment uses the Consensual Assessment Technique (CAT) to measure the product creativity as well as the relationship between creativity and the criteria proposed. Then, EFA is considered to extract the irrelevant items and provide the optimum underlying structures for the factors used in each assessment. The validity of the models will then be investigated using the comparison of the goodness of fit indices between the estimated factor loadings calculated by CFA measurement and the empirical data collected from the second study. It is anticipated that the findings of this experiment will result in three dissimilar tools, where each comprised of specific indicators that appropriately established with respect to various product functionality.

# Design Processes

TUESDAY, AUG 22

D1.3

**11:30 am – 12:30 pm**

**2301**

CHAIR

*Jeffrey Herrmann*

## A comparison of design decisions made early and late in development

**James Tan[1], Kevin Otto[2], Kristin Wood[1]**

[1]Singapore University of Technology and Design, Singapore; [2]Aalto University, Finland

The occurrence rates and cost impact of design changes made early and later in the design process were studied, to test and quantify the 80-20 rule of design cost impacts, that early design decisions account for the majority of costs in a development program. Cost and schedule impact of decisions made throughout the development process was carried out at a large aerospace firm on two programs covering 7 years of development with 275 person-years effort. The underlying data used was the rate and cost of design changes made. We found no significant difference in the rate of occurrence of design change decisions made, but we found a significant difference in the cost impact of the design changes. Overall, early design change decisions cost 5 times more than later design change decisions. This difference is primarily due to the inability to determine if an early design decision is correct until later in development during testing.

## Current state of practices in open source product development

**Jérémy Bonvoisin[1], Laetitia Thomas[2], Robert Mies[1], Céline Gros[2], Rainer Stark[1], Karine Samuel[2], Roland Jochem[1], Jean-François Boujut[2]**

[1]Technische Universität Berlin, Germany; [2]Université Grenoble Alpes, France

Open source innovation is a well-studied phenomenon of the ICT sector, but its evolution towards the field of tangible hardware product development is a newer phenomenon which remains mostly theoretical. Existing literature has identified that to push existing open source product development (OSPD) practice towards the achievement of high quality complex products, methods and tools adapted to this specific organisation of work are needed. The objective of this article is to explore the practices emerging from OSPD communities in order to support the development of appropriate process support in the future. It reports first observations made during a qualitative and comparative empirical study performed with participants of 23 OSPD projects through semi-directed interviews. Activating a formerly published framework, these observations address four themes: the organizational structure of OSPD's surrounding communities, their design process, their underlying business models and the supporting online tools they use. The preliminary results are delivered to the engineering design and management scientific community as an impulse for further research.

# Design Processes, cont'd

**TUESDAY, AUG 22**

## D1.3

**11:30 am – 12:30 pm**

**2301**

CHAIR

*Jeffrey Herrmann*

### Process model for change management in the system of chassis-mounted parts of commercial vehicles

**Johannes Michael Stocker[1], Christoph Thoma[1], Michael Schmidt[1], Matthias Kreimeyer[2], Markus Lienkamp[1]**

[1]Technical University of Munich, Germany; [2]MAN Truck&Bus AG, Munich, Germany

Due to the high amount of interrelations, such as spatial dependencies, material exchange, energy transfer and information flow, the chassis-mounted parts, located between the axles of a commercial vehicle, form a complex system. To use the limited installation space in an optimized way, which is restricted by the wheelbase and customer requirements, chassis-mounted components are grouped together in specified patterns, so-called layouts. As a consequence of the long product life-cycle of commercial vehicles, requirements concerning chassis-mounted parts change and modifications within the initially optimized layouts occur. To guarantee the robustness of defined layouts it is important to gain transparency concerning the consequences of changes. Therefore, this paper aims at developing a methodology which can visualise and quantify the dependencies between chassis-mounted parts. In the case that layouts must be rearranged, the methodology has to be able to assess the propagation of change within a layout in order to support the decision-making regarding the arrangement of the considered parts.

### Efficient application of optimization methods by using concurrent and simultaneous optimization

**Andreas Wünsch, Sandor Vajna**

Otto-von-Guericke-University Magdeburg, Germany

The present paper addresses the research question of the efficient execution of optimization tasks in product development by using parallelization methods and by considering the existing resources within an organization. Based on analogies between optimization processes and the execution of tasks in interdisciplinary teams, a method for efficient parallelization of evaluation processes of optimizations is introduced and implemented prototypically into a framework for distributed optimization. Thereby the parallelization of evaluation processes is based on the decomposition of both the optimization model and the evaluation model. Since the processing of these process elements depends only on the availability and the stability of required information and resources, high flexibility in the application and dynamic response to spontaneous changes in the resources can be ensured. Within this environment resources include available hardware, installed software, and available licenses. Furthermore, we show how the efficiency of an optimization can be further increased by using priority-based processing of the process elements of the evaluation process.

# Project Management and Design

TUESDAY, AUG 22

D1.4

11:30 am – 12:30 pm
2306/2309

CHAIR
*Martin Steinert*

## The coexistence of design thinking and stage and gate in the same organisational context – Challenges and need for integration

**Giulia Franchini, Clio Dosi, Matteo Vignoli**
University of Modena and Reggio Emilia, Italy

The current product innovation scenario is facing important changes that require the New Product Development (NPD) process to be adjusted. Despite Stage and Gate (SG) is the most adopted framework, several studies inquired how to overcome its limits; new innovation methods emerged from the practitioners' world, and, among them, Design Thinking (DT). To our knowledge, no research has inquired the coexistence of the two methods inside the same organizational context. This study is based on a single case study of a food company where the two methods co-exist. The aim is to understand if the perceptions of the employees are coherent with the pros and cons of literature and to investigate if the two methods can be compared, integrated or are mutually exclusive. Our study shows that the two methods, as parallel processes, lead to confusion among employees, due to the overlapping of some activities, with a perception of wasted resources. Moreover, emerged an interesting balance among the pros and cons of the two methods, where items have been identified as complementary. Results highlight a call for integration among the two methods with the limits of SG overtaken by the benefits of DT.

## Assessment of back-up plan, delay, and waiver options at project gate reviews

**Alison Olechowski[1], Steven Eppinger[1], Nitin Joglekar[2]**
[1]Massachusetts Institute of Technology, United States of America; [2]Boston University, United States of America

In a staged development process, the planned work is not always complete at the gate review, yet a gate decision must be made. We present a more complete explanation of the reality of gate decision options, with the addition of Waiver (with and without re-review), Back-up plan, and Delay, along with Go and Kill. We also show how it is feasible to extend the simple decision tree modelling approach currently used for the Go/Kill choice to analyze the expected value of the broader set of options available. We demonstrate this new approach with studies from industrial application of the method. These case studies show that it is possible to estimate the parameters needed to conduct the decision tree analysis. Our case work also identifies heuristics that are prevalent in gate decisions. Coupling such heuristics with our decision analysis can formalize the underlying trade-offs and inform decision makers on the risks (or benefits) of waiver, delay, and back-up plan options.

# Project Management and Design, cont'd

**TUESDAY, AUG 22**

## D1.4

**11:30 am – 12:30 pm**
**2306/2309**

CHAIR
*Martin Steinert*

### Challenges in managing new product introduction projects: An explorative case study

**Koteshwar Chirumalla**
Mälardalen University, Sweden

In today's market conditions, manufacturing companies are under pressure to constantly launch new products or product variants to the market in short intervals. The project management of new product introduction therefore play a significant role in the success of new product development. The existing literature covers a wide range of issues and disturbances in the product introduction process in different industries. However, little research exists on the management of new product introduction projects from a project management perspective especially from the viewpoint of production. Based on a case study at a manufacturing company, this paper examines the challenges in managing new product introduction projects in the production organisation. The study identified nine key challenges in the management of new product introduction projects which are associated to the resources, time-readiness and schedule, gated administration, ways of working, communication and time-sharing, learning, business case, co-ordination and alignment, and competences.

### Engineering design resource planning: A case study in identifying resource forecasting opportunities in research project planning

**Alexander Holliman, Avril Thomson, Abigail Hird**
University of Strathclyde, United Kingdom

Resource forecasting is a key element to project planning, this is particularly true for research and design. Due to uncertainties inherent in such fields, resource demand forecasting is a specific challenge. This presents an opportunity for mapping out research planning processes, identifying opportunities for resource forecasting methods. Building on research conducted at an engineering research centre, this study explores the two types of engineering research projects (Commercial and Public Research & Development). Individual projects can utilise multiple engineering teams within the research centre and both project types have their own distinct planning process. This study outlines these existing project planning processes, the resource planning stages within the process, what informs the resource planning and what opportunities are present for improvement of these processes.

# Methods for Early Design Stages

TUESDAY, AUG 22

D1.5

11:30 am – 12:30 pm

2311

CHAIR

*Amaresh Chakrabarti*

## Extended target weighing approach – Identification of lightweight design potential for new product generations

**Albert Albers, Sven Revfi, Markus Spadinger**
Karlsruhe Institute of Technology (KIT), Germany

In the development process of vehicles, especially electric vehicles, lightweight design becomes more and more important. Lightweight design efforts often result in increasing costs of a product and are thus mainly reserved for vehicles in the premium sector. The presented paper suggests the extension of the Target Weighing Approach, which was proposed to match mass and function, based on the systematic approaches of target costing and value engineering. This approach allows the identification of where the most promising weight reductions could be achieved. The Extended Target Weighing Approach includes a new methodical procedure which allows to analyse systems existing of only one single component by matching the functions to their functional areas. Furthermore, the analysis of potential of the current product generation and new concepts for the next product generation are extended by the dimensions CO2 footprint and costs. Additionally, a method to evaluate the uncertainties related to new concepts is proposed.

## Designing the missing link between science and industry: Organizing partnership based on dual generativity

**Milena Klasing Chen[1], Patrice Aknin[2], Lilly-Rose Lagadec[3,4], Dominique Laousse[1,5], Pascal Le Masson[5], Benoît Weil[5]**
[1]SNCF, France; [2]IRT SystemX, France; [3]SNCF Réseau, France; [4]IRSTEA, France; [5]PSL Research University Paris, France

Industry-academic research partnerships are mostly considered interesting to increase industrial innovativeness, and its benefits have been discussed in the flourishing open innovation literature. However, how to create mutually beneficial partnerships seems to be a question that has not been sufficiently studied. Through this article, we discuss the goals of these partnerships by modelling different types of collaboration. We defend that their real value has to be evaluated not only by looking at the knowledge created, but also at the increase of generativity we observe, due to interactions between academia and industry. Furthermore, we propose a model based on C-K theory that can be used to design a research collaboration that increases generativity, going beyond problem solving and knowledge transfer logics. We illustrate it through a case study, which shows that value creation in an industry-research partnership is increased by a model of co-generation, instead of considering these relations as a one-way transfer. Furthermore, we show that conflicts in a partnership can be solved through a C-K based tool.

# Methods for Early Design Stages, cont'd

**TUESDAY, AUG 22**

## D1.5

**11:30 am – 12:30 pm**

**2311**

CHAIR

*Amaresh Chakrabarti*

### Value-driven simulation: Thinking together through simulation in early engineering design

**Massimo Panarotto[1,2], Johan Wall[1], Marco Bertoni[1], Tobias Larsson[1], Pontus Jonsson[3]**

[1]Blekinge Institute of Technology, Sweden; [2]Chalmers University of Technology, Sweden; [3]Dynapac Compaction Equipment AB, Sweden

The topic of 'design for value' has lately attracted a great deal of attention within the engineering design community. 'Predicting' the value of a future solution is however difficult, especially in early design phases. Modelling and simulation is believed to be able to support this challenging task. A simulation process for value-driven engineering design is presented. The performances of a design concept along the lifecycle are aggregated to a monetary system value function. The results of this multi-model simulation environment for value are displayed through a colour-coded CAD model for easier interaction. Verification activities indicate that enabling effective design space exploration and visualization of cause-effect relationships become important elements in order to 'think together' using a simulation driven design approach. Furthermore, the proposed multidisciplinary 'value model' fosters cross-functional knowledge sharing and collective deliberation about the value, forcing stakeholders to synthetize their perceptions about the value of a design and to discuss where conclusions differ.

# Resource-Limited Societies: Applications

TUESDAY, AUG 22

D1.6

11:30 am – 12:30 pm

2314

CHAIR

*Alex Duffy*

### Mixed-flow irrigation pump design optimization for Bangladesh

**Su Yu, Jonathan S. Colton**
Georgia Institute of Technology, United States of America

Irrigation pumps are indispensable to the production of major crops in Southeast Asia. This study proposes a design method to optimize the design of a mixed-flow irrigation pump model in a cost-effective and energy-efficient manner through a case study in Bangladesh. This method deviates from standard ones in industrialized nations to account for resource limitations in developing countries. Based on this approach, the paper optimizes four design parameters using numerical simulation, computational fluid dynamics, and analysis of variance. The results of numerical simulations reveal that the pumping strength may be increased from 0.286 to 0.348 (22%), while the efficiency may be increased from 40.2% to 54.2% (14.2%) when operated at 1500 RPM. This study also ranks the effectiveness of each design parameter and their interactions. An optimized design is presented for the current model, and an optimization procedure is developed for all axial-flow and mixed-flow pumps.

### Improving needs-finding techniques for medical device development at low resource environments using Activity Theory

**Shalaleh Rismani, Mike Van der Loos**
The University of British Columbia, Canada

It is critical to evaluate and improve existing needs-finding techniques for design in new and complex spaces. In the recent decade, more companies and organizations are focusing on medical device development (MDD) for low-resource environments. This paper proposes and studies a novel needs-finding technique based on Activity Theory that can be used for MDD for low-resource settings. This novel technique aims to offer a more comprehensive analysis of a design problem by considering the clinical, technical and socioeconomic factors. The paper describes and discusses a design study that was done with seven biomedical engineering student teams. The goal of the study was to compare the Activity Theory-based Needs Finding (ATNF) technique with a more conventional technique. The results indicate that novel ATNF technique can be successfully used by design teams and the technique allows for a more comprehensive analysis of the problem scope.

TUESDAY, AUG 22

D1.6

11:30 am – 12:30 pm

2314

CHAIR

*Alex Duffy*

# Resource-Limited Societies: Applications, cont'd

## Design for micro-enterprise: A field study of user preference behavior

**Jesse Austin-Breneman**[1], **Maria Yang**[2]

[1]University of Michigan, United States of America; [2]Massachusetts Institute of Technology, United States of America

Product development serving the Base of the Pyramid (BoP) is an increasing part of many organizations' growth strategies, from social enterprises to large multi-national companies. In response to this need, research has focused on developing new design approaches for reaching these users. Previous work by the authors identified targeting micro-entrepreneurs as one increasingly used strategy. This field study expands on the previous work by examining micro-entrepreneur purchasing decisions in the public toilet sector in East Africa. Results from interviews with thirty-three franchisees of a public toilet franchise and other stakeholders in the system are presented. Analyses of purchasing practices and interview responses highlight how the micro-entrepreneur's business strategy is key to the purchasing decisions and therefore should be closely examined by designers.

## Using local invasive species and flora to manufacture collagen based biodegradable plastic tableware

**Kathryn Willett**, **Bryan Howell**

Brigham Young University, United States of America

This paper explains how we designed, developed and tested a locally sourced; environmentally sensitive, biodegradable collagen plastic. It discusses the creation of simple moulds for manufacturing tableware and the accompanying workshop proving the viability of both the process and product. Tests were conducted using commercially available collagen materials to understand its attributes. A unique formulation was developed from hides of local agricultural vermin and powders derived from invasive flora. Plaster and concrete moulds were created for the manufacture of simple tableware. A workshop occurred were 12 participants tested the quality of the plastic, the robustness of the moulds, the simplicity of the manufacturing process and the aesthetics of the tableware. Finally, four of the bowls were successfully tested for bio-degradability and fully degraded within 12 weeks of contact with soil. The workshop demonstrated the success of all aspects of the process and how this development process could be used in emerging communities globally to encourage local manufacture of sustainable products.

# New Approaches in Systems Engineering

TUESDAY, AUG 22

D1.7

11:30 am – 12:30 pm

2504

CHAIR

*Harrison Kim*

### Improving product configurability in ETO companies

**Sara Helene Markworth Johnsen, Katrin Kristjansdottir, Lars Hvam**
Technical University of Denmark, Denmark

For engineer-to-order (ETO) companies, it is from a strategic perspective crucial to be able to supply highly customized solutions to customers, while at the same time improving re-usability across projects to increase efficiency. To address the challenges this study aims to support ETO companies by improving their product configurability without compromising the flexibility, by focusing on product modularization. For this purpose, a 5 step framework is proposed with the aim of creating a product overview with a post perspective on requirements to improve the modularity of the product platforms. The framework was based on a literature review and tested in a case company, where it proved to be beneficial as it provided a structured approach to identify improvements to the products platforms modularity.

### Integrated process and data model for applying scenario-technique in requirements engineering

**Iris Graessler, Philipp Scholle, Jens Pottebaum**
Paderborn University, Heinz Nixdorf Institute, Germany

Originating from strategic management, scenario-technique yields potentials for requirements engineering. In this paper an integrated process model for such an application of scenario-technique is proposed. Flanked by an Integrated Scenario Data Model (ISDM), efficient prognosis of changes in complex requirements models is facilitated. The ISDM support this process by interlinking scenario data, requirements management data and additional data sources such as PDM/PLM systems. Scenarios are interpreted as results of interrelations among requirements. Combined with consistency assessment, the anticipation of potential future changes in requirements is facilitated, reducing potential risks for the product development process. Alongside the product development process, developers can develop reaction strategies for changes of requirements. The ISDM reduces the required effort for scenario derivation significantly by integrating data analytics and semantic modelling. In addition, the combination of process and data model allows efficient adaptations of scenarios to depict the dynamics of requirements. Intuitivism of derived scenarios is enhanced by the proposed approach.

# New Approaches in Systems Engineering, cont'd

**TUESDAY, AUG 22**

**D1.7**

**11:30 am – 12:30 pm**

**2504**

CHAIR

*Harrison Kim*

## Using point cloud technology for process simulation in the context of digital factory based on a systems engineering integrated approach

**Vahid Salehi, Shirui Wang**

Munich University of Applied Sciences, Germany

Currently, there is a huge potential to improve the digital factory information by using a 3D scanner to build up the digital factory environment. The results of the scanning process are point clouds which are generated with less effort yet in a very high quality. In this way, it is possible to digitalize manufacturing environments in large scales. Compared with the processes in the past, it is not necessary to build up the manufacturing and factory building information by means of CAD generated entities. This paper will first present the state of the art regarding the development of digital factory as well as the current process of utilizing 3D point cloud data within it out of a comprehensive literature survey. Based on the literature review, challenges and problems during the application of the 3D scanner and point clouds in the digital factory in respect of the corresponding processes and methods will be recognized. Moreover, taking the shortages and disadvantages of current methods in digital manufacturing into account, an improved solution approach using systems engineering will be suggested and elaborated.

## A CBR approach for supporting ecodesign with SysML

**Sébastien Joël Bougain, Detlef Gerhard**

TU Wien, Austria

Taking environmental and sustainability issues adequately into account within the design process is mandatory but leads to additional complexity since even more engineering domains have to be involved in the process and since lifecycle information, like use of resources, has to be integrated and managed. Model-Based Systems-Engineering (MBSE) is an approach for managing the product's complexity by using interconnected models. Yet, means for integrating information on environmental impacts are missing. Moreover, the knowledge integrated in the model, which reflects decision making processes, is not reused properly as a design experience for future products. This paper presents previous research about integrating environmental impacts and ecodesign in SysML to introduce a new Case-Based Reasoning (CBR) approach for adequately reusing previous MBSE experiences and results, such as environmental impacts. To do so, two databases are developed: one for the SysML models and one for storing own environmental impacts. Moreover, a specific retrieval process for selecting the relevant experiences is proposed. The paper ends with a discussion and a brief outlook about the research.

# Information and Knowledge Management – Applications

TUESDAY, AUG 22

D1.8

11:30 am – 12:30 pm
2506

CHAIR
*Christopher McMahon*

## Knowledge-based engineering applications for supporting the design of precast concrete facade panels

**Jacopo Montali[1], Mauro Overend[1], P. Michael Pelken[2], Michele Sauchelli[2]**
[1]University of Cambridge, United Kingdom; [2]Laing O'Rourke Plc, United Kingdom

Precast concrete facade panels, despite guaranteeing higher environmental performances, quality and quicker installation, are still designed starting from a conceptual, relatively constraint-free solution, in which details are included as the design develops. This traditional approach does not reduce risks in decision making, but rather, it increases the likelihood of devising a solution which is difficult to manufacture and/or unable to meet performance requirements, thus leading to inefficient use of time and human resources. This paper illustrates how a specific digital, knowledge-based engineering (KBE) application can support the design of single-leaf, non-loadbearing precast concrete panels. The application includes knowledge about preferred design and manufacturing constraints, and supply chain availability of a specific facade manufacturer. The result of this study is a digital application that informs design teams about the "tenderability" of the chosen solution, its approximate costs and expected performance. Future work will include additional functionalities, the development of specific metrics for assessing the impact in real-world projects and subsequent validation.

## A new knowledge management tool for product development in micro-companies

**Martin Huret, Camille Jean, Frédéric Segonds**
Arts et Métiers ParisTech, France

The main purpose of this paper is to present a new Knowledge Management (KM) tool for product development in micro-companies. To develop this proposal, the first part presents a state of the art about knowledge management and micro-companies specificities and shows the need for them to get, with reduced resources consumption, new and easy-to-use KM tools. The second part presents the new KM tool. The idea is to create information cards to capture knowledge by conducting interviews. To deliver the knowledge in an easy and efficient way, all the information cards specify the job and the step of development related to their contents. The third part presents a case study on a specific micro-company. 16 knowledge cards in an 18-hours work were written and are currently exploited by the micro-company. Future works are ongoing to determine how exhaustive are the cards and to measure qualitatively and quantitatively the performance of this KM tool. We believe it will save time, reduce costs and reduce risks of errors for product development in micro-companies.

# Information and Knowledge Management – Applications, cont'd

**TUESDAY, AUG 22**

## D1.8

**11:30 am – 12:30 pm**
**2506**

CHAIR
*Christopher McMahon*

### The knowledge benchmarking process framework: A new basis to analyze megaprojects challenges and practices

**Patrick Mbassegue[1], Mickaël Gardoni[2], Zain Tahboub[3]**
[1]École Polytechnique de Montréal, Canda; [2]École de Technologie Supérieure Montréal, Canada; [3]Dubai Aviation Engineering, United Arab Emirates

Megaprojects faced many pathologies and challenges to provide the attended impacts. These pathologies contribute to overshadow the results and outcomes needed by those who promote these kind of projects. So, we need to unsderstand and assess properly the dynamics related to megaprojects. To overcome this situation we present a new way to analyze megaprojects based on a knowledge benchmarking process framework.

### From elicitation to structuring of additive manufacturing knowledge

**Christelle Grandvallet, Franck Pourroy, Guy Prudhomme, Frédéric Vignat**
Université Grenoble Alpes, France

Manufacturing, whether subtractive and additive, requires complex operations and process rules are not so easy to structure or define. Although efficient CAD/CAM software have been developed to support the design and manufacturing tasks, knowledge management systems are still fighting to formalize those manufacturing practices, and the way they impact the design of parts and systems. This paper deals with Additive Manufacturing (AM) knowledge which is still in construction in industries. It aims at proposing approach and method for AM knowledge structuration. A case study about the influence of supports onto the quality of EBM (Electron Beam Melting) metallic parts enables us to confirm the benefits of a collective elicitation. Two elements contribute to its success: the use of an influence matrix and an argumentative situation between experts. Furthermore, four categories of AM knowledge are identified (definitions, examples, influences, and rules broken down in Action Rules and State Rules). They proved to be useful for identifying and structuring AM knowledge in our case study.

## Lunch

**12:30 pm – 2:00 pm Atrium Lower Level**

# Co-Creation

**TUESDAY, AUG 22**

D2.2

**2:00 pm – 3:00 pm**
**Art Gallery**

CHAIR
*Milene Gonçalves*

### Taking into account life situation during a co-creativity session: An exploratory study

**Justine Lobbé, Florence Bazzaro, Marjorie Charrier, Jean-Claude Sagot**
Université Bourgogne Franche-Comté, France

Users today are looking for an experience and not only for technology. Products must be acceptable and desirable, and in this regard must be designed with the needs and desires of the end user. To facilitate the integration of the usage, esteem and technique triptych into the product design process, an ergonomist and a product designer are also involved. That necessarily implies working on methods that promote co-creation. In this perspective, we focused on two complementary approaches, the User eXperience and the life situation resulting from tangible elements and from intangible elements. In this article, we will ask how the life situation elements are treated by the design team during the phases of analysis and ideation of the co-creativity process through the compilation of all the traces of the project. Our exploratory study on an industrial project highlights the complementarity of the paper's tools, the verbal and non-verbal communication during the co-creativity project, to integrate all the elements of the life situation. Moreover, our results show that the tools used are not sufficient to collect and to keep all the information useful during the creativity process.

### Co-creation with diverse actors for sustainability innovation

**Liridona Sopjani[1], Mia Hesselgren[2], Sofia Ritzén[1], Jenny Janhager Stier[1]**
[1]KTH Royal Institute of Technology, Integrated Product Development, Sweden; [2]KTH Royal Institute of Technology, Product and Service Design, Sweden

Sustainability driven innovations differ from current established technologies imposing new requirements on users and often interdependent with other actors' changes. Strategic Niche Management (SNM) stresses interactions between actors through niches i.e. protected spaces for experimentation to support innovation. However, it is unclear what activities are necessary when different actors are involved in developing and diffusing sustainability innovation. This paper aims at identifying activities crucial for sustainability innovation in an implemented mobility project. The results show that co-creation through iterations and reflections by combinations of diverse actors and users can be considered a core process for sustainability innovation. Six activities are identified as critical: matching the interdependencies by combining the actors' diverse competences and resources; facilitating to steer the group of actors into actions; engaging users at early stages of innovation; trying to drive change by offering the users an opportunity; co-creating through a multitude of actors with the development and usage simultaneously; steering and facilitating to enable co-creation.

# Co-Creation, cont'd

**TUESDAY, AUG 22**

## D2.2

**2:00 pm – 3:00 pm**
**Art Gallery**

CHAIR
*Milene Gonçalves*

### Characterisation of a co-creative design session through the analysis of multi-modal interactions

**Niccolo Becattini[1], Cedric Masclet[2], Fatma Ben-Guefrache[2], Guy Prudhomme[2], Gaetano Cascini[1], Elies Dekoninck[3]**
[1]Politecnico di Milano, Italy; [2]Université Grenoble Alpes, France; [3]University of Bath, United Kingdom

The paper presents an investigation that aims at describing the behaviour of designers, designers' client and products' end user in collaborative design sessions, which are characterized by language barriers and significant differences in the background and competencies of the involved stakeholders. The study has been developed within a European project aimed at developing a Spatial Augmented Reality based platform that enriches and facilitates the communication in co-design. Through the analysis of a real case study in the field of packaging design involving a team of ten design actors, the paper analyses with an original joint approach both the gestures and the verbal interactions of the co-design session. After describing the two tailored coding schemes that capture different facets of, respectively, the gestures and the content of the communication occurring between the participants, the paper describes the partial results and the outcomes of the joint analysis, revealing the importance of combining the two forms of study to suitably characterize the behaviour of the design actors.

### User involvement in pharmaceutical packaging design – A case study

**Giana Carli Lorenzini[1], Annika Olsson[1], Andreas Larsson[2]**
[1]Lund University, Sweden; [2]Blekinge Institute of Technology, Sweden

Different levels of user involvement in product design range from understanding user needs to co-designing with users. Previous research shows older patients face difficulties to handle the medication packaging. Yet the participation of older patients in pharmaceutical packaging design is underexplored. The purpose of this study is to explore the role of older patients in the design and development of pharmaceutical packaging. Two empirical examples of one drug manufacturer and one pharmaceutical packaging supplier build one case study. The findings reveal new pharmaceutical packaging development starts with market research about patients' populations. The packaging development is then led internally or with external partners. Later, patients test the packages concepts developed. These findings go in line with previous research about the involvement of users in industries with a high technology orientation. This study is aligned with the about limited resources in healthcare and contributes with a conceptual framework of user involvement, a useful tool for managers and developers to benchmark their design process.

# Design Theories and Frameworks

TUESDAY, AUG 22

D2.3

2:00 pm – 3:00 pm

2301

CHAIR

*Pascal Le Masson*

## Studying design abduction in the context of novelty

**Ehud Kroll[1], Lauri Koskela[2]**

[1]ORT Braude College, Israel; [2]University of Huddersfield, United Kingdom

Design abduction has been studied over the last several decades in order to increase our understanding in design reasoning. Yet, there is still considerable confusion and ambiguity regarding this topic. Some scholars contend that all regressive inferences in design — and design is mostly done by such backwards or regressive reasoning — are in fact abductions. Others focus on formal syllogistic forms in their attempt to clarify abduction. In contrast, we argue here that a defining characteristic of abduction is the production of, or the potential to produce, novel outcomes. Novelty is shown to be relative and depend mostly on what is known to the "reasoner" at the time of making the inference. Novelty is also shown to not necessarily be part of the direct outcome of an abductive inference; but rather, an attribute of an abductive design strategy that is intended to produce a new idea.

## A method for systematic elaboration of research phenomena in design research

**Imre Horvath**

Delft University of Technology, The Netherlands

The mission of design research is to discover and investigate not or partially known phenomena, and to formulate statements concerning their manifestations and relationships with other phenomena. Identification of phenomena happens in the fuzzy front end of research projects and the early explorative phases of research cycles. In spite of their determining nature, defining and processing research phenomena happen in an intuitive manner, often resulting in complications in the conduct of research. This paper proposes a method for a systematized handling of research phenomena in design research. Systematization is done in the framework of defining a research model and devising a research design based on it. The proposed method places a phenomenon in a local world, and specifies the involved things, attributes, effects and relations. Decomposition of a complex phenomenon to constituent phenomena is facilitated by a combinatorial mechanism. The paper demonstrates the applicability of the method in a concrete case. Further research concentrates on obtaining empirical evidence concerning the use and effect of the proposed method in multi-year PhD projects.

# Design Theories and Frameworks, cont'd

**TUESDAY, AUG 22**

## D2.3

**2:00 pm – 3:00 pm**

**2301**

CHAIR

*Pascal Le Masson*

### The PSI matrix – A framework and a theory of design

**Yoram Reich[1], Eswaran Subrahmanian[2]**

[1]Tel Aviv University, Israel; [2]Carnegie Mellon University, United States of America

Real life design situations often involve addressing complex multidisciplinary problems that are hard to formulate and solve, attempted by a diverse group of people, working in different organizations with different cultures, collaborating through a variety of contracts. Many design efforts fail due to incomplete understanding of design contexts. Can we create a framework that will help us unpack this complexity into a structure that allows us to explain, predict, and control failures and improve such situations to help organizations design better? We present a framework, called the PSI matrix that was developed by combining knowledge from diverse disciplines; following numerous case studies with industry to address the above-mentioned challenge. We describe the framework and its evolution from an earlier version, demonstrate its applicability to several diverse design examples, and mention several other cases on which it was tested. We have found it to be robust in supporting its objectives and continue to develop it to improve its added value to design by conducting multi-case, transdisciplinary, multi-context study with numerous partners.

### The development of a novel standardisation-customisation continuum

**Juan Antonio Heredia Jiménez, Robert Ian Whitfield, Michael Ward, Hilary Grierson**

University of Strathclyde, United Kingdom

Published work on product-oriented customisation lacks clarity in establishing how it is characterised, how it is bounded, and how one would define increasing levels of customisation. This paper describes the development of a standardisation-customisation (S-C) continuum which consists of 13 distinct intervals, starting with "standardisation", or absence of customisation, and ending with "evolution customisation", or absence of standardisation. Each interval is defined using nine characteristics that collectively define the boundaries of the intervals within the continuum. Analysis using a randomly selected sample of products from a range of industries has demonstrated the continuum's capability for distinguishing the associated level of S-C. Furthermore, no industry investigated develops products at each level of S-C, however, when combined all industries do. The number of possible levels of S-C tends to depend on the product's complexity and number of components. The continuum framework clarifies the concept of customisation, provides a scale for determining the product's customisation and supports the analysis of markets and industries against S-C.

# Complex Product Development

TUESDAY, AUG 22

D2.4

**2:00 pm – 3:00 pm**
**2306/2309**

CHAIR
*Steven Eppinger*

## Dynamic modelling of relationships in complex service design systems

**Mohammad Hassannezhad[1], Steve Cassidy[2], P. John Clarkson[1]**
[1]University of Cambridge, United Kingdom; [2]BT Research Laboratories, United Kingdom

Today's market conditions such as globalisation and digitalisation have made it challenging to design an effective service system that can efficiently balance organisational service capacity and customer service quality, hence ensure achieving business growth. One key reason might be related to the complex structure of relationships within and across functional disciplines that in often cases are dynamic and uncertain while occurring in multiple layers. Therefore, effective understanding of these interrelationships might be a significant step towards understanding the dynamics of a complex service system. In response to this challenge, this paper presents development and application of a systematic modelling and analysis framework that uses functionality of Change Prediction Method and System Dynamics to integrate multiple levels of relationships. The objective is to help decision makers understand key influencing factors and their underlying risk and impact on the system behaviour, i.e., customer experience, thus making organisation more adaptive in responding to changes and uncertainties. The ideas are illustrated through an expanded case study in British Telecom company.

## Towards cross-linked development of highly complex products

**Ferdinand Toepfer, Thomas Naumann**
Daimler AG, Germany

Within the distributed development of highly complex products, complexity among involved individuals is a major issue. In order to allow transparency and consistency of information in between individuals and their Engineering Objects (EOs), Parameter Management is discussed as an approach which functions as an intermediator of information on basis of engineering parameters. Based on case studies in the automotive industry, the paper describes the underlying framework of the approach, addresses differences to Model-Based Systems Engineering (MBSE) and describes structures used to purposefully organize and cross-link parameter information.

# Complex Product Development, cont'd

**TUESDAY, AUG 22**

## D2.4

**2:00 pm – 3:00 pm**
**2306/2309**

CHAIR
*Steven Eppinger*

### Introduction to operations architecture for complexity management in product design and operations

**Kwansuk Oh, Daeyoung Kim, Yoo S. Hong**
Seoul National University, Republic of Korea

Manufacturing firms have been trying to develop high variety of products to cope with continuously changing customer requirements in marketplace. However, the demand for high variety of products generates inefficiencies which is called complexity (or complexity cost) in operations. Although some studies tried to see the complexity in overall viewpoint, the relationship between design and operations phase is not structurally taken into account. In this paper, operations architecture (OA) is introduced which is a tool for describing the structure and the relationship between design and operations phase to manage the variety-induced complexity. Using the OA, complexity sources considered at the previous studies are newly classified based on the four domains in the architecture. From the result of classification, the authors identified that the complexity sources are not only staying in a domain but propagating their impacts to other domains. Then, applicability of the OA is discussed showing three applications.

### Modeling decisions in complex projects

**Ghadir Siyam, Robert Wilson Robinson, Malia Kilpinen**
BP Exploration Operating Co. Ltd., United Kingdom

The upstream business of oil and gas industry is decision intense. The selection of a resource sensitive and economically designed concept is critical to the project success and requires making good decisions on time. Using an industrial example, this paper proposes a systematic modelling approach to identify and map decisions and options in complex projects. The approach applies a Dependency Structure Matrix (DSM), building on expertise of the application of DSMs to major capital project in industry over the past 10 years, and has demonstrably enabled clarity and alignment on project scope.

# Function-Oriented Modeling and QFD Applications

TUESDAY, AUG 22

D2.5

2:00 pm – 3:00 pm

2311

CHAIR

*Kristin Wood*

### Nonlinear quality function deployment: An experimental analysis

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

Quality Function Deployment (QFD) is a common model to frontload engineering design activities with, linking the characteristics of a product vs. the voice of the customer using linear relationships. This approximation is often claimed to be misleading when dealing with the design of complex engineering systems. The paper presents the results of experimental activities aimed at verifying usability and effectiveness of nonlinear functions as extension of the QFD logic. A total of 40 experiments was conducted in a given design episode, involving 139 participants, to analyse the trade-off between the benefit of introducing nonlinearity vs. effort and cost triggered by increased complexity in the modelling. The results show that nonlinear functions, while improving the granularity of the QFD mapping, keeps the method simple enough to work as 'boundary object' in cross-functional design teams, irrespectively from the experience of design team members. The experiments also highlight how users' cognitive attention in the task is dependent from the format by which nonlinear merit functions are presented.

### Enhanced integrated sensitivity analysis in model based QFD method

**Seyed Sina Shabestari, Beate Bender**
Ruhr University Bochum, Germany

This manuscript presents a methodology to mathematically calculate the relation between the technical customer requirements and the technical product characteristics. This methodology is used to fill the house of quality tool of the quality function deployment method during the product design and development. In addition, the critical to quality characteristics of the product are identified. Further, the direction of optimization of the characteristics is determined. The sensitivity method is used to calculate the relations namely the elements of the transfer matrix by means of an analytical model of the product. The proposed method is applied to a model of a Segway consisting of kinematic/dynamic relations as well as actuation and control unit models.

TUESDAY, AUG 22

D2.5

2:00 pm – 3:00 pm

2311

CHAIR

*Kristin Wood*

# Function-Oriented Modeling and QFD Applications, cont'd

## Process integrated product concretisation: Extending conceptual design with function focus by processual product design

**Ilyas Mattmann, Hermann Kloberdanz, Eckhard Kirchner**
Technische Universität Darmstadt, Germany

Existing development approaches usually focus on the product function as the starting point of development activities, since function fulfilment is the main carrier to ensure stakeholder satisfaction with the technical product. However, the early anticipation of technical processes provides huge potential to develop technical products with better product properties that e. g. tap potentials of new manufacturing processes or realise a resource-sensitive design. Product designers face the challenge of finding possible solutions that realise the product function and holistically match the intended product life cycle processes. Therefore, the paper extends the functionally focused development process by property-based product modelling in the process context to systematically tap potentials of entire product life cycle processes. Desired properties and desired factors harmonise the different structures between requirements and solution finding in function and process context. Thus, the Extended Mapping Model provides a valuable base for methodological support for a holistic process integrated product concretisation in context of the entire product life cycle processes.

## The application of quality functional deployment to modular offsite construction products

**Tanawan Pang Yew Wee[1], Marco Aurisicchio[1], Ireneusz Starzyk[2]**
[1]Imperial College London, United Kingdom; [2]Laing O'Rourke, United Kingdom

This paper investigates requirement management practices in the construction industry, and proposes and evaluates the application of Quality Functional Deployment as a requirements analysis tool for offsite construction products. Two case studies were carried out. The first involved analysing technical documents and conducting interviews with engineers from the collaborating company to understand current requirements management practices. The second evaluates the application of QFD to a modular plant-room product. A QFD model was developed using a reverse engineering approach, which involved extracting requirements information from technical documents. The QFD model was subsequently validated by engineers from the collaborating company during a workshop. This research highlights that QFD has a strong potential as a requirements analysis tool for advanced offsite construction. This is because QFD offers a more systematic, holistic and structured approach to requirements management than current processes adopted in the industry. The novelty of this study lies in the implementation of a functional approach to QFD and how QFD has been tailored and organised to handle modular products.

# Design for Emotion

TUESDAY, AUG 22

D2.6

2:00 pm – 3:00 pm

2314

CHAIR

*Yvonne Eriksson*

## Investigating the relationship between customer emotions and sportsbike aesthetics

**James Mamo, Philip Farrugia, Tonio Sant**
University of Malta, Malta

When designing a sportsbike, design engineers need to adopt a multidisciplinary approach to develop a product which is aesthetically pleasing as well as aerodynamically optimised as possible. The objective of this research is to investigate the emotions experienced by motorcycle enthusiasts when looking at sportsbike designs. For this study, a literature review was carried out and an online questionnaire was designed with the expert input of two psychologists. The main part of the questionnaire consisted of eight motorcycle images together with a set of Emocards. The results were analysed and verified by using statistical methods. The outcomes of this study can be used to formulate a set of guidelines which can be implemented in a Knowledge Intensive Computer Aided Design (KI-CAD) system.

## Similarities and differences between humorous and surprising products

**Yuri Borgianni[1], Gillian Hatcher[2]**
[1]Free University of Bolzano-Bozen, Italy; [2]University of Strathclyde, United Kingdom

Innovative products can be described as both useful and novel — or 'unexpected'. Literature suggests that surprise combined with humour may be a powerful tool in creating the positive 'unexpectedness' than can enhance perceived value and foster meaningful relationships between product and user. Surprise and humour both rely on mismatches of expectations and unexpected outcomes, however, they are not inter-changeable. Their relationship when embodied in product design is not fully understood, and guidelines for creating surprising and humorous products with long-lasting impact have yet to be defined. The objective of this research was to analyse the mutual effect taking place between the perception of humour and the display of surprise embodied in products, and in particular the capability of humorous characteristics to boost the effect of surprise. Building on previous experiments in which a set of products were evaluated for surprise, we verified humour in the same products with a group of comedians and non-comedians. Results indicate that products evaluated as 'funny' positively influence their capability to evoke surprise, but other factors are likely to be highly influential.

# Design for Emotion, cont'd

**TUESDAY, AUG 22**

**D2.6**

**2:00 pm – 3:00 pm**

**2314**

CHAIR

*Yvonne Eriksson*

### The emotive qualities of patterns: Insights for design

**Lewis William Robert Urquhart, Andrew Wodehouse**
University of Strathclyde, United Kingdom

The role of pattern use in the visual arts has not been fully analysed in terms of its emotive and semantic values. Patterns have played a dominant role in art, architecture and design for thousands of years but their nuanced relationship with human observers has not been systematically analysed — the emotive and semantic qualities of their forms are yet to become fully clear. This paper presents work in experimental aesthetics, analysing the emotive and semantic qualities of commonly used patters. Focus groups were used as a means of analysing a set of sixteen distinct patterns where each group considered each pattern and assigned each one emotive and semantic values. The patterns were sourced from a wide variety of cultures and varied hugely in terms of their underlying geometry; angular forms, curved forms and symbolic content. Our results reveal that many patterns have complex emotive connotations and can sometimes convey strong value judgements that we suggest are derived from the qualities of their form and foundational structure. The possible reasons for these phenomena and the implications for design practice and design research and subsequently discussed.

### Human-centred design blending smart technology with emotional responses: Case study on interactive clothing for couples

**Wang Weizhen[1,2], Yukari Nagai[1], Fang Yuan[1,2]**
[1]Japan Advanced Institute of Science and Technology, Japan; [2]Dalian Polytechnic University, Japan

Following the further development of the Internet of Things (IoT), rapid dissemination of smart clothing will begin. Previously, researchers have generally focused on high-tech approaches to implementing smart clothing design, with some success. Nevertheless, the complex sociological aspects of clothing, i.e., its interactive symbolism and properties of emotional expression, should not be ignored. In this paper, interactive clothing for a couple is used as a representative example to investigate the "why, how, and what" design principles, with a human-centred bias. Focusing on blending smart technology with emotional responses, LEDs and range sensors are integrated into prototype clothing design, both design and engineering concepts are employed in the interactive clothing development process. Adjective pairs extracted via a semantic differential method are used for a kansei evaluation. Then, the emotional structure underlying human clothing-related behavior is examined. The development of interactive clothing to date is summarized, along with further perspectives and actions required to proceed from the present development stage of 1.0 to stage 3.0.

# Model-Based Systems Engineering (MBSE)

TUESDAY, AUG 22

D2.7

2:00 pm – 3:00 pm

2504

CHAIR

*Clement Fortin*

## Model based systems engineering (MBSE) approach for configurable product use-case scenarios in virtual environments

**Atif Mahboob[1], Christian Weber[1], Stephan Husung[2], Andreas Liebal[1], Heidi Krömker[1]**

[1]Technische Universität Ilmenau, Germany; [2]em engineering methods AG, Germany

Today, the designers have to deal with a great amount of uncertainties in the design process due to the lack of information about the product, its behaviour and the context in later life-phases (phase specific actors and surroundings). Current development primarily focuses on modelling of the product and its behaviour. The consideration of the product context also plays an important role. Virtual product development has the potential to support the designer by giving a blink into the later life-phases and context. It supports the early verification of product requirements and can also help to discover unseen requirements by means of use-case scenarios inside VR. A user and task oriented development method using VR can help to reduce the design uncertainties considerably. Therefore, in the paper a concept for user and task oriented model for product development in VR is presented. This model implements the actor(s) and the surrounding(s) along with the product inside VR using a MBSE approach. The standardised multidisciplinary modelling language the Systems Modelling Language (SysML) will be used for the modelling and an example will be presented as a proof of the presented concept.

## Efficient application of MBSE using reference models: A PGE case study

**Marvin Müller[1], Paul Schiffbänker[2], Albert Albers[1], Andreas Braun[2], Nikola Bursac[1]**

[1]Karlsruhe Institute of Technology (KIT), Germany; [2]AVL Deutschland GmbH, Germany

Product engineering has become more and more complex, as there are multiple interrelated elements with high dynamic and variance. To support the work of designers and managers, various methodologies have been proposed in the literature. In this paper, it shall be evaluated how the reuse of information stored in reference models can improve the approach of model-based systems engineering to add value in the design process. Therefore a case study is conducted in the battery development department of the AVL List GmbH. A detailed and quantified evaluation of problems caused by complexity is used to derive specific solutions based on the usage of reference models in a model-based approach. Through this approach a reduction of unnecessary effort by 60 % is estimated showing how the usage of reference models adds value in the design process and is a relevant foundation of methodology development.

**TUESDAY, AUG 22**

## D2.7

**2:00 pm – 3:00 pm**
**2504**

CHAIR
*Clement Fortin*

# Model-Based Systems Engineering (MBSE), cont'd

### An approach for holistic model-based engineering of industrial plants

**Yousef Hooshmand, Dmytro Adamenko, Steffen Kunnen, Peter Köhler**
University of Duisburg-Essen, Germany

Systems Engineering has been proven to be an effective approach to cope with the increasing complexity of systems, consisting of mechanical, electrical, electronic and software components. However, as the systems getting more interdisciplinary and in particular more software-intensive, classical document based methods cannot efficiently master the growing complexity. In contrast, model-based approaches look promising in gaining the control over the complexity of systems and the development processes. For this, a formalized system model, integrated in the IT landscape, is indispensable. Thus a pragmatic approach has been developed, which enables a (semi-)automatic creation of formalized system models in SysML. Furthermore, an ontology has been developed to define the relationships and to enrich the system model with more semantic. The system model and the ontology will be then used to connect the domain models and artefacts along the development process. This ensures the required traceability and enables, inter alia, an automatic impact analysis, if any change arises. The federalized solution for the heterogeneous model landscape of industrial plants is applicable to other domains.

### Lightweight visualization of SysML models in PDM systems

**Christian Nigischer, Detlef Gerhard**
TU Wien, Austria

Increasing product complexity and diversity especially in case of mechatronic products leads to the need for extended method and tool support during product development. Specialized authoring tools allow the creation of descriptive product models utilizing modelling languages like the Systems Modelling Language (SysML). The high level of complexity also requires a lot of coordination and collaboration effort and the associated data exchange between a variety of stakeholders. Although specifications exist, exchange of SysML model data — in particular of graphical diagram information — is often not possible due to compatibility problems. Hence, a concept for visualizing SysML models in Product Data Management (PDM) systems without using an authoring tool is introduced. A layer model generated by using design phase information delivered by the Requirements, Functional, Logical, Physical (RFLP) product design approach is proposed. Furthermore, various functions of the visualization module are presented. The so-called "Lightweight Visualization" approach shall ease the exchangeability of SysML model data within distributed development networks.

# Knowledge Intensive Design

TUESDAY, AUG 22

D2.8

2:00 pm – 3:00 pm

2506

CHAIR

*Åsa Ericson*

### Utilizing unstructured feedback data from MRO reports for the continuous improvement of standard products

**Michael Abramovici, Philip Gebus, Jens Christian Göbel, Philipp Savarino**
Ruhr University Bochum, Germany

Industrial product-service systems (IPS²) enable new opportunities for the IPS² provider as the development department gets access to valuable feedback information from the use phase in order to improve follower product generations or currently active product instances. Yet, systematic analyses of this data during product improvement processes at most consider key figures from structured sources or subjective feedback information. The paper proposes a feedback design assistant that allows product developers to derive requirements from knowledge-based analyses of a product's unstructured and structured feedback information, whereas the knowledge extraction from unstructured data is emphasized.

### Gathering and analysing external influences on the product design – a case study

**Daniel Kammerl, Stefan Echle, Markus Mörtl**
Technical University of Munich, Germany

The early phase of each development process is characterised by severe decisions under great uncertainty. To facilitate these decisions, it is crucial to know the (external) influences on the product and the corresponding product development, to offer as large a base of information as possible. There is a broad variety of factors influencing the product and the associated development, which may include legislative changes or mutating customer behaviour. To help the developers make the right decisions it is essential to provide a vast number of information to support this task. The results presented in this paper provide the basis for the approach of including the prognosis of external influencing factors into the planning procedure of products or product-service systems. At first, a literature review was conducted to identify relevant external influencing factors for product and product development. In the following within the framework of the cooperation with an industry partner an approach was elaborated and evaluated. It supports selecting the most important factors for the product or the company, determining the interrelations between them and for weighting their specific impact.

# Knowledge Intensive Design, cont'd

**TUESDAY, AUG 22**

## D2.8

**2:00 pm – 3:00 pm**
**2506**

CHAIR
*Åsa Ericson*

### Framework of the evolution in virtual product modelling and model management towards digitized engineering

**Michael Bitzer[1], Martin Eigner[2], Karl-Gerhard Faißt[2], Christian Muggeo[2], Thomas Eickhoff[2]**

[1]Accenture, Germany; [2]Technische Universität Kaiserslautern, Germany

Manufacturing industries typically have a strong history and focus on development and production of physical products as their strategic core competence. However, today due to more and more software within mechatronic products one can recognize a rethinking towards interdisciplinary product development. Further, in many areas of manufacturing industries the pure product-oriented focus shifts to the stakeholder (customer) needs. Those two aspects drive the need to describe the physical product not only by geometry and properties, but also by its structure and behavior, as well as to interpret and predict the product and its behavior. This paper is a concept paper to discuss the evolution of virtual product modelling and model management in order to determine potential areas of future research and discussion. Previous and ongoing research work and projects are referenced and brought in context. Moreover, a framework is introduced which helps to position previous, ongoing and future research work as well as industry concepts. Further, it provides boundaries of future steps of evolution in the field of virtual product modelling and model management towards "Digitized Engineering".

### Mediating constraints across design and manufacturing using platform-based manufacturing operations

**Jonas Landahl[1], Julia Madrid[1], Christoffer Levandowski[1], Hans Johannesson[1], Rikard Söderberg[1], Ola Isaksson[1,2]**

[1]Chalmers University of Technology, Sweden; [2]GKN Aerospace Sweden, Sweden

To meet the needs of an array of customers, platforms can provide means to achieve commonality and distinctiveness among a family of products. However, typically the producibility of product variants are not ensured until the late platform development phases. This may lead to increased development lead-time, due to lack of integration across design and manufacturing. To be better suited in making early producibility assessments, a model to improve the integration across product platforms and manufacturing platforms is presented. The model is embodying manufacturing operations and marries platform models of two technical systems — products and manufacturing equipment. To serve the concurrency needed to explore cross product-manufacturing alternatives during the early phases of platform development, manufacturing operations can be modeled to serve improved integration of product platforms and manufacturing platforms. By modeling functions, control parameters, and key characteristics, the constraints across design and manufacturing can be mediated.

# Improving Learning Experience

TUESDAY, AUG 22

D2.9

2:00 pm – 3:00 pm

2514

CHAIR

*William Ion*

## Educational games for design and innovation: Proposition of a new taxonomy to identify perspectives of development

**Ana Cortes Sobrino[1], Miliane Bertrand[2], Enzo Di Domenico[2], Camille Jean[2], Nicolas Maranzana[2]**

[1]Universidad del Norte, Colombia; [2]Arts et Metiers ParisTech, France

The main purpose of this paper is to present a new taxonomy to identify perspectives of development of educational games for design and innovation. To develop this proposal, we first presented a state of the art about educational games definitions and taxonomies. After describing their limitations, we then proposed a new taxonomy in the second part with three specific criteria: public, purpose and skill. In the third part, we classified within this new taxonomy all the articles concerned by educational games of the Design Society Database containing more than 7000 papers. Finally, the results are discussed to identify perspectives of development of new educational games.

## Improving the sketching ability of engineering design students

**Ethan Clark Hilton[1], Myela Paige[1], Blake Williford[2], Wayne Li[1], Tracy Hammond[2], Julie Linsey[1]**

[1]Georgia Institute of Technology, United States of America; [2]Texas A&M University, United States of America

From improving spatial visualization skills to concept generation, sketching is both a useful practice and a powerful tool for engineering designers. The method of teaching free-hand sketching in engineering courses has changed little in recent decades as CAD programs become more prevalent. This paper discusses a new method of teaching free-hand sketching in engineering design using pedagogy borrowed from Industrial Design curricula focusing on perspective sketching. An experiment comparing pre- and post-course sketches shows how the perspective method and more traditional method of teaching sketching impact students' sketching ability. The experiment finds that students in the perspective-based sketching course are more likely to improve their sketching ability over the course of the semester. Observing improvements in sketching ability could lead to observations in correlations between sketching ability and other necessary skills in engineering design. These observations could greatly impact our understanding of successful designers and how to train students in engineering design courses.

# Improving Learning Experience, cont'd

**TUESDAY, AUG 22**

## D2.9

**2:00 pm – 3:00 pm**

**2514**

CHAIR

*William Ion*

### Dropping concept bombs: Arguing for a knowledge-focused intervention in sketching to stimulate student engagement with visual thinking

**Charlie Ranscombe, Katherine Bissett-Johnson, Blair Kuys**

Swinburne University of Technology, Australia

Sketching is acknowledged as being a crucial tool in both exploring and representing ideas during the engineering design process. Despite this importance design educators experience difficulties in encouraging students to engage in this type of visual thinking. Existent research attempting to improve engagement focuses on building sketching skills. The objective of this paper is to present an argument for a knowledge-focused intervention providing augmented domain knowledge when designing, in addition to increasing sketching skill. The basis for the argument is the consideration of sketching as a reflective design activity requiring a degree of analogous or domain knowledge, where a lack there of forms a barrier to fluent engagement. Observations and reflections on deploying the intervention (the Concept Bomb) over 3 years of teaching provide evidence for the success of the intervention. Successes are manifested in increased momentum in engaging with design projects, and greater time efficiency when sketching. Reflections also lead to a number of opportunities for further research into the causality of preliminary findings and influence of the Concept Bomb on design fixation.

### Enhancements in engineering design education at Austrian HTL

**Andreas Probst[1], Detlef Gerhard[2], Norbert Ramaseder[1], Martin Ebner[3]**

[1]HTBLA Linz LITEC, Austria; [2]TU Wien, Austria; [3]TU Graz, Austria

In Austria there is a unique curriculum of technical education which is taught at Federal Secondary Colleges of Engineering, commonly known as HTL. This paper gives an overview about continuous research activities together with TU Wien (Vienna), best practises and methods, planned enhancements and the gained experiences concerning PDM (product data management) and systems engineering as well as the impact to daily engineering education.

# NOTES

**TUESDAY, AUG 22**

# Collaborative Design 1

**TUESDAY, AUG 22**

D3.2

**3:15 pm – 4:15 pm**
**Art Gallery**

CHAIR
*Maaike Kleinsmann*

## Using embedded design structures to unravel a complex decision in a product development system

**Alison McKay[1], George Sammonds[2], Saeema Ahmed-Kristensen[2,3], Aleksandra Irnazarow[1], Mark Robinson[1]**
[1]University of Leeds, United Kingdom; [2]Imperial College London, United Kingdom; [3]Technical University of Denmark, Denmark

Early design decisions have an impact on downstream product development processes. Poor decisions can reduce efficiency and effectiveness, and have a detrimental effect on product quality, delivery time, and cost. However, the range of tools suitable for use in early design is limited, in part because of ambiguity in available design definitions. This paper reports research that investigated the role of complex decision making in a quality incident that occurred in the development of a complex product system. A case study approach with document analysis and semi-structured interviews was used. Data were analysed using lenses from both social sciences and engineering design. In this paper, we report the use of embedded design structures to gain insights into the downstream consequences of design decisions. Results indicate that embedded product, process and supply network structures have the potential to underpin a new generation of design tools for considering downstream complexities arising from early design choices. Such tools could both improve the quality of design decisions and support improved management of development processes by highlighting areas of future risk.

## A study on the impact of HOVER platforms on design teams collaborative behaviors during collocated collective early preliminary design activities

**Andrea Luigi Guerra[1,2], Thierry Gidel[1], Enrico Vezzetti[2]**
[1]UTC, Sorbonne Universités, France; [2]Politecnico di Torino, Italy

HOVER platforms are interactive digital working space composed of HOrizontal and VERtical interconnected tactile surfaces. Since ICED 2011, we defended the hypothesis that interactive surfaces can greatly increase the effectiveness of the early preliminary design phase by increasing collaboration. So it is pivotal to understand the impact of such interactive surfaces on collaborative behaviors of design teams. We present the TATIN-PIC HOVER platform, an example of HOVER platform, that we built as a test tool. We describe our experimental protocol to assess if HOVER platforms change the collaborative behaviors of design teams throughout the idea generation phase, compared to traditional pen-and-paper mediating tools. To achieve this goal, we compare pen-and-paper against HOVER platforms. We measure the equity of contributions in the common objectification process (i.e. writing concepts on post-it) with a sample of 40 young practitioners. Our preliminary results show that HOVER platforms tend to change collaborative behaviors from an exclusive collaboration mode to a mutual one. This opens interesting research paths that are presented in the conclusion.

### Interrelations between processes, methods, and tools in collaborative design – A framework

**Ann-Kathrin Bavendiek, David Inkermann, Thomas Vietor**
Technische Universität Braunschweig, Germany

Handling the increasing complexity of modern products like mechatronic systems requires knowledge from different disciplines. Engineers are called to collaborate across companies and disciplines in order to acquire the knowledge needed. However, collaborative design is an established way of product development in practice, there is an increasing need to describe and understand the challenges between processes, methods, and tools as well as the persons involved. We propose an overall framework containing an explanation model and a concept to support the application of methods and communication. The explanation model comprises three views namely process, personal, and technical-methodical view to describe the elements within collaborative design in detail and give insights for the interrelations between the views. The purpose of the model is to analyze collaborations to plan and implement new methods and tools as well as changes in corresponding processes. Based on a detailed description of the single views and prior research on interrelations between personal, process and technical-methodical view, an overall framework and a detailing explanation model are introduced.

### Literature based review of a collaborative design taxonomy

**James Righter, Doug Chickarello, Hallie Stidham, Steven O'Shields, Apurva Patel, Joshua Summers**
Clemson University, United States of America

A 2003 paper at ICED established a collaborative design taxonomy that can be used to breakdown and categorize engineering design teams. This collaborative design taxonomy was evaluated to determine its usefulness, consistency, and applicability. The taxonomy was used to evaluate 24 papers presenting studies on engineering design teams. Results of this literature review provided insight into what has been recently studied in collaborative engineering design and identified that open-ended responses describing design teams need improvement. The group composition merits further review based on its high frequency of occurrence and the need to better characterize complex teams. The distribution branch requires reconsideration of its organization while temporal criteria require additional details to increase its objectivity. These results provide a direction for future work to apply the taxonomy to real time collaborative design scenarios.

# Data-Driven Design Approaches

**TUESDAY, AUG 22**

D3.3

**3:15 pm – 4:15 pm**

**2301**

CHAIR

*Wei Chen*

## Data-driven engineering design research: Opportunities using open data

**Pedro Parraguez, Anja Maier**
Technical University of Denmark, Denmark

Engineering Design research relies on quantitative and qualitative data to describe design-related phenomena and prescribe improvements for design practice. Given data availability, privacy requirements and other constraints, most empirical data used in Engineering Design research can be described as "closed". Keeping such data closed is in many cases necessary and justifiable. However, this closedness also hinders replicability, and thus, may limit our possibilities to test the validity and reliability of research results in the field. This paper discusses implications and applications of using the already available and continuously growing body of open data sources to create opportunities for research in Engineering Design. Insights are illustrated by an examination of two examples: a study of open source software repositories and an analysis of open business registries in the cleantech industry. We conclude with a discussion about the limitations, challenges and risks of using open data in Engineering Design research and practice.

## Mining data to design value: A demonstrator in early design

**Alessandro Bertoni[1], Tobias Larsson[1], Jonas Larsson[2], Jenny Elfsberg[2]**
[1]Blekinge Institute of Technology, Sweden; [2]Volvo Construction Equipment, Sweden

The paper presents a study run to verify the applicability of data mining algorithms as decision support in early design stages of a complex product development project. The paper describes a scenario built in two-stages providing the rationale for the application of data science in engineering design. Furthermore, it describes a demonstrator where usage data are fed back to the early design stage and used to populate value models to reduce the uncertainty in engineering design decision making. The development of a new machine for construction equipment, a wheel loader, is the subject of the demonstration and machine learning algorithms are applied on a dataset built on machine performances and contextual and environmental data. The demonstrator allows the estimation of the fuel consumption of different design concepts and the analysis of the performance variations given by a change in a contextual or environmental variable. Finally, the demonstrator allows the visualization of how much the tested performances of a new design deviate from the original designers' expectations.

## Design analytics is the answer, but what questions would product developers like to have answered?

**Ívar Örn Arnarsson[1], Emil Gustavsson[2], Johan Malmqvist[1], Mats Jirstrand[2]**
[1]Chalmers University of Technology, Sweden; [2]Fraunhofer Chalmers Centre, Sweden

There is a growing need for data expertise and data analysis. Companies are looking more towards analytics for improvement opportunities within the business and products. Data collection is growing at a fast pace and we need capabilities to be able to analyze it. The data volume that companies are sitting on makes this task even more important. The paper presents interviews performed with product developers who have worked on a large complex system development project. The findings explain questions and needs developers are facing and what answers they are looking for with data mining. By Identifying beneficial and meaningful outputs from data mining and data analytics, developers can be supported in making better decisions for a new designs/re-designs and ultimately make a superior robust product. The paper further accounts for 20 heterogeneous purposefully sample interviews, ranging in project roles from product development to manufacturing and testing.

## Investigating usage data support in development processes – A case study

**Manuel Höhn, Christoph Hollauer, Julian Wilberg, Daniel Kammerl, Markus Mörtl, Mayada Omer**
Technical University of Munich, Germany

The design of new product development processes which integrate customer perspective promises great potential regarding rising volatility of external influences, shorter product life cycles and exponential technological advancements. However, the collection of data places great demands on organization's resources and is only useful, if the data collection can ensure adequate quality. Product-Service Systems are a promising approach to collect usage data during their operational phase. A case study was conducted to provide insights to serve as the basis for an information management concept that aims to integrate usage data into design. The observed development process was documented and reconstructed, to identify factors influencing the use of data and information as well as questions that arose during the development project that could be answered by providing usage data. The findings imply that accurate usage data should be provided as early in the development process as possible and that the creation and distribution of information from usage data must be controlled. The proposed concept is designed to meet these requirements by establishing a demand driven information market.

# Organisational Process and Management in Design

**TUESDAY, AUG 22**

D3.4

**3:15 pm – 4:15 pm**
**2306/2309**

CHAIR
*Chris Snider*

## Design of flexible product development processes – An automotive case study

**Christoph Hollauer, Bianca Frisch, Julian Wilberg, Mayada Omer, Udo Lindemann**
Technical University of Munich, Germany

Structured, flexible and tailorable standard processes help companies to conduct development projects successfully. When putting them into practice major issues arise. Often, there is an inadequate documentation of these processes. An additional problem is that the project leaders do not have sufficient support through appropriate methods in order to adjust the processes to their projects. They do not have a detailed overview of all the influencing factors affecting their processes, which effects they have on the development process and how they change over time. Hence, an initial methodological procedure to determine process specific influencing factors has been developed in order to generate project specific adoptable development projects. This work covers the validation and improvement of this procedure via a case study in an OEM in the automotive sector. Furthermore, part of the influencing factors, which were conducted with the mentioned method, are presented along with a developed categorisation scheme.

## Innovation processes in SMEs: Exploring the influence of varying degrees of control

**Anna Karlsson, Anna Öhrwall Rönnbäck, Erika Lind**
Luleå University of Technology, Sweden

Previous research in the field of product innovation management has focused on large firms. This is unfortunate because small and medium-sized enterprises (SMEs) have features that clearly distinguish them from their larger counterparts and also play an important role in the global economy. In addition, SMEs often have more varying control of the whole innovation process — from identification of a customer need to delivering customer value — compared to larger companies. This article addresses this research gap by exploring how SMEs with growth ambitions, and varying degree of control, can leverage their innovation process. The article outlines results from a SWOT analysis utilizing data from a multiple case study of eight SMEs. Both 'product owning' companies (with either in-house or outsourced manufacturing) as well as manufacturing industry subcontractors were sampled. The results show indications of the influence of varying degree of control of the innovation process — relating to different phases, how knowledge and competence are considered and being reliant on others — and how SMEs and their offerings can be considered as parts of larger systems.

### Large-scale engineering prototyping – Approaching complex engineering problems CERN-style

**Achim Gerstenberg, Martin Steinert**
Norwegian University of Science and Technology, Norway

During the early concept creation phase of complex engineering problems with high degrees of uncertainty the design requirements are mostly unknown. Therefore, modules, usually used in manufacturing, and their boundaries cannot be predefined. During the fuzzy front end, requirements need to evolve according to discoveries. We suggest a wayfaring approach consisting of designing, building and testing of ideas where the learning of a test outcome leads to the next design. Instead of rigid boundaries, we suggest flexible envelopes, self-assigned areas of expertise and responsibility, which adapt to changing requirements and project needs. Unproblematic design changes within the envelope are directly implemented but changes that influence neighboring envelopes are negotiated by the developers through a justification and sense-making process. This bottom-up approach, inspired by an organizational structure at CERN, supports interlaced knowledge that enables developers to understand the various design ideas and to debate conflicting design choices already during the ideation phase. Furthermore, the project organization architecture can emerge evolutionary according to the actual needs.

### Process model for data-driven business model generation

**Christian Benta, Julian Wilberg, Christoph Hollauer, Mayada Omer**
Technical University of Munich, Germany

Digitalization is advancing fast and at the same time the volume of data is increasing. Examples from industry show that business models using big data can lead to competitive advantages. Currently the number of smart products is rising, which means more data will be available to engineering companies. The challenge is to extract additional profits and value from it. The literature review revealed that existing process models and methods for business model generation do not consider data in a distinct way. This paper synthesises existing work on business model generation and experience gained during a case study in an engineering student project to develop additional support for the generation of data-driven business models. The developed business model canvas helps to better outline the data requirements of business models. The developed process model describes the important phases for generating data-driven business models. The results of the case study indicate that the support helps to make the data perspective more visible and leads to new ideas. Furthermore, the support improves the coordination between product and business model development. The paper closes with a outlook.

# Design Representations

**TUESDAY, AUG 22**

D3.5

**3:15 pm – 4:15 pm**

**2311**

CHAIR

*Gaetano Cascini*

## Does prototype format influence stakeholder design input?

**Michael Deininger[1], Shanna Daly[1], Kathleen Sienko[1], Jennifer Lee[1], Samuel Obed[2], Elsie Effah Kaufmann[2]**

[1]University of Michigan, United States of America; [2]University of Ghana, Ghana

This research investigates how prototype format, here defined as the physical nature of a prototype, influences feedback from stakeholders in the process of designing a medical device. We presented medical practitioners with a variety of prototypes, including a sketch, a cardboard mock-up, a CAD model and a 3D printed model, of the same idea for an assistive, contraceptive implant insertion device and asked for their feedback. We found that the prototype format influenced the distribution within the answer categories. We also found that the type of question influenced the distribution within the answer categories.

## Evolving LEGO: Prototyping requirements for a customizable construction kit

**Duncan Boa, David Mathias, Ben Hicks**

University of Bristol, United Kingdom

The PhysiCAD project is a technical feasibility study into the creation of tangible interfaces for Computer Aided Design (CAD) using construction kits. Construction kits, such as LEGO, are a collection of pre-defined physical elements that can be combined using standardised interfaces to produce more complex artefacts. Construction kits like LEGO have a low skill threshold to start using and are highly reconfigurable. The aim of the PhysiCAD project is to merge the benefits of construction kits with CAD. This paper concentrates on one aspect of the PhysiCAD project, how construction kits can be changed to support the representation of physical concepts. To this end we propose the concept of an evolving construction kit with the capability to define and generate new element types within the system. In this paper five requirements for an evolving construction kit are identified along with technical solutions for implementing them. Examples of some of the technical solutions are included along with a discussion about how they could be used to generate new evolved construction kit elements.

### Use case based methodology for conceptual design of industrial mechatronic products

**Régis Kovacs Scalice, Gian Ricardo Berkenbrock, Yesid Ernesto Asaff Mendoza**
UFSC Universidade Federal de Santa Catarina, Brazil

Mechatronic products play an important role on industry, providing solutions to increase productivity and cost reduction. On the other hand, to develop products for industrial use requires a different set of tools and methods than the ones employed by the design of consumer goods. The existing methods for mechatronic design in general does not focus on industrial product specifically, or provides just an overview of the process for a generic mechatronic product, without focusing on tools and activities. Our proposal integrates the Task Clarification and Conceptual design phases providing an iterative procedure to the design of mechatronic industrial products. The core of this proposal is the use of Use Case Diagrams to provide information necessary to requirements definition, functional modelling and solution principles establishment. To evaluate the proposed method, it was employed on the development of an Automated Vehicle for Railroad Inspection, a maintenance task regularly performed to guarantee the railroad safety. It was observed the viability of the proposal to obtain the desired information from Use Case Diagrams.

### A crowdsourced design experiment using free-hand sketch design method based on the cDesign framework

**Hao Wu, Jonathan Corney**
University of Strathclyde, United Kingdom

In the age of ubiquitous, global Internet the process of product design is no longer confined to individuals or groups of employees but can be carried out by the combined efforts of many people through systematic, iterative processes. Although the literature reports several qualitative experiments, the process of specifying the details of an Human-based Genetic Algorithms process has been less considered. This paper reports the results of an experimental assessment of a generative design task that has been crowdsourced by an HBGA process specified by application of the Crowdsourced Design (cDesign) framework.Additionally, the application of free-hand sketch method in crowdsourced design task is firstly introduced based on the cDesign framework. The paper first describes the cDesign framework used to structure the creation of a car key fob design task on a commercial crowdsourcing platform and then presents the results to test the effectiveness of the free-hand sketch method in cDesign. The paper concludes that the free-hand sketch method can be well applied in the HBGA cDesign framework and cDEC assessment methodology effectively to generate creative design solutions.

# Experience Design

**TUESDAY, AUG 22**

D3.6

**3:15 pm – 4:15 pm**

**2314**

CHAIR

*Hideyoshi Yanagisawa*

## Proposal for a new usability index for product design teams and the general public

**Anthony Brandy[1,2], Fabrice Mantelet[2], Améziane Aoussat[2], Pierre-Vincent Pigot[1]**

[1]H4D Health for Development, France; [2]ENSAM, France

Usability is a key notion in most of products, especially for the medical devices. Nevertheless, sometimes this notion can be shelved in favour of other priorities such as reliability of the product. However many incidents related to products find their origin in bad usability. It's the reason why usability should reaffirm its role in product design by a greater inclusion. The challenge of this situation is to introduce the usability notion in the design process of products as medical devices in a simple and easily understandable way while the sector of medical devices for example is mostly made up of SMEs. A usability quantification would enable the enforcement of its role in this type of design. Moreover, usability quantification tools are often seen with a point-in-time approach that inhibit a complete integration in the design process. Finally usability quantification in the form of an index monitoring the product during its design process could be a solution to help the design team in decision-making, enhance the communication in the design team about usability and popularize the notion among the general public.

## On the products and experiences that make us happy

**Xi Yang, Marco Aurisicchio, James Mackrill, Weston Baxter**

Imperial College London, United Kingdom

The study of happiness is receiving increasing attention both in positive psychology and design. A key issue in current literature is the lack of empirical evidence linking products and happiness. We address this examining 87 reports of product-mediated happy experiences and analysing their relations to well- being. Six types of products with experiential attributes were reported to contribute more systematically to happiness. Digital devices and food are the two dominant products followed by vehicles, books, clothing & accessories and sport equipment. These products make us happy by creating: hedonic experiences in which we relieve stress, get rest and increase joy; and eudaimonic experiences in which we establish positive social relationships, develop self-identity, achieve personal growth and gain competence and autonomy. In such experiences, products acted as carriers of reflective meanings, and enablers of experiencing. These insights provide an initial mapping of the relationship between products and happiness and suggest approaches to designing products that can bring happy experiences.

### Positive and negative contamination in user interactions

**Weston Baxter[1], Marco Aurisicchio[1], Ruth Mugge[2], Peter R. N. Childs[1]**
[1]Imperial College London, United Kingdom; [2]Delft University of Technology, The Netherlands

The purpose of this paper is to present contaminated interaction as a design construct. Interactions with an object can be altered, positively, neutrally or negatively, due to some prior use. In such cases, the interaction departs from the designed condition and is said to be contaminated. This is particularly significant as objects, physical or non-physical, have multiple uses or are shared amongst users. We propose an ontological model of contaminated interaction based on a review of literature and an analysis of user experiences. The model outlines the process of contaminated interaction including the drivers and outcomes. In a negative context, contamination can lead to consumers misusing, negatively experiencing, or avoiding the object altogether. Positive contamination sees the opposite effect in which usability can increase, users report more positive experiences and users seek out or cherish the object. Together, this model presents an approach to understanding and addressing contamination in the design process to enable the creation and maintenance of meaningful experiences.

### Experiential qualities of science museum exhibits: A thematic analysis

**Jose Ocampo-Agudelo[1,2], Jorge Maya[1]**
[1]Universidad EAFIT, Colombia; [2]Parque Explora – Science Museum, Colombia

Designing and supporting the visitor experience with interactive exhibits in science museums is a complex endeavor, particularly because many factors are interrelated and its subjective and dynamic nature. Over the past two decades, a number of studies have addressed this subject from different perspectives. However, the majority of published work addresses only some aspects and most of them are under-articulated. To address this issue, this article attempt to understand how different approaches relate and complement each other. A 'theoretical' thematic analysis was conducted to identify the essential constituent elements of the visitor experience with interactive science museum exhibits. The results of this paper indicate that the visitor, the interactive exhibit, the physical and social context, the engagement process, the learning experience and the science museum purpose are interconnected. Each element is reviewed and defined in detail, delineating its major characteristics.

# Product Service Systems 1

**TUESDAY, AUG 22**

D3.7

**3:15 pm – 4:15 pm**

**2504**

CHAIR

*Daniela Pigosso*

## An engineering approach to mapping meanings in products and services

**Gregor Waltersdorfer[1], Kilian Gericke[1], Pieter Desmet[2], Lucienne Blessing[3]**

[1]University of Luxembourg, Luxembourg; [2]Delft University of Technology, The Netherlands; [3]Singapore University of Technology and Design, Singapore

The aim of this paper is to explore how meanings in products and services can be captured, deconstructed, and finally structured, in order to facilitate the deliberate and intentional creation and conveyance of meanings to users and non-users. These analytical steps for mapping meanings are investigated in an empirical study using a qualitative approach and theoretically grounded in Peirce's triadic model of signs. This new methodology in design research seems promising to obtain a new perspective on meaning in products and services. Through the course of the empirical study, we developed a research method, which is also a design method, called MeaningMap, for organising and structuring meanings. A first exploratory evaluation of the method with students showed its comprehensibility and applicability for analysing and structuring meanings within a limited amount of time. We envision that the MeaningMap as a method for design as communication can support designers during task clarification in analysing the voice of customer, defining user group, specifying the intended meanings, and deriving requirements to the communicative potential of products and services.

## Extending system design tools to incorporate user- and contextual elements in developing future products and services

**André Liem**

Norwegian University of Science and Technology, Norway

This article aims to extend systems thinking to include user-, and contextual elements. Such extension should be angled towards increased human intervention and multiple stakeholder involvement in predetermined contexts. Bounded Rationality, Practice Theory and Situated Design were selected as core theoretical concepts to explain that the relationship between Prospective Ergonomics (PE) and Systems Thinking are built upon both positivist and constructivist worldviews. A systems approach embedded within PE intervention provided a foundation for extending structured systems design methods, such as Function-Task Interaction Matrix Method (FTIM), Dependence Structure Matrix (DSM), etc. As user-, and contextual elements were incorporated and juxtaposed in these extended matrices, a more comprehensive approach in using system design tools has been introduced to anticipate future products and services. Such an extended systems design approach significantly operationalises and systematises innovation, while allowing the flexibility to embrace inconsistencies, and emergent ways of strategising innovation and decision making.

### Framing key concepts to design a human centered urban mobility system

**Ouail Al Maghraoui[1,2], Flore Vallet[1,2], Jakob Puchinger[1,2], Bernard Yannou[1]**
[1]CentraleSupélec, Université Paris-Saclay, France; [2]IRT SystemX, France

Urban mobility poses some sustainability and design practice challenges. Mobility components such as vehicles, urban infrastructure, mobility services or other services delivered along a mobility experience are often designed separately. The performance of a global urban mobility system, at a city scale for instance, is therefore parceled out into components' ones that are not integrated from the perspective of a user who interacts with them in a door-to-door journey. This paper starts with relating different perspectives of urban mobility including, in crescendo, the human in the production of a global design solution. Through the examination of design and transport literature as well as practical examples, the paper highlights complexity factors of urban mobility that challenges engineering design. A second contribution is to identify relevant design objects aiming at providing a language for designing urban mobility.

### Modeling the relationship between aviation original equipment manufacturers and maintenance, repair and overhaul enterprises from a product-service system perspective

**Cassio Goncalves, Michael Kokkolaras**
McGill University, Canada

In this paper, we provide the main arguments for developing a collaborative product-service system business model between aviation original equipment manufacturers (OEMs) and maintenance, repair and overhaul (MRO) companies. The premise of this work is that such cooperation should benefit not only the OEMs and the MRO companies, but also other stakeholders such as operators and end-users. We also present the basic components of the model. It should be noted that the mathematical model has been built; however, page limitations do not allow us to present it in detail here. The model is currently utilized to conduct a large-scale case study that will be submitted for publication in the near future.

# Analysis and Capture of Design Rationale

**TUESDAY, AUG 22**

## D3.8

**3:15 pm – 4:15 pm**
**2506**

CHAIR
*Detlef Gerhard*

### How explicit are we in a design meeting: Investigation on meeting knowledge structuring with design rationale

**Xinghang Dai, Frank Velde**
University of Twente, The Netherlands

Knowledge management can improve a company's competitiveness by managing organisational knowledge as a company's capital. However, the knowledge produced in a meeting is hard to be captured due to its collective and volatile nature. In this paper, we want to zoom into the issue of knowledge management for design meetings. Since it is impossible for an individual to reconstruct the group decision making process without any personal bias, and designers are incapable or reluctant to document collectively their reasoning process during a meeting, we want to investigate the feasibility to reconstruct the design rationale of a naturalistic small group meeting, based on a collection of meeting recordings. We want to examine how much explicit knowledge can be extracted from our meeting data. A semantic network based design rationale model is proposed to classify the meeting data, and we will demonstrate the result of using design rationale as a knowledge representation for naturalistic design meeting, as well as the limit of this representation.

### Lessons learnt from experts in design rationale knowledge capture

**Mark Hall[1,2], Pablo Bermell-Garcia[1], Ranjit Ravindranath[1], Christopher McMahon[2,3]**
[1]Airbus Group Innovations, United Kingdom; [2]University of Bristol, United Kingdom; [3]Technical University of Denmark, Denmark

The focus of this paper is on the use of argumentation models and software tools to support knowledge capture in the design of long-life engineering products. The results of semi-structured interviews with a number of experts in the field are presented, exploring their collective experience of knowledge capture and eliciting guidelines for successful implementation of such models and tools. The results of this research may be used as the basis for the design of future tools and techniques for knowledge capture.

### Support management of product families and the corresponding automation systems – A method to capture and share design rationale

**Morteza Poorkiany, Joel Johansson, Fredrik Elgh**
Jönköping University, Sweden

The ability to innovate and launch customized products that are well matched to customer demands is a competitive factor for many manufacturing companies. Development of highly customized products requires following an engineer-to-order business process to tailor the products according to customers' specifications, which brings more value to the customer and profit to the company. Using design automation systems to automate repetitive and time consuming design tasks enables the manufacturers to perform custom engineering in minimum time. To manage and maintain a product family and the corresponding automation systems, updating the design knowledge is required. Use of design rationale will normally become a necessity to allow a better understanding of the knowledge. Consequently, there is a need of principles and methods to enable capture and effectively share the design rationale. In this paper a method for capturing and sharing design rationale is presented. The results are evaluated in a case company which is a supplier of tooling for manufacturing industry.

### Climbing C-trees: Analysing Concept-tree content and construction

**Eric Blanco, Marie-Anne Le Dain, Pierre Lavayssiere, Pierre Chevrier**
Université Grenoble Alpes, France

The aim of the paper is to analyze the rationale of production of C-trees used in innovative design workshop implementing C/K theory. Data had been produced within industrial creative workshops in four Medium industries. Workshops had been conducted by the researchers and 5 C-tree had been produced and analyzed. Existing patterns and rationale in the construction of the C-trees are researched. The Analysis of the content and structure of the C-trees shows that five types of partition are used. The sequence of partition doesn't show any pattern. The subjectivity of the representation is illustrated. Mechanisms of systematic expansion of C space are also illustrated through the C-tree analysis. Based on case study, the paper discuss practical use of C-tree as intermediary object.

TUESDAY, AUG 22

D3.9

3:15 pm – 4:15 pm

2514

CHAIR

*Johan Malmqvist*

# Virtual Design Teams/ Project-Based Learning

## Success factors of an IPD based approach in a remote multidisciplinary team environment – Reflections on a case study

**Narges Asadi[1], Fausto Guaragni[2], Florian Johannknecht[3], Michael Saidani[4], Philipp Scholle[5], Jonathan Borg[6], Daryna Panasiuk[7]**

[1]Mälardalen University, Sweden; [2]Universität der Bundeswehr München, Germany; [3]Leibniz Universität Hannover, Germany; [4]CentraleSupélec, Université Paris-Saclay, France; [5]Paderborn University, Germany; [6]University of Malta, Malta; [7]University of Technology of Troyes, France

Integrated Product Development (IPD) is comprehensively discussed in literature. The human-centered approach offers a parallelized set of work activities in interdisciplinary teams. Due to the rapid globalization of IPD activities in the companies, project members are often obliged to work remotely in teams and through virtual means of communication. However, with the recent shift towards working remotely in IPD teams new challenges have emerged that might adversely affect the success of IPD projects. The objective of the paper is to outline the key factors strengthening and weakening the IPD process in a remote multidisciplinary team environment. To fulfill the objective, a case study on an international multidisciplinary team of postgraduate students working on a design project with an IPD approach, was conducted. The results highlight key success factors and their contributions to the project success in a remote multidisciplinary team environment. Additionally, key weaknesses of such approach and their negative impacts are also indicated.

## Correlation between team composition and team performance in virtual student product development teams

**Nikola Vukasinovic, Vanja Cok, Roman Zavbi**

University of Ljubljana, Slovenia

This paper is presenting an experiment which was performed to investigate the correlation between team composition and team performance in specific case of virtual student teams working on industrial assignments of new product development. The experiment is based on Belbin's team role framework with the hypothesis that balanced teams perform better than unbalanced teams. The paper also briefly introduces the EGPR course and student virtual teams, which served as the objects of the experiment. The experimental results show no correlation between team composition and team performance, which is in line with some other studies. Many researchers argue that team composition indices used in various studies might not be appropriately defined. EGPR course has some specifics which have to be taken into account when evaluating this study: it has student product development teams, although the EGPR projects are characterized by high level of authenticity, the teams are partially virtual and partially co-located, international and coached by experienced university staff. All these characteristics might influence the correlation.

## The use of social network sites in a global engineering design project

**Ross Brisco, Robert Ian Whitfield, Hilary Grierson**
University of Strathclyde, United Kingdom

The global design project challenges students from three European universities to work in engineering design teams on the development of a product. To execute the design process, students have chosen to utilise social network sites as a platform for communication and collaboration. The aim of the study was to investigate how students were utilising social network sites as part of their collaborative work during the global design project and their views on the level of support given. A survey and semi-formal interviews were used to collect data on views and the use of social network sites. The study reveals: (1) the popularity of different social network sites for social and academic tasks, (2) the expectation of support students' and academics' think is required, and (3) a need for greater guidance in the use of social network sites. The use of social network sites by students' is discussed with a focus on how they can be better supported in future projects. This paper proposes that students' and academic staff require guidance on the best practices for using social network sites in global design projects to support students' education.

## Integrated product development project in a multi-cultural and multi-professional background team: challenges and key success factors

**Bastian Lippert[1], Martin Ahrens[2], Jonathan Dekhiar[3], Rim Louhichi[4], Young-Woo Song[5], Ferdinand Toepfer[6], Juan Briede[7], Sandor Vajna[8], Kristin Paetzold[9], Jonathan Borg[10]**
[1]Leibniz Universität Hannover, Germany; [2]Johannes Kepler University Linz, Austria; [3]UTC, Sorbonne Universités, France; [4]Université Paris-Saclay, France; [5]Ruhr University Bochum, Germany; [6]Daimler AG, Germany; [7]Universidad del Bío-Bío, Chile; [8]Otto-von-Guericke-University Magdeburg, Germany; [9]Universität der Bundeswehr München, Germany; [10]University of Malta, Malta

This paper describes the key success factors of an integrated product development project involving several stakeholders from different professional and cultural backgrounds. Based on a summer school project, a detailed case study is described to illustrate the importance of project team commitment and member profile complementarities in achieving the project requirements under time, geographical and cultural constraints. The case study consists in designing a human washing device for elder people to allow them a certain degree of freedom and privacy to wash themselves. Thereby, engineering, manufacturing as well as a business aspects has to be considered in the final concept. After analyzing the case study, challenges as well as opportunities during the project are summarized and described in an adapted approach. At the end, the main influence factors for a successful integrated product development project are analyzed and concluded hierarchically.

## Break

**4:15 pm – 4:30 pm Atrium Lower Level**

**TUESDAY, AUG 22**

# D3.9

**3:15 pm – 4:15 pm**
**2514**

CHAIR
*Johan Malmqvist*

**TUESDAY, AUG 22**

# Collaborative Design 2

TUESDAY, AUG 22

D4.2

**4:30 pm – 5:30 pm**
**Art Gallery**

CHAIR
*Maaike Kleinsmann*

## Designing with LEGO: Exploring the influence of low fidelity visualisation on collaborative design activities

**Charlie Ranscombe[1], Katherine Bissett-Johnson[1], Duncan Boa[2], Ben Hicks[2]**
[1]Swinburne University of Technology, Australia; [2]University of Bristol, United Kingdom

Sketches, cardboard mock-ups, and digital modelling software are typical media at a designer's disposal for visualising and evaluating ideas. Recent research indicates the benefits of using such media with a limited level of detail (low fidelity) when representing designer's concepts. Similarly LEGO has gained traction as a visualisation media in co-design and strategy building contexts, where its low fidelity is key to communication across different disciplines. The research in this paper compares LEGO with traditional visualisation media (sketching, cardboard mock-ups and CAD) to understand its influence on collaboration . An experiment was conducted where teams of industrial designers were given a short design task for which to develop solutions using different visualisation media. Results from the study showed that teams using lower fidelity visualisation engaged in more collaborative behaviour than those using traditional media and generated more ideas. This suggests that there are benefits to constraining the level of detail in visualisation media for concept generation during early stages of design process.

## Which are the limitations of ICT tools for collaborative design with suppliers?

**Yassine Talas[1], Lilia Gzara[1], Marie-Anne Le Dain[1], Valéry Merminod[1], Alejandro Germán Frank[2]**
[1]Université Grenoble Alpes, France; [2]Universidade Federal do Rio Grande do Sul, Brazil

New Product Development (NPD) is increasingly relying on Information and Communication technologies (ICT) to support collaborative activities conducted by NPD actors. On the other hand, companies growingly integrate suppliers into their NPD process in order to enhance their innovation capability. The purpose of this paper is to explore the limitations of ICTs usage in the context of collaborative design with suppliers. To address this question, we propose to analyze usage drawing upon a functional classification of ICT tools. The framework will allow us to highlight the limitations according to each main functionality supported by ICTs. In this respect, three case studies are conducted with insight at the company level. The results show that for knowledge management and project and resource management functionalities, limitations will differ according to the use or not of a shared tool to collaborate. The study also shows that for cooperative work functionalities, some ICTs incompatibility issues might occur. Our conclusions pointed out some customer-supplier relationship specificities that condition ICT usage, like trust, and power and dependence factors.

# Collaborative Design 2, cont'd

**TUESDAY, AUG 22**

D4.2

**4:30 pm – 5:30 pm**
**Art Gallery**

CHAIR
*Maaike Kleinsmann*

### Exploring the decomposition of team design activity

**Tomislav Martinec, Stanko Škec, Mario Štorga**
University of Zagreb, Croatia

Presented research explores the nature of teamwork activity in the conceptual design phase with an aim to unfold the patterns of team behaviour during execution of a specific design task. Teamwork activity process is observed as a sequence of analysis, synthesis and evaluation design operations applied to the problem and solution spaces. Design operations are used to represent abstract and fine-granularity steps of exploring and modifying the problem-solution space. Protocol study was conducted to investigate if teamwork activity can be decomposed into patterns of design operations and problem-solution alternation. Brainstorming sessions of two design teams were coded by employing an operation-based coding scheme. Protocol segmentation revealed the distribution of design operations and problem-solution related discussion, as well as the distribution of transitions between design operations. The emphasis is placed on the cycles of synthesis and analysis that appear within both problem and solution space, but also in-between the two spaces, thus indicating the co-evolution of the problem-solution space. These findings support and complement what has been reported in the literature.

### Fostering collaborative project emergence through divergence of opinion

**Julien Ambrosino[1,2,3], Dimitri Masson[2], Audrey Abi Akle[2], Jérémy Legardeur[2,3]**
[1]Aerospace Valley, France; [2]ESTIA, France; [3]Laboratoire IMS, France

In the context of the emergence of collaborative innovation projects between competitiveness clusters, the animation of creative sessions permits to identify new opportunities. The number of ideas generated is a lot more important than the number of collaborative innovation projects implemented subsequently. To improve this ratio, we verify that group discussions could be facilitated by improving the ideation and evaluation phases of ideas during innovation process. Especially, in this article, we test many hypotheses in order to show that divergence of opinions can foster collaborative project emergence.

# Cyber-physical systems and Digitalisation

TUESDAY, AUG 22

D4.3

4:30 pm – 5:30 pm

2301

CHAIR

*Henrique Rozenfeld*

## Fundamental challenges in developing Internet of Things applications for engineers and product designers

**Timon Heinis[1], Carlos Gomes Martinho[2], Mirko Meboldt[1]**

[1]ETH Zurich, Institute of Design, Materials, and Fabrication, Switzerland; [2]ETH Zurich, Institute of Robotics and Intelligent Systems, Switzerland

Decreasing cost for computing power, connectivity and electronics arouse potential for a variety of Internet of Things (IoT) applications but the development of value-adding IoT applications evolves still relatively slowly. To foster their realisation, IoT application development must be approached holistically. The identification of development challenges is a necessary groundwork for a holistic design methodology. This paper presents the development of an IoT application based on an existing mechatronic product as case study and derives challenges faced by developers with an engineering design background. An IoT add-on device is integrated into a mechatronic system. The use of actuators can be monitored in real-time. The identified challenges relate to the identification of added value, making of design decisions, understanding the target physical object, keeping iteration cycles equally short and learning of new skills. The identified challenges inhibit the realisation of IoT applications and must be addressed to foster IoT applications in industry. In future, methods to identify value-adding IoT applications and tools to efficiently realise such applications must be developed.

## Value chains and digitization of product development processes

**Bernhard Meussen**

NORDAKADEMIE gAG, Germany

Currently, the digitization of value chains in the industrial context is intensively researched upon and discussed in engineering science. In the beginning, the scientific discourse was mainly technically driven. Soon, it became evident that the efforts for digitization may not only be economically justified by rationalization of processes, but that new business models, better products and types of services could benefit from these techniques. Consequently, research evolved into the direction of value chains and business models that could be improved by digitization. Possible improvements are individually designed products to better match customer requirements and new digitized types of services that go along with the use of cyber-physical systems (CPS) as products. Recent studies predict huge economical benefits, both for national economies and for businesses. An aspect of this development to be considered is the full digitization of the product development. This paper tries to give an practical approach how digitization of product development should take place.

# Cyber-physical systems and Digitalisation, cont'd

**TUESDAY, AUG 22**

D4.3

**4:30 pm – 5:30 pm**
**2301**

CHAIR
*Henrique Rozenfeld*

## Cyber-physical effects on the virtual commissioning architecture

**Benjamin Illmer[1], Jerome Kaspar[2], Michael Vielhaber[2]**
[1]ZeMA – Zentrum für Mechatronik und Automatisierungstechnik gGmbH, Germany;
[2]Saarland University, Germany

In order to satisfy the growing customization desire and, thus, effecting an increasing product variability, future manufacturing systems have to be harmonized with new technologies such as cyber-physical systems. This leads to different actual challenges inside various technical working areas, for example, manufacturing and assembly. Beside the implementation of new technologies, developers are faced with the challenge to reduce the time-consuming commissioning of the manufacturing systems by using already established methods, such as the virtual commissioning, which provides the possibility to detect mechanical design errors and achieve a very high maturity level during the planning phase. The basis will set with the generation of a virtual manufacturing model, which can be used to visualize and validate the physical behavior of production systems in a very early phase of the production planning process. These planning strategies have to be set in a transferable method to enable the practical introduction of cyber-physical systems. Therefore, this publication gives an approach of the effects that cyber-physical systems have on the virtual commissioning architecture.

## Life cycle development – A closer look at strategies and challenges for integrated life cycle planning and upgrading of complex systems

**Anja Cudok, Tobias Huth, David Inkermann, Thomas Vietor**
Technische Universität Braunschweig, Germany

Life cycle development provides a framework for methods and strategies to develop a product and its related processes regarding technical, economic, ecological and social properties over the whole life cycle. Several disciplines are involved to plan, design and implement the product life cycle. This contribution states that current modelling approaches are mostly driven by one discipline and, thus, focus on certain groups of modelled properties. It is hypothesized that integrated modelling approaches, combining the interests of the parties involved, have to be developed to display the properties and their relations in one model. This paper first introduces the life cycle development framework and existing methods to support the phases of planning, design and implementation. Two needs for further research are derived and motivated, addressing certain excerpts of life cycle development: (I) an analysis of existing modelling approaches in life cycle planning, aiming at the detection of links between these approaches and developing integrated models; (II) an approach to integrate software and hardware modelling with the aim of extending a mechatronic product's life time.

# Agile Design Approaches

TUESDAY, AUG 22

D4.4

**4:30 pm – 5:30 pm**
**2306/2309**

CHAIR
*Boris Eisenbart*

## Towards Agile Product Development – The Role of Prototyping

**Annette Isabel Böhmer, Rafael Hostettler, Christoph Richter, Udo Lindemann, Jörg Conradt, Alois Knoll**
Technical University of Munich, Germany

The complexity in all products and processes increases and the need for operative agility is seen as a key factor of success (Link and Lewirck, 2014). Agile approaches are extremely beneficial for situations with high uncertainty and a continuously changing environment. During the exploration new insights are gathered and an abstract vision becomes a concrete product idea. Based on testing and user feedback the feature set is adapted. The guiding principles are the interdisciplinarity and the strong design orientation. Rapid implementation of ideas into objects ("manifestation") triggers internal and external communication and feedback mechanisms. The prototype is seen as a process- and phase-spanning driver of the innovation process. However to date, there is no clear understanding of how an agile development actually looks like in the field of mechatronics and what the role of prototyping is in this context. Thus, the goal of this explorative study is to evaluate how prototyping is related to a mechatronic project path with regards to agile development. To this end, a prototyping roadmap is used to derive an agile mechatronic product development.

## The agile toolbox – Adaptation of agileMPPs to the mechatronic development process

**Kristin Goevert, Michael Baumgartner, Udo Lindemann**
Technical University of Munich, Germany

Product development is challenged by the customer needs of individualization or own space of action. To solve these challenges, new methods, procedures and principles for product development are necessary. Agile development methods from software development are a promising approach, which could be adapted to mechatronic development. However, many adaptions fail. Therefore this paper develops the agile toolbox, which supports the selective use of agile methods, procedures and principles (agileMPPs). One reason of failed adaptions is a non-consistent understanding of what agile development is. This paper first provides an overview of agile methods, procedures, and principles. They are analyzed and the results are structured in the agile toolbox. The toolbox allocates the agileMPPs at the phases of the v-model. So, the toolbox supports the selective use of agileMPPs in the mechatronic development process. Only the selective use of agileMPPs made the benefits of agile development possible. The contributions of the agile toolbox are evaluated within a series of expert interviews.

# Agile Design Approaches, cont'd

**TUESDAY, AUG 22**

D4.4

**4:30 pm – 5:30 pm**
**2306/2309**

CHAIR
*Boris Eisenbart*

### Agile development and the constraints of physicality: A network theory-based cause-and-effect analysis

**Tobias Sebastian Schmidt, Abdo Chahin, Johannes Kößler, Kristin Paetzold**
Universität der Bundeswehr München, Germany

Not only software development, but also many companies developing physical products (not purely software) face high uncertainties and dynamics which raises the need for agile practices well-proven in software development. However, so-called constraints of physicality (e.g. duration to build potentially shippable increments) make it very difficult to become agile. Challenges associated with the constraints of physicality are highly interdependent and form an entangled, complex system. It is not obvious to find the root or pinpoint challenges with extraordinary high influence on others. Therefore, the investigation's goal is to identify most important challenges by separating between causes and effects. Knowing this can increase the effectiveness of research efforts in the realm of agile development. The investigation identifies 153 challenges and 160 interdependencies, and detects four backbones through the network that experts from industry rate highly influencing. Those point in particular to issues with product separation into increments, flexibility and scaling that represent very effective directions to overcome or reduce the impact of the constraints of physicality.

### Approaches to increasing method acceptance in agile product development processes

**Nicolas Reiß, Albert Albers, Nikola Bursac**
Karlsruhe Institute of Technology (KIT), Germany

This paper presents the results of a 4-year study dealing with concept for increasing the method acceptance in development processes. Therefore, three approaches are presented and discussed. During product creation, product developers can apply various methods to be supported in their work and enhance the quality and efficiency of the respective processes. Even though the additional benefits and added value of the different methods have been verified in many studies, they are not used very widely due to insufficient transparency about relevant methods suitable for the specific situations and requirements, deficiencies in user friendliness, and a lacking sense of achievement during everyday use. This paper points out and discusses different approaches to increasing the acceptance of methods applied during agile product development processes.

# Computational Conceptual Design

TUESDAY, AUG 22

D4.5

4:30 pm – 5:30 pm

2311

CHAIR

*Jonathan Cagan*

## The Analogy Retriever – an idea generation tool

**Ji Han, Feng Shi, Liuqing Chen, Peter R. N. Childs**

Imperial College London, United Kingdom

Idea generation plays a vital role in design, but coming up with ideas, especially creative ideas, is often challenging. Analogy is considered as a fundamental component of creativity and a beneficial method for idea generation. This paper presents a computer-based tool, named the Analogy Retriever, for assisting designers in idea generation and prospectively in idea elaboration. The tool is based on an algorithm simulating aspects of the human cognitive process of analogy. It is focused on solving proportional analogy problems (A:B::C:X) by retrieving the unknown term X from a knowledge database. The Analogy Retriever has been indicated to be useful and effective for helping the designers concerned generate creative ideas through conducting a case study. The results indicate that the Analogy Retriever, in its current formulation, can significantly improve the quantity, quality, novelty, and variety of the ideas produced. The tool is suggested to be greatly beneficial to design space exploration and expansion.

## An automated generation method of system architecture with component's multi-criterion evaluation

**Ruirui Chen[1], Yusheng Liu[1], Ying Liu[2], Zhinan Zhang[3], Xiaoping Ye[4], Jie Hu[3]**

[1]Zhejiang University, People's Republic of China; [2]Cardiff University, United Kingdom; [3]Shanghai Jiao Tong University, People's Republic of China; [4]Lishui University, People's Republic of China

System architecture is important for the design of complex mechatronic systems since it acts as a connection between conceptual design and detail design. An efficient automatic system architecture generation method is imperative for successful system design. However, some deficiencies remain, such as the omission of function-component mapping, the component combination explosion etc. In this study, an automatic system architecture generation method is proposed. First, the unified model of architecture information is established and two mapping manners are proposed. Then, the set of components which can realize the same function are further filtered and evaluated according to specific requirement. Finally, the compatible components are combined together to fulfill the overall function of the product. This method is supported by ontology knowledge base, and has good visual effect using SysML, which enables system designers to design a product efficiently. A case study is provided to demonstrate the feasibility and efficiency of the method.

# Computational Conceptual Design, cont'd

**TUESDAY, AUG 22**

D4.5

**4:30 pm – 5:30 pm**

**2311**

CHAIR

*Jonathan Cagan*

## Generic generative design systems to imprint personalities in consumer products: Preliminary results

**Alejandra Beghelli[1], Juan Briede[2], Miguel Carrasco[1], Pablo Prieto[3]**

[1]Universidad Adolfo Ibañez, Chile; [2]Universidad del Bió-Bió, Chile; [3]Universidad Técnica Federico Santa María, Chile

Generative design is a computer aided design system that automatically or semi-automatically produces design solutions. Generative design systems help designers to save time and labor during the conceptual stage of the design process by providing them with a high number of design alternatives or emergent design patterns the designer can use to further refine the final design solution. They can also be used by non-specialists to quickly generate much needed design solutions. Several generative design techniques for different consumer products have been proposed to date. However, none of them allow imprinting a personality to the product in such a generic way that the method is independent of the product being designed. Given that customers prefer products whose personality is similar to their own, the capability of generating personality-based products is key for their successful introduction to the market. In this paper we present preliminary results of ongoing research on the development of generative design techniques that imprint personalities to consumer products. Unlike previous work, the techniques here explored are generic enough as to be used with any consumer product.

## Towards non-hierarchical system descriptions for automating functional analysis

**Andas Amrin[1], Christos Spitas[1,2]**

[1]Nazarbayev University, Republic of Kazakhstan; [2]Delft University of Technology, The Netherlands

The case is made that current functional representation methods for engineering systems and in particular Function-Behaviour-State models rely on defining hierarchies of states, behaviours and functions that in turn rely for a large part on subjective designer input. With the goal of automating the functional description and analysis of such systems, basic concepts of an Idea Algebra are introduced, which allow the peer-to-peer non-hierarchical functional coupling of Ideas such as components and interfaces into so-called Synaptic Networks and the objective definition of system functions and subfunctions in terms of the states of the basic Ideas forming said networks. By offering a robust mathematical definition for system topology and functionality and dispensing with several subjective steps required by current methods, the presented framework opens significant possibilities for automating functional analysis.

# Design Ergonomics

**TUESDAY, AUG 22**

D4.6

**4:30 pm – 5:30 pm**

**2314**

CHAIR

*Peter Törlind*

## A hand gesture-based interface for design review using leap motion controller

**Yu Xiao, Qingjin Peng**
University of Manitoba, Canada

Computer-aided Design (CAD) has improved the original pencil and paper-based design drawing method. Designers can modify their designs using the mouse and keyboard as input devices of CAD commands. But there is a lack of design tools using a natural interface with an intuitive way for the design input. A hand gesture-based design interface is proposed in this paper for the review of CAD models in virtual environments. Leap Motion Controller is used to capture hand gestures of users to operate CAD models and model components. A template mapping method is applied in the gesture recognition for the manipulation of CAD models. Applications of the proposed interface show that the gesture input can effectively operate the model. User test results verify that the proposed system provides a natural and intuitive user experience in the CAD model manipulation compared to the traditional input method using the computer mouse and keyboard.

## An objective methodology for blind spot analysis of HGVs using a DHM approach

**Russell Marshall, Stephen Summerskill**
Loughborough University, United Kingdom

This paper presents research into the quantification and evaluation of driver's field of view (FOV) from Heavy Goods Vehicles (HGVs). The research explores the nature of any blind spots to drivers' vision resulting from the vehicle design and configuration. The paper is the first of two submitted to ICED17. This paper focuses upon the methodology for the quantification of blindspots and the second paper presents the results and outlines the need for a direct vision standard (Summerskill and Marshall, 2017). The research builds upon previous work by the authors exploiting a volumetric projection technique that allows the FOV to be visualised in order to quantify the magnitude of any blind spots. The approach also provides a means to compare vehicle designs and scenarios involving the vehicle and other road users. Using this volumetric approach, the research determined the size and location of any bind spots around 19 HGVs. The sample consisted of the most sold vehicles in the year up to 2014 from major manufacturers. This paper describes the methodology employed for the evaluation of the HGV blind spots aimed at providing an objective approach to the evaluation of drivers' FOV.

# Design Ergonomics, cont'd

**TUESDAY, AUG 22**

## D4.6

**4:30 pm – 5:30 pm**
**2314**

CHAIR
*Peter Törlind*

### Identifying opportunities for the implementation of UX design in industrial goods development

**Christian Wölfel[1], Frank Gärtner[2], Jens Krzywinski[1], Sandra Siwek[1]**
[1]TU Dresden, Germany; [2]Aalen University, Germany

The approach of designing for experience has been developed in interaction design and adopted for product design in the recent years. There are scattered efforts on bringing the approach of designing for experience (or user experience design) to the field of industrial goods. There are few companies and research institutions exploring this field. Recent research and practice focused on exploring different approaches and models of designing for experience. One particular approach of Hassenzahl and colleagues stresses the fulfilment of specific basic human needs in order to provoke positive experiences. There is a number of examples applying specific methods for evaluating or measuring product experiences. We report on current research on the transfer and adoption of particular evaluation methods to the field of industrial goods. Industrial goods development is a usually a long-term complex process with many different stakeholders. In this paper we present findings from a series of expert interviews on the current state of user participation in industrial goods development. Based on the findings, we discuss the potential for the application of UX methods in these processes.

### Defining the requirement for a direct vision standard for trucks using a DHM based blind spot analysis

**Stephen Summerskill, Russell Marshall**
Loughborough University, United Kingdom

The aim of the study was to understand the nature of blindspots in the vision of drivers of trucks caused by vehicle design variables such as cab design. The paper is the second of two submitted to ICED17. This paper focuses upon the results for the quantification of blindspots and the first paper presents the methodology (Marshall & Summerskill, 2017). In order to establish the cause and nature of blind spots 19 top selling trucks were scanned and imported into the SAMMIE DHM system. A CAD based vision projection technique allowed multiple mirror and window aperture projections to be created. By determining where simulated VRUs could be positioned without being visible in the direct vision of a driver, the vehicles were compared. By comparing the drivers eye height and the obscuration distance of VRUs a correlation was identified. By exploring the design features of outliers in this correlation, it was determined that direct vision blind spots are affected by various design variables. This led to the definition of a requirement for a direct vision standard for trucks, with a standard now being defined by the authors in a project funded by Transport for London.

# Product Service Systems 2

TUESDAY, AUG 22

D4.7

4:30 pm – 5:30 pm

2504

CHAIR

*Tim McAloone*

## Coping with the challenges of engineering smart product service systems – Demands for research infrastructure

**Bernd Kuhlenkötter, Beate Bender, Uta Wilkens, Michael Abramovici, Jens Christian Göbel, Michael Herzog, Alfred Hypki, Kay Lenkenhoff**

Ruhr University Bochum, Germany

Driven by innovations of information and communication technologies as well as increasingly demanding customer expectations on individualized products and services Smart Product Service Systems become success factors for any enterprise acting on a globalized market. Increasing product complexity on the one hand as well as flexible autonomous (re)configurations and adaptations throughout the entire product lifecycle on the other hand call for dedicated research methodologies on supporting the inter- and mulitdisciplinary engineering process. Active experimentation and simulation of typical Smart PSS lifecycle situations are key to developing new methodologies. The approach specifically fosters the integration of customers into all steps of the engineering process, which is again key to meeting the characteristically interdisciplinary requirements to Smart PSS. On this basis, the paper outlines the scientific concept of an Interdisciplinary Research Center on Engineering Smart Product Service Systems jointly funded by the federal government of Germany as well as the state government of North Rhine-Westphalia.

## 15 industry cases of product-service systems for manufacturing companies and their comparison framework

**Yong Se Kim, Yunhwa Choe**

Sungkyunkwan University, Republic of Korea

Many manufacturing companies develop Product-Service Systems (PSS) based on their product strengths by devising service elements to achieve business innovation. Such servitization processes and resulting PSSs are all different reflecting the corresponding company's business context and customer needs. We have developed a representation framework for PSSs to help compare different PSSs and to support the design process of a new PSS through comparisons of many different PSS from diverse viewpoints. In this paper, we compare 15 PSSs developed for servitization of manufacturing companies using the representation framework. It is intended that the utility of the representation framework can be assessed through comparisons of these industry cases.

# Product Service Systems 2, cont'd

**TUESDAY, AUG 22**

D4.7

**4:30 pm – 5:30 pm**

**2504**

CHAIR

*Tim McAloone*

### Engineering design research methodologies in product-service systems: When the complex gets tough

**Åsa Ericson, Johan Lugnet, Johan Wenngren**
Luleå University of Technology, Sweden

The research field of Product-Service Systems (PSS) emerged within the engineering design field to address sustainability and radically lower environmental impact from production and product use stages. PSS research has progressed insights of the industrial phenomena, but are often grounded in either product or service development, and the sustainability perspective had diminished over time. The deviation from what was intended might depend on research methodologies that do not meet the requirements of PSS multidisciplinary research. Some reflections of our research and craftsmanship are thus needed, which is also the purpose of this paper. PSS are used in the paper as a framework to highlight some of the facets of engineering design research activities. The paper suggests that multidisciplinary research has to manage different methodologies and different theories, this can be achieved if underlying assumptions are made transparent and if contradictions between those and the conclusions are discussed. Finally, the paper make an effort to encourage discussions about research methodologies to improve not only research but also implementation in industry.

### Directives to support the design of changeable (I)PSS

**Marcus Vinicius Pereira Pessôa, Juan Manuel Jauregui Becker**
University of Twente, The Netherlands

Product service models (PSM) benefits are not limited to its providers and costumers, but the whole society might also take advantage from its sustainability impact. Achieving these benefits, though, require changeable product service systems ((I)PSS). Changeability means the (I)PSS' modules have built in robustness against small use variations, adaptability to use changes, and flexibility to further updating and upgrading. In order to face this design challenge and support early modular design decisions, this paper defines a set of design directives based on the here proposed AEIOU variables (Acceptance, Ephemerality, Importance, Operational, and Urgency). This paper's second contribution is a modification from the Value Function Deployment (VFD) technique. While the original VFD is a Lean Product Design and Development (LPDD) technique that supports decision making until releasing the design to production, the adaptation, which includes the AEIOU variables, extends this capability to the whole (I)PSS lifecycle. To illustrate and show the viability of the work, a fictional product development case and related design decision scenarios are discussed.

# Reuse and Classification of Information and Knowledge

TUESDAY, AUG 22

D4.8

4:30 pm – 5:30 pm

2506

CHAIR

*Alison McKay*

## Improving engineering information retrieval by combining TD-IDF and product structure classification

**David Jones[1], Jason Matthews[2], Yifan Xie[3], James Gopsill[1], Martin Dotter[3], Nicolas Chanchevrier[3], Ben Hicks[1]**

[1]University of Bristol, United Kingdom; [2]University of the West of England, United Kingdom; [3]Airbus Group, United Kingdom

Engineering Information Management (EIM) and Information Retrieval (IR) systems are central to the day to day running of large engineering organisations. The capture, interrogation, retrieval and presentation of information from design to disposal is considered to be a key enabler for greater efficiency and decision making and in turn improved productivity, profitability and competitiveness. This paper presents a contribution to the field of engineering IR through combining TF-IDF with classification against the product structure. The results of this initial investigation show that Precision, Recall and F1-Scores can be improved depending on the method of results integration and thus tailored to the search system and context.

## k-MORE – A methodology to manage documented knowledge for reuse

**Cristina Carro Saavedra, Udo Lindemann**

Technical University Munich, Germany

The reuse of documented knowledge still represents a challenge for engineering design companies. Most of the research and practice in knowledge management has focused on the systematic collection, storage, and transfer of knowledge, assuming that if those actions are performed, the knowledge will be reused automatically. However, this does not seem to be true. We conducted a research in order to understand how the reuse of documented knowledge during the design process can be supported and based on that, we developed the k-MORE methodology (Knowledge Management for Optimised REuse). k-MORE is structured in six phases, in which methods and guidelines are suggested for the planning of the complete knowledge reuse cycle. Especial focus is on the impact of each phase of the cycle on the moment of knowledge reuse, which had been traditionally disregarded in research. All the planning is conducted under consideration of the specific company's situation and the individual needs and behaviours of its employees. We illustrate the industrial application of the methodology on the case study of a video camera development company.

# Reuse and Classification of Information and Knowledge, cont'd

**TUESDAY, AUG 22**

D4.8

**4:30 pm – 5:30 pm**
**2506**

CHAIR
*Alison McKay*

## Technical inheritance: Information basis for the identification and development of product generations

**Iryna Mozgova[1], Sebastian Barton[2], Christian Demminger[2], Timo Miebach[3], Piriya Taptimthong[4], Roland Lachmayer[1], Peter Nyhuis[3], Wilfried Reimche[2], Marc Christopher Wurz[4]**
[1]Leibniz Universität Hannover, Institute of Product Development, Germany; [2]Leibniz Universität Hannover, Institute of Materials Science, Germany; [3]Leibniz Universität Hannover, Institute of Production Systems and Logistics, Germany; [4]Leibniz Universität Hannover, Institute of Micro Production Technology, Germany

Industry 4.0 opens great potentials in development and production processes by networking of machines and systems as well as all processes along the lifecycle components. E. g., new developed intelligent systems are able to collect, store and transmit data during their complete lifecycle based on physical principles. For the development and usage of such systems, the basic processes are analyzed, information chains are set up and targeted information from the life cycle is identified, transferred and returned to the product development phase. This aims to adapt the products and to develop new product generations. This previously presented approach has been named Technical Inheritance. An important aspect here is the relevant key information on the basis of which an identification and analysis of the state for each exemplar of the product is made. In order to implement such identification in the context of Technical Inheritance a so-called genetic code of the product is used. This aspect of the methodology of the Technical Inheritance will be discussed in detail.

## Information extracted from patents as creative stimuli for product innovation

**Mehdi Parvin, Gaetano Cascini, Niccolo Becattini**
Politecnico di Milano, Italy

This paper investigates the impact of information extracted from patents on the creative performance of R&D engineers involved in new product design tasks. The creative stimuli originated by domain specific patent sources are proposed in the form of problem-solutions maps possibly enriched with TRIZ contradiction models related to the challenges addressed by the patents. The effectiveness of this kind of creative stimuli has been checked with a two-phase experiment that involved 56 professional engineers as testers subdivided into design teams of 2 people each. The teams were initially asked to brainstorm and generate innovative ideas in the field of devices for walking support (walkers). The 28 teams were, then, exposed to 4 different treatments (7 teams each): simple brainstorming as control group, problem-solution maps with and without related TRIZ contradiction models, patent-text used as far-field sources of analogy. The results of the experiment show that the problem-solution maps alone enhance variety of generated solutions, while enriched by the TRIZ contradiction models have a higher impact on novelty despite with a smaller variety.

# Design Education – Assessement Tools

TUESDAY, AUG 22

D4.9

**4:30 pm – 5:30 pm**

**2514**

CHAIR

*Jonathan Borg*

## Rapid prototyping products mapping live-data streams into tangible user interfaces

**Marina Carulli, Monica Bordegoni**
Politecnico di Milano, Italy

The very rapid evolution of digital technologies and the "Internet of Things" phenomenon are today some of the most important issues that product designers have to face. Consequently, today designers need to understand and manage these new technologies in order to exploit their potential into innovative products. Therefore, it is recommendable that designers focus their activities on the design of the meaning and on the user interaction of products, in order to create smart products that are easy-to-use and enjoyable. In order to address all these issues, the authors set up an experimental workshop in which students with different backgrounds in design-related disciplines were asked to collaborate to the design of a domestic product that allows new tangible interaction with live-data streams. In addition, students were asked to develop the functioning prototype of their design solution, by using rapid prototyping and physical computing techniques. The students were able to develop working prototypes of products that are capable of communicating information derived from real-time data streams. Some of the most representative results of this workshop are presented in the paper.

## Reflection on classroom assessment in capstone design

**Robert Brennan, Simon Li**
University of Calgary, Canada

In this paper, we use the general literature on classroom assessment as a basis to attempt raise some important issues in the area of classroom assessment in capstone design courses, and place this in the context of the authors' experience with a capstone design course in mechanical engineering. Classroom assessment is analyzed in the context of both course learning outcomes and graduate attributes. Our results show that a combination of direct and indirect assessments are needed, both to provide a higher level of validation for the results, as well as to be able to reflect on the bigger picture of overall capstone design course objectives.

TUESDAY, AUG 22

D4.9

4:30 pm – 5:30 pm

2514

CHAIR

*Jonathan Borg*

# Design Education: Design Education – Assessement Tools, cont'd

## Change in peer efficacy of senior design students during a design project: A case study

**Apurva Patel, Steven O'Shields, Doug Chickarello, Joshua Summers, Cameron Turner**

Clemson University, United States of America

Engineering students gain knowledge regarding mechanics, thermodynamics, and other topics throughout their undergraduate curriculums. However, often their instruction regarding design is not presented until students' senior years. The purpose of this study is to gain an understanding of senior design students' opinions of their peers, specifically in regards to engineering efficacy. The data necessary for this evaluation was collected using a survey tool. Survey responses were solicited twice over the course of a semester in the pre-capstone senior design course. The initial set of responses was captured on the sixth week of the semester, and the second set of responses was captured during the final week of class (week fifteen). The results from both surveys collected were analyzed to evaluate the change in responses over the course of the semester. The results indicate that in general, the student perception of their peers improved regarding their technical knowledge and creativity, however their perception regarding project skills and social impact changed negatively.

## Towards assessing student gains in systems thinking during engineering design

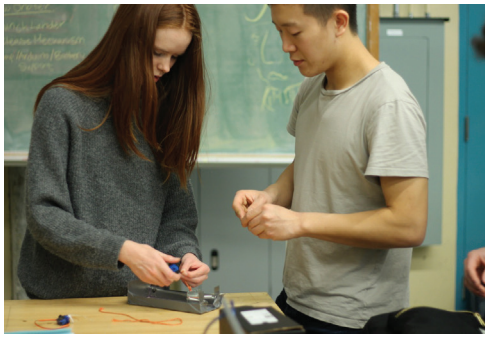
**Megan Tomko[1], Jacob Nelson[2], Julie Linsey[1], Matt Bohm[3], Robert Nagel[2]**

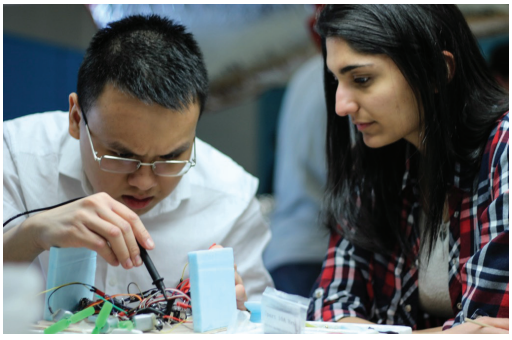
[1]Georgia Institute of Technology, United States of America; [2]James Madison University, United States of America; [3]Florida Polytechnic University, United States of America

Ultimately, as design educators we want to train our students to consider their world holistically such that they may recognize the interconnected elements of a system as well as synthesize and apply their engineering knowledge effectively when faced with new engineering challenges. The overarching goal of this research is to design both an assessment instrument and an assessment method to assess engineering students' ability to use systems thinking rather than recitation of memorized law or theorem. Toward this goal, the Systems Assessment Test (SysTest) is presented as an instrument for measuring systems thinking. Preliminary assessment measures for the instrument are presented along with results from an application during a sophomore design course where students taught functional modeling were compared to students taught function enumeration. The analysis demonstrates promise that the students taught functional modeling versus only being taught enumeration are using more of a systems thinking approach when approaching the SysTest design problem.

## Student Design Fair

**4:15 pm – 5:45 pm Atrium Lower Level**





The ICED17 Student Design Fair is your opportunity to explore what students from all levels are doing in the field of Resource-Sensitive Design. Elementary, secondary and university students will be presenting projects completed in the area of resource-sensitive design in a casual poster session.

The Student Design Fair will include projects from courses, workshops, camps, clubs, and co-curricular student design teams. Projects will be judged on technical merit, theme relevance, innovation and communication, and prizes will be awarded at the Tuesday afternoon Keynote talk. The students are excited talk about their work with ICED17 conference participants.

Come grab a coffee and meet the next generation of designers!

*Thanks to our Design Fair Partner organizations for their support – UBC Applied Science, UBC Mechanical Engineering, UBC Mech 2, Vancouver Island University Engineering, Geering Up, eng•cite, and Engineers Without Borders (UBC Chapter).*

## Break

**5:30 pm – 5:45 pm Atrium Lower Level**

**TUESDAY, AUG 22**

**5:45 pm – 6:30 pm**
**Great Hall & Foyer**

CHAIR
*Anja Maier*

# P. John Clarkson
PhD, FREng

**Biography:** John Clarkson is the Director of the Engineering Design Centre at the University of Cambridge (UK). He has three doctorates: a doctorate of Engineering, an honorary doctorate in engineering design, and a doctorate in science. After his first doctorate, he spent seven years with PA Consulting Group's Technology Division where he was Manager of the Advanced Process Group. He was appointed director of the Engineering Design Centre at Cambridge in 1997 and a University Professor in 2004.

At PA John gained wide experience of product development with a particular focus on the design of medical equipment and high-integrity systems, where clients required a risk-based systems approach to design to ensure timely delivery of safe systems. John is directly involved in the teaching of design at all levels of the undergraduate course.

His research interests are in the general area of engineering design, particularly the development of design methodologies to address specific design issues, for example, process management, change management, healthcare design and inclusive design. As well as publishing over 650 papers, he has written and edited a number of books on medical equipment design, inclusive design and process management.

John is currently leading a team with the Royal Academy of Engineering, the Royal College of Physicians and the Academy of Medical Sciences to develop a systems approach to healthcare redesign and continuous improvement.

## What has Engineering Design to Say about Healthcare Improvement?

From firefighting to a systems approach for health and care improvement. Over the past two decades, there have been numerous references to the value of a systems approach in calls to transform health and care, without there being a common understanding of what this might mean. However, many people working to improve health and care are aware of and use systems techniques, leading to improved pathways, processes and patient experience in many areas. Healthcare leaders know intuitively that there is a need to involve stakeholders in decisions, think across pathways and deliver integrated care, but lessons can be learned from the analysis and rigour applied in complex engineering systems.

**TUESDAY, AUG 22**

**5:45 pm – 6:30 pm**
**Great Hall & Foyer**

CHAIR
*Anja Maier*

John will reflect on his personal experience of acquiring the knowledge and skills of the systems engineer whilst working as a technology consultant and more recently as a researcher in engineering design. Through stories of firefighting, beer, inhalation devices and micromorts he will explore the engineer's world of systems design and risk.

John will then describe a unique project, based on an extended conversation within a forum of systems engineers, health and care professionals, quality improvement experts and patient representatives, to develop a new and integrated approach to guide service design and improvement in health and care. This project, led by the Royal Academy of Engineering, in collaboration with the Royal College of Physicians and the Academy of Medical Sciences, brought together ideas from engineering and health and care to define a new framework for improvement.

Finally, John will present this new framework, focusing on the language and terms developed with the health and care professionals. A systems approach will be described as a standalone set of questions, with reference to systems, design, risk and people thinking, and as a design 'spiral' borrowed from the world of ship design. The talk will conclude with reflections on the value of pursuing engineering design research in health and care and highlight some of the opportunities and challenges ahead.

**TUESDAY, AUG 22**

CHAIR

*Peter Törlind*

# Young Members Event

**6:45 pm – 8:45 pm Great Hall & Foyer**

## Design in 2030 – The Future of Design

In 13 years a lot of things will change, imagine a future where you as a researcher still work with design research, what are the great design challenges that we as humans face today and how shall we address them until 2030.

The Young Member Event at ICED17 will be a high-paced event where new ideas and visions will be presented and all participants have the opportunity to network and collaborate together to create a vision for the future. Refreshments will be served.

**Alexandra Blösch-Paidosh, ETH Zürich, Switzerland**
Resource-Sensitive Additive Manufacturing

**Pedro Parraguez, Technical University of Denmark (DTU), Denmark**
Designing faster, cheaper and more sustainably than ever before

**Jacopo Montali, University of Cambridge, UK**
Digital tools supporting facade design

**Mario Le Glatin, Mines ParisTech, France**
Schism between design and decision for management

**Alejandro Lecuna, HTW Berlin, Germany**
The hidden beauty of ugly ideas

**Amanda Willis, Simon Fraser University, Canada**
Designing for the next generation

# WEDNESDAY AT A GLANCE

## WEDNESDAY, AUG 23

| Location | 9:00 am – 10:30 am | 11:00 am – 11:45 am | 11:45 am – 12:30 pm | 2:00 pm – 3:00 pm | 3:15 pm – 4:15 pm | 4:30 pm – 5:30 pm | 5:30 pm – 6:30 pm | 6:30 pm – 10:00 pm |
|---|---|---|---|---|---|---|---|---|
| Great Hall & Foyer | | Keynote Catherine Roome | Keynote Julian Vincent | | | Design Society General Meeting | | |
| Performance Theatre | **P2.1:** User Related Requirements Management | | | **D5.1:** Advanced Requirements Management | **D6.1:** User Feedback | | | |
| Art Gallery | **P2.2:** Design Synthesis and Fixation | | | **D5.2:** Physiological Experiments | **D6.2:** Computational Design Cognition Studies | | | |
| 2301 | **P2.3:** Evaluation & Assessment of Design Methods | | | **D5.3:** Design Process in Context | **D6.3:** Design Process – Supporting Tools | | | |
| 2306 / 2309 | **P2.4:** Studying PD Process Performance | | | **D5.4:** Risk Management 1 | **D6.4:** Risk Management 2 | | | |
| 2311 | **P2.5:** Physiology-Based Design | | | **D5.5:** Virtual Reality-Related Design | **D6.5:** Design of Mechatronic Systems | | | |
| 2314 | **P2.6:** Resource-Conserving Frameworks | | | **D5.6:** Resource-Conserving Applications | **D6.6:** Resource-Conserving Methods | | | |
| 2504 | **P2.7:** Modular and Platform Design 1 | | | **D5.7:** Modular and Platform Design 2 | **D6.7:** Materials and Design 1 | | | |
| 2506 | **P2.8:** Design Education – New Approaches | | | **D5.8:** Patent-Based Analysis | **D6.8:** Information and Knowledge Management – Extracting knowledge | | | |
| 2514 | **P2.9** Additive Manufacturing Case Studies in Industry 1 | | | **D5.9:** Additive Manufacturing Case Studies in Industry 2 | **D6.9:** Computational Design Optimization | | | |
| Museum of Anthropology | | | | | | | | Gala Dinner |

**Legend:** Plenary Sessions; Podium Sessions; Discussion Sessions; Workshops; Design Society Event; Special and Social Events

# User Related Requirements Management

WEDNESDAY, AUG 23

P2.1

9:00 am – 10:30 am
Performance Theatre

CHAIR
*Marco Bertoni*

## Identifying affordances from online product reviews

**Tianjun Hou[1], Bernard Yannou[1], Yann Leroy[1], Emilie Poirson[2], Ivan Mata[3], Georges Fadel[3]**
[1]CentraleSupélec, Université Paris-Saclay, France; [2]École Centrale de Nantes, France; [3]Clemson University, United States of America

Affordance based design is developed since the beginning of 21st century. Affordances being revealed properties of a system in a context, they may be much diverse and unexpected. Consequently, it is a utopia to think of enumerating all the existing precise affordances in advance. Presently, identifying affordances along a design or redesign process is based on experiments and focus groups, which are time and resource consuming. Although automatic identification strategies have been proposed, the lack of affordance database along with clear categorization technique makes it unpracticable and non-repeatable today. In this paper, the theoretical basis and technical basis of identifying affordances from online reviews are discussed. A framework of affordance identification is proposed by capturing constitutive affordance elements with natural language processing algorithms. Meanwhile, a case study of 303 review sentences of Kindle Paperwhite from Amazon.com is conducted with one expert in affordance based design and six participants. The result shows that the framework is effective in affordance identification. It provides basis for automating the identification process in the future.

## Bridging the semantic gap in customer needs elicitation: A machine learning perspective

**Yue Wang[1], Jian Zhang[2]**
[1]Hang Seng Management College, Hong Kong S.A.R. (China); [2]Dongguan University of Technology, Hong Kong S.A.R. (China)

The elicitation of customer needs (CNs) is a critical step in product development. However, these needs are often expressed in ambiguous, simple language and not in the form of well-defined specifications, causing a semantic gap in the product development process. Traditional methods to bridge the gap rely heavily on human action. Product development teams need to manually link CNs to product specifications in an ad hoc manner. This may be infeasible for large product variant spaces or evolving product families. We propose a machine learning mechanism to automatically bridge the semantic gap. This task is considered as a classification problem, with CNs being the class. The mapping function from product specifications to CNs is learned from training data by using a support vector machine and decision tree classifier. Given a new product variant, the learnt classifier can determine the needs that the product variant can satisfy. Numerical experiments show that the proposed method can achieve very high mapping accuracy. It can also shield product development teams from the tedious labour of linking CNs to product variants, and thus improve the efficiency of needs elicitation.

## On the relationship between affordance and expected performance

**Nicolo De Benetti[1], Gualtiero Fantoni[2], Filippo Chiarello[2], Andrea Bonaccorsi[2], Georges Fadel[3], Ivan Mata[3]**

[1]Scuola Superiore Sant'Anna, Italy; [2]Università di Pisa, Italy; [3]Clemson University, United States of America

The paper describes an attempt to understand if and how product affordances and guessed performance alter the user ability to assess real performances during actual interaction with the product. The research work tries to experimentally find evidences of the existence of the "expectations about performance" guessed when the users see the product, if they correlate with product affordances and how the following interaction with the product modifies the users' opinion. The experiment has been performed by using four common flashlights as products and more than one hundred students as a users sample. The results of the performed test demonstrated that expectations about performance and affordances are concepts deeply intertwined.

## Using the ACD$^3$-ladder to manage multi-phase requirements on end-user products

**Cecilia Berlin[1], Lars-Ola Bligård[2], Eva Simonsen[2]**

[1]Chalmers University of Technology, Division of Production Systems, Sweden; [2]Chalmers University of Technology, Division of Design and Human Factors, Sweden

During the development of any end-user product, a multitude of design decisions need to be made. But if design activities and decisions happen at the wrong time, or not at all, unintentional and sometimes negative design outcomes can be the result. Determining all requirements early in the product development is traditionally recommended, but may force design decisions to be made prematurely on the basis of incomplete preconditions. Requirements at different degrees of resolution are useful and purposeful at different stages of the development process. To address these requirements management challenges, this paper proposes an approach for incrementally developing requirements in parallel with design, based upon a previously developed framework called ACD$^3$, which draws on a combination of theoretically compatible ideas and concepts from Design Engineering, Human Factors/Ergonomics, Usability and Systems Theory. This approach helps designers identify and handle the possible interdependencies of design variables. The paper also theoretically motivates and demonstrates with an example how the different resolution levels of requirements relate within the framework.

**WEDNESDAY, AUG 23**

# P2.1

**9:00 am – 10:30 am**
**Performance Theatre**

CHAIR

*Marco Bertoni*

# User Related Requirements Management, cont'd

WEDNESDAY, AUG 23

P2.1

9:00 am – 10:30 am
Performance Theatre

CHAIR
*Marco Bertoni*

### Need network analysis: A process to understand the stakeholder need structure in multi-actor service systems

**Yoonyee Pahk, Joon Sang Baek**
UNIST Ulsan National Institute of Science and Technology, Republic of Korea

The network analysis and the need matrix can be used together to investigate the relationships of different stakeholders formed by the needs they have towards one another in a multi-actor system. We argue that they serve the goal more effectively when they are used together than alone because: (1) the network analysis allows for a quantitative analysis of the relationships while the need matrix analyses them qualitatively, (2) the network analysis provides a means to visualise the need matrix, (3) these tools supplement each other in approaching complex problems (complex because the diverse stakeholder needs are often interwoven) in the system. We demonstrate the effectiveness of the tools from an empirical study to design new service systems for the energy service companies (ESCO) in South Korea.

# Design Synthesis and Fixation

## An exploration of design synthesis

**Chris McTeague, Alex Duffy, Gerard Campbell, Madeleine Grealy, Laura Hay, Laura Pidgeon, Tijana Vuletic**
University of Strathclyde, United Kingdom

Building on the contributions of existing works in the area of design ontology, this paper presents a hypothetical model of design synthesis which depicts design activities, design outputs and two modes of thought in design. The model is used as a basis upon which to explore design synthesis at multiple levels of cognitive granularity. Studies of conceptual design cognition lend support to a distinction between the creation of design elements and their composition. Additional studies of cognitive processing are reviewed and summarised in order to identify cognitive processes which might be involved in design composition. The review highlights several cognitive processes which have yet to be studied in an ecologically valid design context but which could form the basis of a multi-level model of design synthesis.

## Design fixation to examples: A study on the time decay of fixation

**Vimal Kumar Viswanathan**
San Jose State University, United States of America

When designers fixate during an idea generation session, they replicate the features of any available example or their prior ideas. This paper presents an empirical study to understand the variation in number of novel ideas generated by designers during an idea generation session. Two research questions are investigated (1) Do number of ideas decay over time? and (2) does the fixation to an example design decay over time? A controlled experiment with two conditions using a peanut sheller design problem investigates these two questions. The participants in one condition are given a pictorial example in addition to the design problem statement. The percentage decrement in new ideas is explored as a function of time in both conditions. The results show a decrement in the percentage of new ideas over time. This result is in agreement with some of the prior studies. The quantity of new ideas also shows a very similar trend. However, the ideas derived from example in the Fixation group do not show this decay. In essence, these results show that when an example is available participants remain fixated to the example throughout the session and the fixation effects do not decay over time.

**WEDNESDAY, AUG 23**

P2.2

**9:00 am – 10:30 am**
**Art Gallery**

CHAIR
*Carlos Coimbra Cardoso*

# Design Synthesis and Fixation, cont'd

**WEDNESDAY, AUG 23**

## P2.2

**9:00 am – 10:30 am**
**Art Gallery**

CHAIR
*Carlos Coimbra Cardoso*

### Studying design fixation with a computer-based task

**Maria Adriana Neroni, Luis Arthur Vasconcelos, Nathan Crilly**
University of Cambridge, United Kingdom

The term 'design fixation' refers to a phenomenon where designers unknowingly limit the space within which they search for solutions. In an attempt to study this phenomenon experimentally, researchers typically set participants open-ended design problems, prime them with an example solution and measure their performance through subjective metrics. This gives rise to various problems, including limited data capture and highly subjective evaluation of design behavior. To address these problems, we studied design fixation with a computer-based task inspired by psychological paradigms used to study 'mental set'. The task consisted of a game-like activity requiring participants to design a bridge within a specified budget. The use of a digital environment facilitated continuous data capture during the design activities. The constrained task (and direct quantitative measures) permitted a more objective analysis of design performance, including the occurrence of fixation. The method used and the results obtained show an exciting alternative for studying design fixation experimentally and promote a wider exploration of the variety of design activities in which fixation might occur.

### Design finds a way: Creative strategies to cope with barriers to creativity

**Milene Gonçalves**
Delft University of Technology, The Netherlands

Creativity is quintessential in design ideation, as it fuels innovation in an ever-changing world. However, designers often experience states of being stuck and fixated, either on their own solutions, on examples or on the design process. A think-aloud protocol study and interviews were conducted with 31 novice designers in order to capture their strategies to cope with fixation and other types of hindrances to creativity. The findings corroborate past research on design fixation, adding a qualitative perspective to the existing growing body of knowledge on this topic. Furthermore, the study reveals the opportunistic and sometimes unexpected strategies designers apply in order to continue ideation. This paper contributes to the understanding of the opportunistic behaviour of designers in ideation and has implications for the study of design fixation and other barriers to creativity at the methodological level.

## Tool for creating a defined task as preparation for a target-oriented idea generation process

**Thorsten Herrmann, Hansgeorg Binz, Daniel Roth**
University of Stuttgart, Germany

Knowledge and information concerning a need or a problem are important for the steps of creating solution ideas which lead to the design of successful products. However, this information is often not provided accurately, meaning that an analysis of a need or a problem does not take place properly before starting with the steps of creating potential solution ideas. A tool which will close the information gap has been elaborated and is presented in this paper. This tool functions as a problem analysis which prepares the information needed for the subsequent steps of solution idea creation within the front end of the product development process. In particular, the elaboration of the set of information needed and the way the information is elaborated, stored and transformed or — in other words — how such a problem analysis might take place is presented. As an evaluation step, the presented tool has been partially assessed by a group of experts from the engineering design sector and the applicability, usefulness and comprehensibility are confirmed.

**WEDNESDAY, AUG 23**

P2.2

**9:00 am – 10:30 am**
**Art Gallery**

CHAIR
*Carlos Coimbra Cardoso*

# Evaluation & Assessment of Design Methods

WEDNESDAY, AUG 23

P2.3

9:00 am – 10:30 am

2301

CHAIR

*Ehud Kroll*

## Rise and fall of platforms: Systematic analysis of platform dynamics thanks to axiomatic design

**Julien Legrand, Maxime Thomas, Pascal Le Masson, Benoît Weil**
MINES ParisTech, France

While platforms are multiplying across industries, the laws governing their dynamic are still poorly understood. The high diversity of disciplines covering the topic, spanning from strategy management to engineering design, made it difficult for any new model to integrate the numerous phenomena at stakes. In a new effort to bring them together, we exhibit Suh's Axiomatic Design as an ideal framework to systematically analyse platforms dynamics when market and technology forces meet and interact. Exporting the current description of platforms from Design Structure Matrices to Design Matrices, our research enables us to systematically explore platforms potential evolutions. While the model leads us to rediscover classical behaviours, it also uncovers new results, such as situations of split leadership and platform overthrow, in which complementors challenge the platform leader. Both can be linked to two necessary conditions: functional generativity and technical genericity. We then identify those behaviours in several cases.

## Structure sharing for resource effective solutions: Improving measures to account for importance and quality of functions

**Ehsan Ghazanfari, Vishal Singh**
Aalto University, Finland

Structured sharing is believed to improve resource effectiveness of design solutions by allowing multiple functions to be achieved from the same shared structure. The current measures for assessing structure sharing and resource effectiveness account for the number of functions and structures in the solutions, but they do not take into account some of the basic aspects of functions from the customer and user perspective, which may determine whether the structure shared solution is desirable or not. This paper addresses this gap by improving the existing measures of structure sharing and resource effectiveness to take into account: (1) Relative importance of the different functions performed by the product (2) Quality of functions, which answers how well are the functions in the structure shared products performed when compared to a typical non-structured product serving the same function, and (3) emergent negative functions in the shared product that did not exist in the non-shared counterparts. The paper presents the derived equation, findings from the empirical tests conducted to test and validate the developed measures, and implications and recommendations for future research.

## Concept for investigating the application of methods in product development

**Peter Gust, Marco Kuhlmeier, Marie Garbe, Sebastian Kampa**
University of Wuppertal, Germany

The use of methods is a success factor in modern product development and is of decisive importance for the overall economic success of a company. The positive effects of using a method have been extensively described in numerous scientific investigations. However, existing investigations also repeatedly show that the application situation of methods in industry differs significantly from the theoretical guiding principles, and that a comparatively subdued use of methods takes place in companies. This article describes the results of a literature research and an investigation into the current status of the use of methods in product development. Based on these initial findings, a basic research approach is described in order to improve the use of efficient methods in future practice. Obstacles to the use of current methods have to be identified and incentives for the use of new methods established.

## What do we need to say about a design method?

**Kilian Gericke[1], Claudia Eckert[2], Martin Stacey[3]**
[1]University of Luxembourg, Luxembourg; [2]The Open University, United Kingdom; [3]De Montfort University, United Kingdom

Method development is one of the raisons d'etre of engineering design research and method uptake by industry is perceived as an important success criterion. This paper argues that one of the problems with methods is the lack of clarity about what is actually proposed to industry and the academic community when a new method is put forward, in terms of how detailed, strict, precise and rigorous the method is and what it can deliver. This paper puts the concept of method in the context of related concepts and proposes a multi-level model of the elements of a method to argue that a contribution on each of these levels can be of value and that the introduction of methods can fail on each of these levels. Implications thereof for industry and academia are discussed, concluding that a clear description of methods and their intended use is important for enabling proper validation of each of the method's elements and for communicating methods to academia and industry.

**WEDNESDAY, AUG 23**

# P2.3

**9:00 am – 10:30 am**
**2301**

CHAIR
*Ehud Kroll*

# Evaluation & Assessment of Design Methods, cont'd

WEDNESDAY, AUG 23

P2.3

**9:00 am – 10:30 am**

**2301**

CHAIR

*Ehud Kroll*

### Theoretical explanation of "Y-gaya" through general design theory

**Kazuya Oizumi, Kazuhiro Aoyama**
The University of Tokyo, Japan

"Y-gaya", which is a habit that engineers thoroughly discuss for long period of time, has been seen as a prominent mechanism to realize synthesis of design leading to actualization of brand new product. Though its effectiveness has been discussed empirically and given philosophical explanations, there has never been any theoretical explanation or systematized methodologies. This paper attempts to understand effectiveness of "Y-gaya" based on general design theory as a theoretical foundation. As a result, it is found that quite large part of "Y-gaya" could be understood through general design theory, whereas there are some factors (such as culture and human factors) still not to be proven or explained. In the end, this paper discusses future prospects for systematization of "Y-gaya".

# Studying PD Process Performance

## Usability of processes in engineering design

**Lucia Becerril, Jan-Timo Stahlmann, Jesco Beck, Udo Lindemann**
Technical University of Munich, Germany

Processes in Engineering Design are generally optimized towards efficiency, quality, costs, risks, etc., however an analysis that includes requirements from the process users' view is missing. Within the last years, the concept of usability has being introduced to examine business processes. This is a promising approach for Engineering Design, by involving process "users" (designers, engineers, software developers, project managers, etc.) in the process planning phase, several issues such as consistency flaws or counter-intuitive information flow can be identified beforehand. This paper aims to explore the transferability of usability concepts and evaluation methods to processes in the field of Engineering Design. The goal of this paper is to set a basis for further studies with regard on how to plan and design processes that interact efficiently, effectively and satisfactorily with the people involved. For this purpose ten process usability attributes are consolidated from the overlap between usability attributes (of products and systems) and process system properties. Moreover, five usability evaluation methods are examined on their applicability for evaluating design processes.

## Identifying the influences on performance of engineering design and development projects

**Chris Snider[1], Lia Emanuel[2], James Gopsill[1], Sian Joel-Edgar[2], Ben Hicks[1]**
[1]University of Bristol, United Kingdom; [2]University of Bath, United Kingdom

Performance of engineering design and development projects depends on myriad factors, creating challenges in implementation and management. These are compounded by potential for high variation across contexts. This work investigates influencers upon performance and contextual variation through relationship between real industry issues and factors that influence project performance. Through survey, interview, and network analysis, issue-causing groups of features in each specific case are identified and compared. The results find a majority of issues arising from person-centric sources. They also identify both discrete groups of issues with narrow source and influence, and with broad ties across the project context; forms which may stem from conditions of the scenario. Finally, they show similarity in the influences on performance across contexts with a caveat that, while the influential area remains, the structure to be taken within may vary. General analysis clarifies performance in engineering and highlights those areas in which support-system development is of most use, and specific analysis gives areas in which industry managers should focus for best benefit to the project.

**WEDNESDAY, AUG 23**

**P2.4**

**9:00 am – 10:30 am**
**2306/2309**

CHAIR
*Josef Oehmen*

# Studying PD Process Performance, cont'd

WEDNESDAY, AUG 23

P2.4

9:00 am – 10:30 am
2306/2309

CHAIR
*Josef Oehmen*

### Modelling and simulating the effect of coordination on PD performance while handling change

**Janaka Rajapaksha, Katja Mirkovic, David Robinson, David Wynn**
University of Auckland, New Zealand

Analysing effect of coordination on performance of complex Product Development (PD) processes and understanding impact of change within PD processes on performance have been recognised as pivotal in acquiring insights into behaviour of PD process. Therefore, this paper focuses on effect of information flow coordination on PD performance while handling change. A computer model was developed to capture PD processes and simulations were carried out considering two communication models, centralised and decentralised. An initiation of change was simulated to study the effectiveness of each communication model while handling change through measuring performance. Results were collated for both with and without change set-ups. Findings showed evidence on existence of a strong relationship between coordinator effectiveness and project performance. Importance of having right number of integrators for coordination with apt communication model was also observed. Moreover, as a result of exploring an under-researched area, the paper also presents suggestions for future research to further develop the understanding of coordinators role in design process in handling changes.

### An empirical survey on efficiency improvement for the collaboration between design and simulation departments

**Sebastian Schweigert, Minghai Xia, Udo Lindemann**
Technical University of Munich, Germany

Efficient collaboration between design and simulation departments is a challenge in many industries. Under the cost and time pressure of product development, CAD/CAE integration has become increasingly important. This paper presents the results of an online survey and expert interviews within the German industry to analyse the collaboration of design and simulation departments. Four aspects of CAD/CAE integration were considered in the research project: people/communication, process, data, and tools. A similar questionnaire survey, which was conducted in 2006, is the base for this research. Through the analysis of the results and a comparison with the survey from 2006, weak points of the current collaboration were discovered. Thereby, a need for further research in this area is proven. In interviews, the survey results were discussed with experts to find solutions for the discovered issues. This paper provides an overview of the current collaboration of these two departments and also its challenges. The insights provided by the survey show directions for further research on the collaboration between design and simulation departments and where the greatest impact can be achieved.

## Applying multiple metrics in the performance measurement of design sessions in industry: a co-design case study

**Mendy Mombeshora[1], Elies Dekoninck[1], Jamie O'Hare[1], Jean-François Boujut[2], Gaetano Cascini[3]**

[1]University of Bath, United Kingdom; [2]Université Grenoble Alpes, France; [3]Politecnico di Milano, Italy

The recently launched SPARK project (www.spark-project.net), aims to understand how Spatial Augmented Reality (SAR) technology can be used to support the co-design process. The project aims to develop, build and test a SAR technology for co-design. This paper presents the testing of a suite of metrics to assess the performance of co-design sessions in industry. These metrics will be needed in the SPARK project to help iteratively develop that technology, as well as to provide insights into the overall effects of using SAR tools in co-design. The aim of the study reported in this paper was to design, develop and test a process for applying a suite of co-design session metrics. During the study, the metrics application process was applied to two industry cases and based on the outcomes, refinements were made. This resulted in a proposed process for the evaluation of the effectiveness of co-design sessions. The work presented in this paper will be of particular interest to other researchers seeking to evaluate the impact of a product development tool on a specific design session.

**WEDNESDAY, AUG 23**

P2.4

**9:00 am – 10:30 am**
**2306/2309**

CHAIR

*Josef Oehmen*

# Physiology-Based Design

WEDNESDAY, AUG 23

P2.5

9:00 am – 10:30 am

2311

CHAIR

*Antony Hodgson*

## Development of a tongue machine interface for quadriplegic patients

**Alejandro Velásquez-López, David Velásquez-Rendón, Juan Sebastian Amaya-Quiroz, Luis David Jimenez-Franco, Helmuth Trefftz**

Universidad EAFIT, Colombia

This article presents the development and validation of a wheelchair mobility solution. The solution is based on a Tongue Machine Interface (TMI) involving the use of Force Sensing Resistors (FSRs). The semantics and functionality of the development are compared with two other interfaces: a Joystick and a Brain Computer Interface (BCI) implemented on the same wheelchair. Each development is described from the electric, mechanic and informatic domains. Surveys and user's tests were performed in order to explore which technology had a more positive impact on the mobility of quadriplegic persons in terms of effectiveness, better ergonomics, lower costs and better functionality. The quantitative and qualitative results are described and analyzed.

## A concept of an integrated system for monitoring changes on the human skin

**Dragan Zezelj[1], Nenad Bojcetic[1], Latica Pletikapic Exle[2]**

[1]University of Zagreb, Croatia; [2]Palfinger Marine d.o.o., Slovenia

In this study, a concept of an integrated system for monitoring changes on the human skin is presented. The system is based on a static or mobile self-service front-end facility. Its purpose is to support an early detection of abnormal changes on the skin surface within a skin cancer prevention scheme, especially in the countries or areas where the public health care is not appropriate or widely available. Periodically performed skin self-examination is useful but subjective, and thus not reliable. To provide a more reliable method of skin examination, a design concept of a front-end facility is introduced. The facility can be a mobile booth that can be easily mounted in a public place with only few installation demands or it can be a permanent facility inside a building. It would be capable of making automatic video recordings or of taking photographs and, based on the given user ID, of comparing samples and detecting changes via a connection to the central monitoring system. Advantages of the system would be its accessibility for general public, unmanned operation, and a centralized database and detection system operated by medical experts.

## Biofidelic design of the forearm of a myoelectric prosthesis with maximum functional volume

**Mathieu Ramananarivo, Maxime Raison, Olivier Barron, Sofiane Achiche**
École Polytechnique de Montréal, Canada

The congenital or traumatic amputation of upper limbs leads to strong mobility and socio-psychological disabilities. The amputees can choose between three types of prostheses: cosmetic, body-powered and myoelectric. The myoelectric prostheses are controlled via electromyographic activity, they provide control over more degrees of freedom. The development of myoelectric prostheses is largely influenced by breakthroughs in robotics, sensors and machine learning technologies. As a consequence, the development of upper-limb prostheses is mainly technology driven without taking into account the low user acceptance. To improve the biofidelity of existing prostheses, a biomimetic approach has been explored by the work presented here. In this paper we propose an alternative biofidelic mechanism developed to be used in an operational prosthesis. The main results are the production of a mechanism optimized to reproduce with a low and controlled error of the pronation-supination movement while using a single actuator. The mechanism solid shapes are designed to be usable in an operational prosthesis.

## Foot plantar pressure offloading: How to select the right material for a custom made insole

**Marco Mandolini, Agnese Brunzini, Steve Manieri, Michele Germani**
Università Politecnica delle Marche, Italy

The custom-made insole is largely recognized as the most important orthotics for decreasing the foot plantar pressure, using additions or cutouts, which modify the geometry of the insole. This paper proposes a procedure for supporting the clinicians in prescribing innovative custom made insoles for offloading the plantar pressure by using specific combinations of materials for the foot peak-pressure areas, without modifying the geometry of the insole. The process starts with the acquisition of the plantar pressure map of the customer and ends with the definition of the customised insole. The aim of the procedure is choosing the best combination of materials for each foot anatomical area for reducing the plantar pressure peaks below a maximum admissible pressure value decided by the physician. The positions and dimensions of the inserts are defined through analyzing the customer plantar pressure while the inserts materials are defined using FEM simulations of the insole-foot interaction. The case study showed a plantar pressure reduction congruent with the FEM simulations results. This procedure is applicable both for subtractive and additive manufacture techniques.

**WEDNESDAY, AUG 23**

# P2.5

**9:00 am – 10:30 am**
**2311**

CHAIR
*Antony Hodgson*

# Resource-Conserving Frameworks

WEDNESDAY, AUG 23

P2.6

9:00 am – 10:30 am

2314

CHAIR

*Cassandra Telenko*

## Telepathic product design for water conservation

**Naren Ramaswamy, Erin MacDonald**
Stanford University, United States of America

Can a product that reads the user's mind behave more efficiently and eventually train the user to conserve? Here, as a first step to answering this big question, we present a design method for telepathic products applied to the case study of a kitchen faucet. The case study is used to illustrate the different steps of the design method: (A) Build cognitive empathy and define cognitive styles; (B) Define design requirements, articulate variables that will control performance, understand limitations and design physical product; (C) Design the machine learning algorithm, inputs, and outputs; and (D) Integration and refinement. This work-in-progress report highlights the intricacies of applying adaptive machine-learning behavior to physical products performance in the "real world" rather than to a website or device such as a smart phone. Interesting findings include that automatic response, typically associated with websites and phones, is not possible with plumbing as water cannot be instantly at the right temperature; and that cognitive styles indeed manifest in dish washing observations, with distinctly different styles in terms of patience, temperature sensitivity, and laziness.

## Technical planning tasks and participants involved in planning Adaptive Buildings

**Clemens Honold, Hansgeorg Binz, Daniel Roth**
University of Stuttgart, Germany

Adaptive Buildings constitute an interdisciplinary approach for realizing the next generation of buildings in order to reduce the immense material requirements and energy demand in all phases of the life cycle. Based on a novel cooperation between the disciplines of architecture, civil and mechanical engineering, adaptive support structures and adaptive building envelopes are developed within a Collaborative Research Centre. In order to reduce the high complexity and achieve a goal-oriented procedure during the planning of such buildings, a holistic planning process is required. The experiences of the development and the application of methods in the field of design methods are therefore required and form part of the interdisciplinary project. The goal of this paper is to analyze current planning processes, existing adaptive elements and to derive the basic technical tasks of the planning process and the participants of the planning team of Adaptive Buildings, taking into consideration the life cycle of these buildings. The results were investigated with the support of architects and civil engineers.

## Methodology for multiple life cycles product ecodesign

**Nadege Troussier[1], Natalia Sirina[1], Pierre-Antoine Adragna[1], Jorge Amaya[2], Tatiana Reyes[1]**

[1]University of Technology of Troyes, France; [2]ESPOL Escuela Superior Politécnica del Litoral, Ecuador

Knowing how to design new production systems in order to better address sustainable development is a major stake. In this framework, designing new value networks that imply new products should integrate a lot of consideration such as technical performance of the product but also environmental impacts of the value network. This paper aims at contributing in design for system innovation and transition. It is based on mainly technical prospective analysis but in order to make people anticipate the main factors that will impact on environment on several product's life cycles as soon as possible when thinking the first life. The main question addressed is then how to define several product life cycles? What are the main technical factors that will influence environmental impacts? It proposes a methodology based on coupling design of experiment with Life Cycle Assessment for multiple life product ecodesign. The proposal is presented on a case study that aims at defining lithium-ion batteries for electric vehicles and home energy management systems.

## Is product design evil?

**Euan Ross Coutts, Jack Edward, Richard Knight, Alex Duffy, Hilary Grierson**

University of Strathclyde, United Kingdom

Product design presents an ethical dilemma. Despite increasing awareness of limited resources the majority of product design endeavours contribute to unsustainable over-consumption. Is the product design industry self-fulfilling; creating products in order to create more products and manufacturing demand to follow suit? Through complacency has product design become unintentionally harmful and morally questionable, has it become the greatest "evil" of our time? This paper intends to provoke thought and reflection over the role of the designer and their responsibilities. Literature on the subject of ethics, morality and responsibility in product design is reviewed and discussed, the key agents who possess responsibility in design are also explored. It is proposed that designers, while aware of sustainability concerns, possess a diminished sense of personal responsibility for these concerns. A study was conducted to assess the level of empathy possessed by product designers in this regard, it is concluded that while on the whole product designers are empathetic they are complacent with respect to environmental concerns to the extent that it may be considered harmful and damaging.

**WEDNESDAY, AUG 23**

# P2.6

**9:00 am – 10:30 am**

**2314**

CHAIR

*Cassandra Telenko*

# Resource-Conserving Frameworks, cont'd

**WEDNESDAY, AUG 23**

P2.6

**9:00 am – 10:30 am**

**2314**

CHAIR

*Cassandra Telenko*

### Hybrid top-down and bottom-up framework to measure products' circularity performance

**Michael Saidani, Bernard Yannou, Yann Leroy, François Cluzel**

CentraleSupélec, Université Paris-Saclay, France

Industrial practitioners are increasingly willing to shift their products and businesses into more circular models. Circular economy paradigm requires optimization of system rather than components. Yet, existing methods and tools, intended to designers, engineers or managers, to assess and improve product circularity potential are both lacking of systemic vision and operational considerations. This research work contributes to fill this gap through the design of a holistic and integrated framework aiming at measuring, improving and monitoring product circularity performance. The developed framework is based on a hybrid top-down — objective-driven — and bottom-up — data-driven — approach including the four building blocks of circular economy defined by Ellen MacArthur Foundation. First mature steps of the proposed framework are detailed and experienced on an industrial case study. Insights for enhanced products' circularity performance measurement and improvement framework are also discussed and lead to further promising research perspectives.

# Modular and Platform Design 1

WEDNESDAY, AUG 23

P2.7

9:00 am – 10:30 am

2504

CHAIR

*Vahid Salehi*

## Good product line architecture design principles

**Niels Henrik Mortensen, Martin Løkkegaard**

Technical University of Denmark, Denmark

Based on existing research concerning product architectures Du et al. (2001), Ericsson and Erixon (1999), Levandowski et al.(2014), Bruun et al. (2015) and studies of more than 200 product architecture projects across a variety of industries, this paper defines ten central principles for design of product line architectures. The first and most important principle is to identify the right number of product architectures to cover a particular market. Having too few or too many architectures can be extremely damaging to profitability and time to market for new products. Despite the importance of having the right set of product architectures, important architecture decisions are often made in individual projects. This is a risky approach, since the total market coverage is not considered, implying that product architectures may overlap or there are areas between product architectures which are not covered. Furthermore, the full benefits of synergies in terms of e.g. increased module/part production volume, increased purchase volume and reduced CAPEX (CAPital EXpenditures) are not harvested.

## On the interplay between platform concept development and production maintenance

**Jon Bokrantz[1], Jonas Landahl[1], Christoffer Levandowski[1], Anders Skoogh[1], Hans Johannesson[1], Ola Isaksson[1,2]**

[1]Chalmers University of Technology, Sweden; [2]GKN Aerospace Sweden, Sweden

To meet a broad customer-base, platforms can be used to achieve commonality and distinctiveness among a family of products. However, producibility of product variants are typically not ensured until late in the platform development phases. This may lead to increased production disturbances. To understand challenges in ensuring producibility of a product family in the early phases of platform development, this paper adopts the concept of lifecycle meetings to describe the interplay between platform concept development and production maintenance. Based on this description, we reason that to make early and credible cross product-production decisions, production system capabilities ought to be regarded as dynamic rather than static. While static implies as designed, dynamic implies change over time. In this paper, maintenance is regarded as one dynamic aspect of production. This reasoning is supported by a theoretical perspective and an illustrating case from the aerospace industry. The contribution of this paper may form the basis for future research on platform development and the effect of product variety on production systems.

# Modular and Platform Design 1, cont'd

**WEDNESDAY, AUG 23**

P2.7

**9:00 am – 10:30 am**

**2504**

CHAIR

*Vahid Salehi*

### Methodology for the contextual design of a modular product platform concept

**Günther Schuh, Michael Riesener, Sebastian Barg, Hendrik Lauf**
RWTH Aachen, Germany

Due to increased competition and cost pressure in the globalized world, business strategies extensively focus on tailoring products to customer's needs. Hence, many companies are facing shorter product lifecycles, additional product development expenses and a wider product portfolio. Therefore, the modular product platform approach of the automotive industry is often directly transferred on other industries. However, a direct transfer of the automotive approach is likely to lead to missing targets and full potentials of a modular product platform. This circumstance is due to the overall situation of the applying company in terms of the company's exogenously given environment and an individual target system for the modular product platform. To meet the exogenous influencing factors as well as to increase the level of target achievement a priori, this paper introduces a methodology for the contextual design of a modular product platform concept in an early design stage. This concept adapts existing matching concepts and considers the given conditions as well as the targets and therefore is aligned to maximize the context and target conformity.

### Towards an impact model of modular product structures

**Jennifer Hackl, Dieter Krause**
Hamburg University of Technology, Germany

Modularization of product families affects firms in many ways. Many of them have been investigated in research and observed in industry. But which effect will most likely occur, by which kind of modular product structure it can be achieved and how this product structure affects other life phases is often not clear because the understanding for the whole system of product structures and effects is missing. The aim of this paper is to show the interrelations between product structures and the effects they entail. Hence it provides the desired system view. For the model development the properties and characteristics are defined to be able to differentiate product family structures. For collection of the effects a literature study was undertaken, the effects and their product structural causes are investigated and displayed in a flow chart based visualization, which is divided into product life phases. The value of the paper lies in the provision of a visual model including product structural cause and its life phase effects on a firm which has been missing in literature and is important for decision-making.

## Variant management toolbox

**Thomas Braun, Martin Strattner**
REDPOINT.TESEON AG, Germany

The approach focuses on methods in the field of product variant management. Drawn from the experience over ten years of variant management work in practice, it suggests a toolbox which improves the application of methods and tools in this area. Starting with the definition of "product variant" from the customer's and a company's internal view, a framework for variant management is outlined. The framework describes, how product features can be translated into component variants. The toolbox for variant management consists of several methods and tools. The presented framework serves as an ordering scheme for this methods and tools. The toolbox includes analytic methods, measures and design principles. To illustrate the application of the variant management toolbox a practical example is given by the concept design of axial piston pumps with a focus on a variant-reduced product structure. Particularly the architecture matrix and the variant-optimized design are carried out in the example. Finally, an outlook raises the question, how the toolbox can be subject to digital transformation.

**WEDNESDAY, AUG 23**

P2.7

**9:00 am – 10:30 am**
**2504**

CHAIR
*Vahid Salehi*

# Design Education – New Approaches

WEDNESDAY, AUG 23

P2.8

9:00 am – 10:30 am

2506

CHAIR

*Christopher McMahon*

## Multidiscipline teams for intelligent innovation: Educating and training engineering and design students to co-creation

**Jenny Faucheu[1], John Boult[2], David Delafosse[1]**

[1]MINES Saint-Étienne, France; [2]Brunel University, United Kingdom

Holistic approach for industrial innovation is obtained in integrated design teams by mixing up backgrounds and skills into multidiscipline teams. However, is mixing enough? To go further than a simple addition of skills and create a synergy, the key ingredient is to favour communication and understanding between individuals in the team. Our contribution as a graduate school of engineering is to impulse the establishment of common languages and favour constructive interactions between future engineers and future designers. A specific educational program has been tailored for French engineering students to favour mind opening through variety of lectures and hand-on activities. The focus point is a multidiscipline international workshop in design and engineering, gathering students from both areas. The workshop process has been studied and it was demonstrated that significant knowledge transfer and efficient complementarities of skills and methods were occurring and led to a global and user-centred response to the Design brief.

## A creative learning space development toolkit: Empirical evaluation of a novel design method

**Katja Thoring[1,2], Roland Mueller[3], Petra Badke-Schaub[1], Pieter Desmet[1]**

[1]Delft University of Technology, The Netherlands; [2]Anhalt University of Applied Sciences, Germany; [3]Berlin School of Economics and Law, Germany

The physical environment in design education can have a significant impact on students' creativity, learning performance, and wellbeing. However, little attention is given to the question, how to design such spaces in a scientifically sound manner and how to involve the relevant stakeholders. Specifically, the future users of the space—students and teachers—might have important insights about the spatial requirements. To support spatial planners, teachers, and students, who want to improve their existing learning spaces or to design them from scratch, we developed a toolkit, consisting of several checklists, card sets, floor plans, and canvases to frame spatial requirements and ideas. The toolkit was tested and evaluated in a workshop at a design school in the UK that was in the process of moving departments to a new building. Hence, this paper presents an action research cycle including the four steps of 1) designing the toolkit, 2) conducting the workshop, 3) observing the workshop and obtaining feedback, and 4) reflecting on and iterating of the creative learning space development toolkit.

## Using studio teaching as an initiator and driver for research collaboration in design

**André Liem[1], Stan Ruecker[2], Juan Alfonso de la Rosa[2]**

[1]Norwegian University of Science and Technology, Norway; [2]Illinois Institute of Technology, United States of America

This article proposes an alternative route towards initiating and developing formal design research projects, where design studios act as an "Initiator" and "Driver" for subsequent research collaboration. A concept for collaborative research, involving different stakeholders, will be introduced based upon the notion that results from sponsored studio projects create avenues for more formal research work, whether fundamental or applied. Building upon "Activity Theory", "Action Research" and "Practice Theory", the authors argue that practice and research are becoming more seamlessly connected through the increasing importance of context. This requires a strategic and educational perspective, where design thinking about social, technological economical, environmental and political aspects completed by collaborative learning determine scholarship as well as synergies between practice and research. Tactically, systematic planning and systems development is essential to develop new knowledge and networks, as well as anticipate future products and services. Operationally, iterative research and design prototyping addresses the systemic, emergent and real challenges of given contexts.

## Social innovation in the curriculum: a model for community engagement and design intervention

**Ian de Vere[1], Daniel Charny[2]**

[1]Brunel University London, United Kingdom; [2]Kingston University, United Kingdom

Social impact implies the capacity to create positive social change for communities and individuals. It is essential that innovation addresses the needs of those less fortunate, and empowers individuals and communities for improved societal well-being. This necessitates a fresh approach to curriculum and pedagogy, and educators have responded by engaging with humanitarian aid agencies to expose students to real world problem scenarios. These social design educational initiatives, however well intentioned, are often remotely located and students lack access to users and communities in need. Without this interaction, cultural and contextual aspects can be misunderstood, and solutions may be misdirected. A local context facilitates engagement and allows co-design processes to occur. The social project discussed in this paper has proven to be an effective model for social design. Students engage with end users within their local community, using design skills to respond to specific needs. Recipients benefit from assistive solutions, whilst students develop empathy and understanding. This design intervention model has delivered successful outcomes, and a unique learning experience.

**WEDNESDAY, AUG 23**

# P2.8

**9:00 am – 10:30 am**

**2506**

CHAIR

*Christopher McMahon*

# Design Education – New Approaches, cont'd

WEDNESDAY, AUG 23

P2.8

**9:00 am – 10:30 am**
**2506**

CHAIR
*Christopher McMahon*

## First View DesignLab: A fuzzy front end platform for innovation and education

**Maria Cristina Hernandez-Monsalve[1], Marcela Velasquez-Montoya[1], Ricardo Mejia-Gutierrez[1], Helga Hohn[2], Marc Tassoul[2]**
[1]Universidad EAFIT, Colombia; [2]Delft University of Technology, The Netherlands

Collaborative design projects in Latin America between academy and industry, have been commonly focused on New Product Development processes. Nevertheless, collaborative experiences at the Fuzzy Front End (FFE) stage are more frequent between company partners to emphasize the potential for organizations to collaborate, rather than academy and industry. This paper presents the experience in the set-up and execution of an international project, so-called "First View DesignLab" organized between Universidad EAFIT and TUDelft to be executed in Colombia with five local companies in collaboration with Product Design Engineering (PDE) students. Each company proposed a company case where the objective was to find new opportunities for new product/service concepts. Design Thinking (DT) tools were used to trigger co-creation and open innovation in order to explore new opportunities by each company. Important aspects have been of great value to identify best practices to better develop academic collaborative projects at the FFE. Reflections are presented as useful insights to enhance innovation capabilities and idea generation skills for both, academy and industry to identify opportunities.

# Additive Manufacturing Case Studies in Industry 1

WEDNESDAY, AUG 23

P2.9

9:00 am – 10:30 am

2514

CHAIR

*Wei Chen*

## A methodical approach to support ideation for additive manufacturing in design education

**Hagen Watschke, Ann-Kathrin Bavendiek, Alexander Giannakos, Thomas Vietor**

Technische Universität Braunschweig, Germany

Additive manufacturing (AM) is a relatively new technology which opens the door to many new design possibilities for end-use products. However, many design engineers often are not familiar with the potentials of AM and therefore do not take advantage of them in the product development process. To overcome barriers in generation of new ideas caused by the limitations of conventional manufacturing processes particularly in the ideation stage, new design methods and tools are needed. Therefore, students as well as non-experts of AM have to be assisted to fully exploit the newly opened design potentials. This paper provides a methodical approach to enrich general design methods for ideation with AM knowledge for ensuring a user tailored support. Combinations between various methods to assist the ideation process are proposed based on the analysis of general ideation methods and existing AM-specific tools which consider potentials as well as limitations of AM. Subsequently, one of these combinations is utilized in an academic workshop and evaluated by the participants. Finally, the results of the evaluation are discussed.

## Additive repair design approach: Case study to repair aluminium base components

**Yousif Amsad Zghair, Roland Lachmayer**

Leibniz Universität Hannover, Germany

Additive manufacturing is considered one of the modest manufacturing techniques. Using this technique in components repair is the state of the art in the industry of maintenance. This paper introduces an additive repair design approach, with focus on Selective Laser Melting technique, and investigates mechanical properties and the bonding force between the damaged components and the added repaired volume. Various load cases and building directions are discussed, and a selected one is simulated and applied on a case study. The candidate metals of the damaged parts are Al-6082 and Al-7075 alloys, and the used powder to repair with the Selective Laser Melting machine is AlSi10Mg. The analysis carried out by means of a finite element numerical model to estimate the axial loading and the induced stresses. Experimental work is implemented, and all analytical and experimental results are discussed and compared. This work aims to develop scientific basics for parts repair using additive manufacturing technologies. Overall, the additive repair approach promises efficiency, but has to be further advanced in the field of maintenance for components in industry.

# Additive Manufacturing Case Studies in Industry 1, cont'd

WEDNESDAY, AUG 23

P2.9

9:00 am – 10:30 am

2514

CHAIR

*Wei Chen*

### A new method for designing porous implant

**Huiyuan Yang, Yaoyao Zhao**
McGill University, Canada

Porous interconnected structure has been widely used in designing bone implant as it provides a three-dimensional space for cell ingrowth and nutrients transportation. Current modeling techniques either uses medical Images reconstruction to form randomized lattice or repeats unit cell spatially to periodical lattice structure. However, none of them is able to achieve sufficient control of mechanical properties. In this paper, a novel method is proposed using the implicit surface modelling and Voronoi diagram to generate randomized porous structure. Implicit surface modelling utilizes 3D scalar mathematical equation to represent complex geometries where several key parameters such as strut thickness and density can be easily determined thus the mechanical properties of the structure can also be determined. The proposed data acquisition method simplifies the CT image to point cloud. The distribution of point cloud is the presence of natural tissue distribution in image data which is inherited the generated artificial porous structure.

### An approach to implement design for additive manufacturing in engineering studies

**Bastian Lippert, Georg Leuteritz, Roland Lachmayer**
Leibniz Universität Hannover, Germany

This paper describes an approach to implement additive manufacturing technologies in engineering studies by analyzing a lecture, which is divided into a theoretical and a practical part. Focusing on the practical part, the concept of a design task is shown, in which students are able to examine the technology intensively by self-contained manufacturing of 3D-printed parts. Describing the concept of an open 3D-printing lab, the basics of fused deposition modelling, as an additive technology, are characterized. After defining project teams with six to eight participants each, a remote controlled electrical vehicle has to be designed by the students. During this process, the project teams have to fulfil a specific design objective, like for example applying internal structures or aiming towards a maximum functional integration. As a result of the case study, two vehicle concepts as well as applied design approaches are presented. Based on the gained experience, suitable design methods and tools to enable multicriteria design objectives are summarized and an estimation about optimization effort is given finally.

### Increasing product attachment through personalised design of additively manufactured products

**Robert Ian Campbell, Roberta Bernabei**
Loughborough University, United Kingdom

The research reported in this paper has demonstrated that emerging digital technologies are offering new methods for designers to work with end users to help them create personalised products. Additive manufacturing provides a manufacturing process that is capable of producing virtually any geometry with little or no cost and time differentials. The most difficult part of the process is the CAD modelling effort required to create highly complex personalised shapes. Conventional CAD struggles to support the user creativity required whereas the advent of Virtual Clay modelling seems to offer some potential in this area. Overall, the combined use of co-design and additive manufacturing results in an exciting new environment for creative designers and users to work together. They can work in a digital medium that mimics the flexibility of 3D physical modelling and yet offers the speed, repeatability and cost benefits of automated production. The increased emotional bonding that users have with personalised products has been shown to be a potential source of greater product usage life and hence improved sustainability.

**WEDNESDAY, AUG 23**

## P2.9

**9:00 am – 10:30 am**
**2514**

CHAIR
*Wei Chen*

## Break

**10:30 am – 11:00 am Atrium Lower Level**

**WEDNESDAY, AUG 23**

**11:00 am – 11:45 am**
**Great Hall & Foyer**

CHAIR
*Harrison Kim*

# Keynote:

## Catherine Roome
### P.Eng. FEC ICD.D

**Biography:** Since 2011, Catherine has been President & CEO of BC Safety Authority (BCSA), an independent, self-funded organization mandated to oversee the safe installation and operation of technical systems and equipment. In addition to issuing permits, licences and certificates, BCSA works with industry to reduce safety risks through assessment, education and outreach, enforcement, and research.

Believing that people have an extraordinary ability to bring a shared vision into reality, Catherine applies her broad organizational experience, particularly her acumen for risk management, into steering BCSA towards its vision of Safe technical systems. Everywhere.

As a creative and principled leader, Catherine values the power of engaging people for a common purpose. She encourages her team to bring their unique potential to building networks that connect all those who use or operate technical equipment in order to share knowledge and expertise to advance safety. A professional engineer, and recipient of several business and leadership awards, Catherine received her degree in electrical engineering from the University of Victoria.

## Nonchalant design of a society's "safety system"

By considering how to deploy our human resources most effectively through the introduction of a decision support tool (while embedding an ethic of transparency), a public safety regulator has embraced constraints and delivered abundance. We used to think that there is a linear relationship between safety, and the number of experts who confirm things are safe. In other words, if you wanted better safety, that meant ensuring there were more people checking everything, all the time. A future-world expectation of decreasing risk tolerance, coupled with fewer and fewer deployable technical resources, has derailed that equation.

With limited resources it is not possible (nor is it desirable) to do 100% inspection of all hazardous equipment across BC – it is only possible to physically assess a fraction of technical equipment assets. This raises the question of how to design a safety system that is complete. BCSA has developed a decision support tool, called the Resource Allocation Program, which allows us to embrace and leverage our human resource limitations by prioritizing tasks based on risk. This algorithm has been designed to continuously learn, by receiving data from every site assessment. By using our limited human resources' insight, experience, knowledge, and training, we can automate and populate a database that can help identify hazards, improve public safety, and deliver safe technical systems everywhere.

In evaluating the tool, we are designing in ethical considerations, so that there is a shared understanding of what risk is acceptable and what is unacceptable. We are also learning from the tool's limitations: If our human technical resources make errors in the ranking of samples, is it more important to deal with false positives or false negatives, especially when a false negative result has a higher cost impact? From an ethical standpoint, which correction is better and deserves greater focus given our limited resources? Additionally, over time as the database matures and become highly populated with our experts' knowledge, our human resources will not have as many opportunities to showcase their experience in selecting the safety priorities – how do we balance professional knowledge with machine-automated priority lists? Do we allow discretion? And to what extent can we allow machine learning to replace humans?

The design of a safety system, and its implicit output as providing for a better human existence, must also take into account the tools used to deliver that safe outcome.

**WEDNESDAY, AUG 23**

**11:00 am – 11:45 am**
**Great Hall & Foyer**

CHAIR
*Harrison Kim*

**WEDNESDAY, AUG 23**

**11:45 am – 12:30 pm**
**Great Hall & Foyer**

CHAIR
*Filippo Salustri*

# Keynote:

## Julian F.V. Vincent
### MA, PhD, DSc, FRES, MIMMM, CEng, FIMechE

**Biography:** Julian Vincent is a zoologist. He took his first degree at Cambridge University and second and third at Sheffield University. In 1968 he started his career at the University of Reading, UK as a zoologist. In 2000 he was invited to the University of Bath, UK, as a Professor of Mechanical Engineering. He was part time lecturer at the Royal College of Art & Design and Imperial College London until 2010.

He has worked in many interdisciplinary contexts, such as mechanical engineering, materials science, architecture, design, creativity, biology, materials, food physics, food texture. He is, and has been, a member of numerous scientific and advisory boards. He cofounded the Centres of Biomimetics in Reading and Bath and is President of the International Society for Bionic Engineering. He is a Senior Research Associate in Zoology at Oxford University, Honorary Professor at the Hochschule Rhein-Waal, Germany, and Adjunct Professor in Engineering and Materials at Clemson University, USA.

## Survival of the Cheapest: Information and Material in Biological Design

In order to be useful, biomimetics has to have a framework to organise the ideas and present a searchable system. Specific problems of design can then find suggestions or answers — if they exist. Further requirements of such a system are that it should be equally accessible to practitioners (designers, biologists and engineers) and that it should cover all areas of biology and design. The design of such a system has been my target for the last 15 years or so. The system is based on the Contradiction Matrix, part of the Russian system of identifying and solving problems, TRIZ. I recently discovered that this part of TRIZ is actually based on trade-offs, not on Hegel's dialectic definition of a problem as even the creators of TRIZ seem to have believed.

Problems in engineering can be expressed as trade-offs; many biological phenomena (especially in behaviour and ecology) are expressed as trade-offs in research papers. In fact there is a good case for thinking that a large part of evolution can be considered as the resolution of trade-offs. So we have robust common ground between the practitioners which can be organised into a framework. Not only that, but from engineering we have mathematical tools for analysing and (probably) identifying trade-offs, even in biological systems which are typically very complex. The descriptive data has been organised within an ontology which has revealed some common themes with such trade-offs as speed-accuracy, reproduction-survival, and tolerance-defence. At the time of writing this we are about to start applying multi-objective (Pareto) analysis to some of these systems.This has already been done in a few systems by biologists, but the overall significance has not been realised. Bringing it all together, it seems that we not only have a framework and underlying system for biomimetics, but a new way of interrogating evolution.

**WEDNESDAY, AUG 23**

**11:45 am – 12:30 pm**
**Great Hall & Foyer**

CHAIR
*Filippo Salustri*

## Lunch

**12:30 pm – 2:00 pm Atrium Lower Level**

# Advanced Requirements Management

WEDNESDAY, AUG 23

D5.1

2:00 pm – 3:00 pm
Performance Theatre

CHAIR
*Shayne Gooch*

## Automotive styling: Supporting engineering-styling convergence through surface-centric knowledge based engineering

**Ulrich Ernst Feldinger[1], Sebastian Kleemann[2], Thomas Vietor[2]**
[1]Volkswagen AG, Germany; [2]Technische Universität Braunschweig, Germany

The emotional impression a car imprints on a potential buyer is as equally important for its commercial success as fulfilling functional requirements. Hence, to create a positive emotional impression of a vehicle, great effort is put into a car's styling process. One of the key aspects during the early stages of the automotive design process is the convergence of styling and engineering design. While requirements stemming from engineering design are usually characterised by quantitative values, styling requirements are rather qualitative in nature. Converging these two requirement types is laborious. The present publication focuses on supporting this process through Knowledge Based Engineering. This is achieved by introducing a method which enables the designer to intuitively regard functional requirements during the styling phase. Moreover, the method improves the process of technical requirement checks regarding the shape and orientation of styling surfaces which exceed conventional package verifications.

## A network-based approach to identify lacking coordination using higher order links

**Dominik Weidmann, Lucia Becerril, Christoph Hollauer, Niklas Kattner, Udo Lindemann**
Technical University of Munich, Germany

Mechatronic products are getting more complex whereas disciplines becoming more interdependent in future. The coordination of discipline-spanning interfaces is going to play a more important role. Based on literature research and industry interviews this contribution identified the need for a better coordination in interdisciplinary development projects. The presented approach addresses the identification of lacking coordination using higher order links with focus on requirements and their affected stakeholders. A network-based approach takes components and functions into account to meet the characteristics of mechatronic development. Workflows can identify missing links between organizational units via the links between the artefacts. Important steps of the approach were successfully realized in an academic context, but the resulting networked based model bears potentials for further analysis and optimization. Especially an increasingly digitalized development environment requests for a software tool to use the great potentials of automatized support to analyze the system.

## Categorizing user pains, usage situations and existing solutions in front end of innovation: The case of smart lighting project

**Alexandre Bekhradi[1], Bernard Yannou[1], François Cluzel[1], Thomas Vallette[2]**
[1]CentraleSupélec, Université Paris-Saclay, France; [2]NOVIA swk, France

Companies make substantial R&D investments in early design stages to develop radically innovative products. However, despite abundant research work in the field of human-centered design, the front end of innovation is the least well-structured part of the innovation process. Radical Innovation Design (RID) methodology has put forward a structured process aiming at exploring, organizing and categorizing required knowledge to design a useful problem in the form of value buckets (i.e. overlooked problems of users) to be evaluated. In this paper, we aim at reinforcing the knowledge acquirement process in parallel with the problem design process to fine-tune the firm's R&D strategies, and to increase the likelihood of successfully reaching the mainstream markets.The contributions of this paper are twofold: i) to provide a set of knowledge acquisition rules in front end of innovation; and ii) to specify a set of problem design guidelines mainly by introducing a tool called Dependency Structure Modeling (DSM)-Value bucket algorithm, which enables a systematic identification of value creation opportunities. The example of a smart lighting project is analyzed in this paper as a case study.

## Derivation, analysis and comparison of geometric requirements for various vehicle drivetrains using dimensional chains

**Matthias Felgenhauer[1], Frank Schöpe[2], Michaela Bayerlein[2], Markus Lienkamp[1]**
[1]Technical University of Munich, Germany; [2]AUDI AG, Germany

Following the development of new drivetrain concepts (e.g. BEV and FCEV) the comparison of drivetrains becomes increasingly important during the vehicle architecture design. Thereby, the geometrical requirements of the drivetrain architectures, respectively the minimal required distances between components, maximal component sizes as well as cross-vehicle dimensions, are often unknown at the beginning of the development. This is predominantly caused by the multitude of requirements and the high variance of components. Thus, as a starting point of a new development, experts are required to manually determine and compare the geometric requirements from existing vehicles. To increase the efficiency, a methodology is developed which derives, analyses and compares the minimal required distances, the maximal component sizes as well as the cross-vehicle dimensions of drivetrain architectures, by using dimensional chains of series vehicles. Thereby, the most relevant load paths and vehicle configurations are identified, hence reducing the complexity. Using the new methodology, it is possible to derive geometric requirements and to compare drivetrain architectures in an efficient way.

**WEDNESDAY, AUG 23**

# D5.1

**2:00 pm – 3:00 pm**
**Performance Theatre**

CHAIR
*Shayne Gooch*

WEDNESDAY, AUG 23

D5.2

**2:00 pm – 3:00 pm**
**Art Gallery**

CHAIR
*John Gero*

# Physiological Experiments

## Modal shifts in concentration indicate creativity

**Philon Nguyen, Yong Zeng**
Concordia University, Canada

Modal shifts are said to indicate heightened creativity in the conceptual design process. These modal shifts are traditionally detected using concurrent verbal protocols. However, it is known that verbal protocols fail in some situations such as when dealing with creativity, insight, nonverbalizable and nonconscious processes. It is an open debate in the design literature on verbal protocols whether nonconscious (nonverbalizable) processing is significant or not. We used EEG signals recorded on subjects who were asked to solve design problems on a sketch pad to detect modal shifts in concentration. We found that modal shifts in concentration were often occurring when subjects were erasing completely their previous solution and restarting a new solution from scratch (i.e. tabula rasa event), indicating heightened creativity. From EEG segments where modal shifts in concentration were deemed to be high, we performed source localization using the LORETA algorithm. Cross-checking with the physiology literature on the neurology of creativity, we found that regions of the brains associated with creativity (e.g. prefrontal lobe) were activated during modal shifts.

## Target based analysis – A model to analyse usability tests based on mobile eye tracking recordings

**Moritz Mussgnug[1], Aleksandra Sadowska[2], Ralf Moryson[3], Mirko Meboldt[1]**
[1]ETH Zurich, Institute of Design, Materials and Fabrication, Switzerland; [2]ETH Zurich, Institute for Biomechanics, Switzerland; [3]Robert Bosch GmbH, Germany

This paper addresses the usability evaluation of tangible products by video analysis. Compared to conventionally conducted videos from the third-person perspective, mobile eye trackers allow to capture the user-product interaction from the first person view, and to measure the location of the gaze. Knowing where a user looks, enables to analyse the interaction more granular, and to draw conclusions about cognitive processes. To address the potential of mobile eye tracking for usability tests of tangible products, we introduce the Target Based Analysis (TBA) — a model structuring the video analyses. On the basis of the location of the gaze, the model decomposes each interaction step in the four reoccurring phases: find, recognize, handle and prepare/wait. The model has been tested in a usability study of two 3D printers with 46 participants. It was possible to map each user-product interaction, to generate comprehensive overviews allowing to quickly identify critical steps, and to compare between tasks, user groups, and products. In the future, an integration of eye tracking measures, such as fixation durations, could further amplify the quantification of user-product interactions.

### The attentional capture of colour in visual interface design: a controlled-environment study

**Emil Andersen, Anja Maier**
Technical University of Denmark, Denmark

The use of colour is an integral component in visual interface design for creating separation between objects and for conveying meaning. It has previously been established that colours can be separated in a hierarchy of primary colours and secondary colours, and that colours are consistently associated with specific mood tones. However, it has thus far not been investigated whether these two factors, which we refer to as the perception-primacy and emotion-conveyance, are associated with attentional capture in a congruent manner. To investigate this, we conducted a visual search task study in a controlled environment, in which 11 participants scanned a 20 item display for a coloured target amongst coloured distractors. We found evidence to support that primary colours capture attention significantly more than secondary colours, and inconclusive evidence that colours convey their meaning at a sufficiently early level of processing to influence attention. We end by discussing implications of our results for design practice and research in psychology.

### Patches in sketches: Which type of sketch is more valuable for the end-user in the early phase of new product development

**Anna Jeannette Klapwijk, Nemo Kostoulas, Petra Badke-Schaub**
Delft University of Technology, The Netherlands

Involving end-users early in the process of New Product Development (NPD) has proven leading positive effects on further developments of the design and success of new products. In the early stages of NPD designers often use sketches to communicate their ideas, to get feedback to iterate and develop the design. While the relevance and value of sketching as part of the design process and the usability to communicate ideas more effectively have been investigated, little research has been conducted looking at the elements that support effective means of generating insights from end-users. Sketches are often used according to the appropriate purpose and context of the situation, different types of sketches can be used to convey their idea. It is important to understand what elements of the different types of sketches are that generate most valuable feedback from the user involved in the development process. Presenting end-users 5 types of frequently used sketches showed that the information sketch was most favorable, followed by the scenario sketch. The use of color, explanatory elements and context of the product were important factors for the preference of these types of sketches.

**WEDNESDAY, AUG 23**

## D5.2

**2:00 pm – 3:00 pm**
**Art Gallery**

CHAIR
*John Gero*

WEDNESDAY, AUG 23

D5.3

**2:00 pm – 3:00 pm**

**2301**

CHAIR

*Kevin Otto*

# Design Process in Context

## A guide to investigating design process models context of use

**Daniel Guzzo Costa, Janaina Costa, Henrique Rozenfeld**
University of Sao Paulo, Brazil

Design process models are created for different purposes, which includes assisting the design team to manage a project and to perform their day-to-day activities. In both cases, process models should be development to attend needs of its users — the design personnel. A good practice to understand systems users' needs is to perform a context analysis of the intended uses. In this research, it is performed a case research which analyses the context of the use of design process model in a multinational company. User-centered techniques as contextual inquiry and empathy map were employed. Based on the application, a guide to investigating design process models context of use is proposed. Four perspectives of the context of use of design process models may be investigated: product, design process, organization, and individual. The description of the context of use of design process models may assist to verify the needs of the users of the process being represented.

## Context-specific process design: An integrated process lifecycle model and situations for context factor use

**Christoph Hollauer, Julian Wilberg, Mayada Omer, Udo Lindemann**
Technical University of Munich, Germany

The development of complex systems such as e.g. Product-Service Systems relies on complex processes. Corresponding design contexts are often complex and evolving over time, with factors such as e.g. organizational structures, location, product type, impacting the development process. Companies rely on process models for a number of purposes. However, process models used within companies are often „flat" and the context the process models are used in is often inadequately acquired and considered during modelling. This becomes evident, e.g. when process models are used as a basis for tailoring project-specific processes. In this paper, we first present a literature-based integrated lifecycle model for product development processes and models thereof. From it we derive situations (application cases), in which identified context factors can be used to improve activities such as reference process modelling, process model use, process analysis, and process evolution. The situations have been partially validated in industrial case studies and serve as the foundation to further develop methodological support to increase context awareness in product development process modelling and management.

## An information model to estimate efforts of product development processes

**Claudia Dittmann, Georg Jacobs, Valerie Felix**
RWTH Aachen, Germany

Due to small batch series or customer orders with specific requirements, costs and especially development cost are hard to determine. Their impact on the overall costs is enormous and cannot be compensated by current production technologies. To evaluate design efforts, standardized processes are known. Common models as the VDI 2221 are therefore unsuitable due to their generic character of the process steps. They are based on ideal theoretically solutions and do not consider limitations by industrial and organizational constraints. Therefore, a more detailed process is necessary, to make a comparison possible. This paper will show an approach to estimate efforts of a design project as a mathematical function. The process is based on project requirements, the process itself and other related factors which are part of the development. The output is a method for the effort estimation.

## Towards a model of the open-design process: Using the grounded theory for modelling implicit design processes

**Etienne Boisseau, Carole Bouchard, Jean-François Omhover**
Arts et Métiers ParisTech, France

The open-source approach arose in the computer industry. It now also impacts physical goods. In order to benefit from alleged benefit of open-design for tangible artefact, it appears needed to model this design process. We thus studied the 12 projects that took part to the PoC21 innovation camp, and construct a model based on interviews of projects stakeholders we have conducted. To develop the model, we followed the methodology of the grounded theory. The two main contributions of this paper are: first, the model of the open-design; and second, the methodology we used to construct this model. We have found that it is possible to use the grounded theory framework for formalizing implicit processes. Our model depicts the open-design process as a process, which features resemble to both traditional product design processes, and open-source software development processes. However, it also presents specifics that are not shown in any of these models detailed in literature. This model can serve as a basic for future prescriptive research on open-design. Moreover, we recommend a grounded-theory based methodology to model undocumented and implicit design processes.

**WEDNESDAY, AUG 23**

# D5.3

**2:00 pm – 3:00 pm**

**2301**

CHAIR

*Kevin Otto*

# Risk Management 1

WEDNESDAY, AUG 23

D5.4

**2:00 pm – 3:00 pm**
**2306/2309**

CHAIR
*Alison Olechowski*

## Challenges for integrating sustainability in risk management – current state of research

**Jesko Schulte, Sophie Hallstedt**
Blekinge Institute of Technology, Sweden

Numerous examples have shown how environmental and social issues can affect companies to an existential level. In fact, today's most urgent business risks, e.g. brand value, legislative change, litigation, and supply chain disruptions, are directly linked to sustainability issues. These risks need to be systematically identified and strategically managed on both strategic company- and operational product development level in order for a company to be long-term competitive. Based on literature review and interviews at case companies, this paper investigates the current state for integrating a strategic sustainability perspective in risk management processes and related support tools. Results show that sustainability risks are not consciously identified and managed at the companies. Research is at an early stage and few frameworks and tools exist. Based on the findings, the study identifies and provides a comprehensive analysis of challenges for sustainability integration, which work as a foundation for future research. Finally, key steps to advance understanding and methods in sustainability risk management are suggested.

## Towards an assessment of resilience in telecom infrastructure projects using real options

**Jonathan Mak[1], Steve Cassidy[2], P. John Clarkson[1]**
[1]University of Cambridge, United Kingdom; [2]BT Research Labs, United Kingdom

This paper employs the concept of real options to quantitatively assess resilience. First, the definitions of resilience are distilled from literature in the fields of engineering, management and ecology to give requirements for further assessment. From this, it was found that resilience requires a system to be robust, adaptable and flexible in the face of uncertainty. The main contribution of the paper is to connect these requirements to real options valuation and demonstrate the evaluation of the robust and flexible cases through real options methods. Specifically, Least Squares Monte Carlo method is used to value each option with the robust case being the benchmark and flexibility representing upgrades to the system. This is applied to an illustrative telecommunications case and the properties of the model assessed. The results show that uncertainties on the system can be captured and valued through this method so that it can aid a decision maker to assess which technology option or investment to select for future planning.

## On characterization of technology readiness level coefficients for design

**Mahi Fahimian, Kamran Behdinan**
University of Toronto, Canada

Technology innovation is an important driving factor in creating competitive advantage in industries that have evolved by convergence of technology and design. In this industries, technology management is a pillar of design management. One valuable source in technology management is Technology Readiness Level (TRL), initially developed for NASA. The application of TRL numbers has been expanded to estimate the cost and risk of acquisition or development of different technologies. However TRL numbers are ordinal and applying mathematical operations on them create incorrect results. TRL cardinal coefficients are developed to eradicate this error. In this paper TRL cardinal coefficient values for seven NASA aeronautic technologies have been calculated based on Analytic Hierarchy Process. For the first time, the cardinal coefficients are calculated based on a quantifiable criterion. The variable progress in cardinal coefficients indicated a realistic reflection of the nature of the technology development. In addition, cardinal coefficient numbers were mathematically meaningful when comparing the maturity of technology development across different technologies.

## Applying lean thinking to risk management in product development

**Pelle Willumsen[1], Josef Oehmen[1], Monica Rossi[2], Torgeir Welo[3]**
[1]Technical University of Denmark, Denmark; [2]Politecnico di Milano, Italy; [3]Norwegian University of Science and Technology, Norway

This paper re-conceptualizes risk management (RM) in product development (PD) through a lean thinking perspective. Arguably, risk management in PD projects became a victim of its own success. It is often implemented as a highly formalized, compliance driven activity, ending up disconnected from the actual value creation of the engineering task. Cost overrun, delay and low quality decision making is common in product development processes even if RM processes are in place. Product development is about reaching project objectives by gradually reducing uncertainty, but often fail to do so without delay or cost overrun. This paper explores the relationship between product development and risk management and proposes to make RM an integrated value adding part of PD. Through a literature review we identify the potential of re-conceptualizing RM through lean thinking. We then conceptualize an outline of how one could apply lean thinking to RM to create a simple, value focused and consensus-forming perspective on how to make RM a meaningful part of PD.

**WEDNESDAY, AUG 23**

# D5.4

**2:00 pm – 3:00 pm**
**2306/2309**

CHAIR
*Alison Olechowski*

# Virtual Reality-Related Design

**WEDNESDAY, AUG 23**

D5.5

**2:00 pm – 3:00 pm**

**2311**

CHAIR

*Sandro Wartzack*

## OSLC based approach for product appearance structuring

**René Ebeling[1], Martin Eigner[2]**

[1]Daimler AG, Germany; [2]Technische Universität Kaiserslautern, Germany

Within early phases of a product lifecycle, a lack of process connections between CAD design, product appearance configuration as well as virtual reality and other visualisation scenarios can still be identified. Therefore, the contribution introduces the basic components of a conceptual framework for holistic management of virtual reality and other related visualisation data in order to enhance the current situation within the different product lifecycle stages. The basis of the approach covers the structuring of geometry entities within CAx-authoring tools and the connection to the underlying data backbone. Hence, the ability to structure geometry within CAx-tools and CAx-based open standard formats will be evaluated and discussed. By using the OSLC (Open Standard for Lifecycle Collaboration ) specification, these results allow the implementation of a CAD integrated tool to connect product data with configurable linked data entities.

## Meta-model for VR-based design reviews

**Martin Gebert[1], Wolfgang Steger[1], Ralph Stelzer[1], Kathrin Bertelmann[2]**

[1]Technische Universität Dresden, Germany; [2]FAB Bertelmann Technologie, Germany

The paper describes the development of a tool to make it possible to generate a Virtual Reality (VR) representation of the current state of an engineering project without additional effort. The VR tool extends the CAD and simulation programs used in the development process through a visualisation module. Making use of current geometry and calculation data, it provides direct visualisation in virtual environments. The tool developed is based on a meta-model generated from the data from different application programs. The tool concept and implementation are described for a configurator applied to energy systems.

## Simulation of acoustic product properties in virtual environments based on artificial neural networks (ANN)

**Antje Siegel[1], Christian Weber[1], Albert Albers[2], David Landes[2], Matthias Behrendt[2]**

[1]Technische Universität Ilmenau, Germany; [2]Karlsruhe Institute of Technology (KIT), Germany

Acoustic product properties are playing an increasingly important role for product developers and designers. At the one hand the sound of a product has influence on the buying behavior of customers and on the other hand manufacturers have to meet many regulations and standards regarding the sound emissions of their products. Limits for these sound emissions are defined in order to protect humans and the animal world from noise pollution. The paper deals with a concept for acoustic simulation in virtual environments so that the acoustic properties of products can be studied. The concept is based on artificial neural networks (ANNs) which are applicable for many different tasks. With help of the virtual acoustic simulation the acoustic behavior of products or of individual product components can be validated during the whole product development process. In this way, noise pollution can be reduced and a higher compatibility with human health and environment can be reached.

## A computational tool for virtual product development exploiting changeability knowledge

**Emmanuel Francalanza[1], Jonathan Borg[1], Carmen Constantinescu[2]**

[1]University of Malta, Malta; [2]Fraunhofer IAO, Germany

Shifts in customer needs coupled with highly competitive markets and technological advances, means that product families evolve over time. Product family evolution has an effect not only on how the current and future manufacturing requirements are defined but also on the manufacturing system design process itself and represents one of the main difficulties in designing manufacturing systems. Two types of factory life cycle consequences have been identified which may occur as a result of design decisions during the manufacturing system synthesis design activity. This research therefore contributes a novel changeability knowledge based product development approach framework to reveal and analyse the consequences of commitments made during manufacturing system design on future product capability, hence on product evolution, and factory changeability. This approach was implemented in a computational tool for virtual product development which exploits changeability knowledge to assist, guide and motivate manufacturing system designers into designing more changeable manufacturing systems.

**WEDNESDAY, AUG 23**

# D5.5

**2:00 pm – 3:00 pm**

**2311**

CHAIR

*Sandro Wartzack*

# Resource-Conserving Applications

WEDNESDAY, AUG 23

D5.6

2:00 pm – 3:00 pm

2314

CHAIR

*Amaresh Chakrabarti*

## An exploratory study to integrate feasibility into the eco-design process: An approach to link design and environmental parameters

**Florian Bratec[1], Nada Matta[1], Tatiana Reyes[1], Nadège Troussier[1], René Diaz Pichardo[2], Thibaut Voinot[3], Guillaume Jouanne[3]**

[1]University of Technology of Troyes, France; [2]Groupe ESC Troyes, France; [3]Altermaker, France

To support environmental practices in industrial design, many software tools have been developed. These tools aim to provide environmental information in a decision context for designers and environmental experts. Although Life-Cycle Analysis tools can provide relevant and precise information, the question of feasibility remains crucial in proposing realistic solutions. In our study, we built a database linking design and environmental parameters in order to facilitate the consideration of technical, organizational and economic constrains in eco-design. We used knowledge engineering techniques, applied to a collection of documents from a young company, to identify the relevant design parameters to implement.

## Helping inhabitants in energy saving and getting inputs from usage for eco-design: Cooking case study

**Audrey Abi Akle, Iban Lizarralde**

ESTIA, France

Inhabitants use energy to perform various activities of daily life in the private sphere i.e. the household scope. The activities they undertake are stochastic in nature and difficult to predict. Moreover there is a significant difference between real and theoretical uses of eco-designed products. It is therefore necessary to address the issue of measuring the real energy consumption of the inhabitants in order to identify their behaviour and decrease their environmental impact. In this paper we present an experimental study focusing on kitchen perimeter and cooking activity with two objectives: (1) ordering 20 advices to send to people by considering the perceived difficulty of practicing them and (2) identification of practice difficulties of eco-gestures by experience feedback. The aims are to get design inputs by increasing the difficulty of the activity and to identify needs related to a "weak" product design and consequently a user need to (re)design products for sustainable outcomes. Despite a low sample of 9 subjects, we get significant results allowing us to define a re-usable advices order and identify two real design needs from user feedbacks validating our approach.

## Environmental impacts during the product usage – Identification and categorisation of influencing factors

**Daniela Kattwinkel, Michael Herzog, Marc Neumann, Beate Bender**
Ruhr University Bochum, Germany

To respond to environmental sustainability challenges, many industries are now facing pressure to improve their environmental performance. A developmental approach that systematically integrates an environmental consideration along the entire product life cycle is called ecodesign. To promote an effective ecodesign application, companies need to recognise their products' inherent potential for environmental improvements early in the development process. This paper represents the first step in that direction by analysing the environmental impacts during the usage phase. Thereby every usage process is characterised by different determinants that influence it. On the basis of a literature review, 72 factors that influence the environmental impacts during usage phase are presented in this paper. The influencing factors are structured according to the system elements of a socio-technical system in relation to its properties. Furthermore, every factor is quantitatively or qualitatively differentiated. Using the example of a refrigerator, the influencing factors are evaluated according to their specific impact on the environment.

## An eco-innovation method for products in Bottom of the Pyramid (BoP)

**Jahau Lewis Chen, Shih-Hou Chung**
National Cheng Kung University, Taiwan

This paper presents an innovation method for Bottom of the Pyramid (BoP) by integrating BoP case database and TRIZ techniques. This method can help the designer to go through the design processes to produce the innovative concepts for BoP. Improving the education tools in BoP is demonstrated as example to illustrate the capability of this method.

**WEDNESDAY, AUG 23**

# D5.6

**2:00 pm – 3:00 pm**

**2314**

CHAIR

*Amaresh Chakrabarti*

# Modular and Platform Design 2

WEDNESDAY, AUG 23

D5.7

2:00 pm – 3:00 pm

2504

CHAIR

*Niels Henrik Mortensen*

## Supporting design platforms by identifying flexible modules

**Dag S. Raudberget[1], Christoffer Levandowski[2], Samuel André[1], Ola Isaksson[2], Fredrik Elgh[1], Jakob Müller[2], Joel Johansson[1], Roland Stolt[1]**

[1]Jönköping University, Sweden; [2]Chalmers University of Technology, Sweden

One way for firms to stay competitive is to adapt a platform approach. In product platforms, modules are used as exchangeable design blocks to create a variety in product performance. This is a proven way to get advantages of scale in production by reusing physical parts and investments in manufacturing. To ensure exchangeability between modules, interfaces between modules must be well defined. Hence, from this point of view, there is no such thing as flexible modules. In this research, flexibility refers to the idea of identifying strategic portions of the platform where flexibility is needed and to create the modular division in a way that the assigned modules are de-coupled in theses areas. The presented approach shows how the Design platform concept can be extended by the introduction of flexible modules. These support the Design Platforms by allowing areas of strategic importance to be more flexible and thereby enable room for uncertainties such as fluctuating requirements and future technical development.

## Assessing the financial potential for modularization: A case study in a global OEM

**Martin Løkkegaard, Niels Henrik Mortensen**

Technical University of Denmark, Denmark

Assessing the financial potential of implementing a strategy, based on sharing of key modules and interfaces across a portfolio is difficult. However, this is a critical input when deciding strategic direction in industrial organizations. Through a case study, this paper gives an example of how to map and evaluate the architectures in a portfolio to identify the financial potential for implanting a platform-based modularization strategy. The approach has been applied in a global world-leading OEM with 50.000+ product variants and a turnover of USD 3,5b (2015). The results show a potential for reducing the cost-base by up to 15% through systematically sharing of key design principles across 80% of the company's portfolio. This has supported the discussion of adjusting innovation strategy in the organization. The core contribution of the paper is the operational application of the systematic Architecture Mapping and Evaluation approach (AME) and discussion of how it can support strategic decision-making related to modularization. The approach builds on the understanding that a top-down assessment can give a starting point for implementing a level of modularity across a portfolio.

## Cost based design of modular product families using the example of test rigs

**Michael Hanna, Sebastian Ripperda, Dieter Krause**
Hamburg University of Technology, Germany

Companies with a wide range of variety on the markets have to reduce their internal variety for reducing their costs. This can be reached through modular product families, where more than one concept is possible. A decision making based on costs is missing for the choice of the developed concepts. In this Paper an approach for developing modular product structure concepts based on cost is presented. Based on literature review the Integrated PKT-Approach for developing modular product families is adapted for analyze cost, process and product structure for developing and cost prognosis of concepts and modified tools for analyzing cost are explained. This approach is used in a case study for an industry company where three cost-efficient variety optimized concepts were developed. The approach is helpful for developing cost-reduced concepts based on cost analyses and gives a cost prognosis for rating the concepts.

## Assessment of modular platform potential in complex product portfolios of manufacturing companies

**Casimir Ortlieb, Tim Runge**
RWTH Aachen, Germany

The globalized economy and the increasing trend of product individualization cause a rising amount of product variants to meet the customer's demands. An increasing number of companies develop new or adapt existing modular product platforms for their product portfolio as an approach in order to tackle these challenges. To improve the modular platform performance, it is crucial to define its structure in the early planning phase. This paper introduces a holistic approach that supports decision makers by offering transparency throughout the initial planning phase of the modular platform design determining appropriate products that suit on a common platform. The holistic method uses data analytics to describe the products within a portfolio and to detect similarities between customer requirements, functions and components. The introduced method analyses modular platform potential that is being evaluated in order to provide a detailed and profound prioritization of products in scope for the following platform design.

**WEDNESDAY, AUG 23**

# D5.7

**2:00 pm – 3:00 pm**
**2504**

CHAIR
*Niels Henrik Mortensen*

# Patent-Based Analysis

WEDNESDAY, AUG 23

D5.8

2:00 pm – 3:00 pm

2506

CHAIR

*Joaquim Lloveras*

## A visual analysis of technical knowledge evolution based on patent data

**Vladimir Smojver[1], Eva Potočki[2], Mario Štorga[2]**

[1]Vehicle Center of Croatia, Croatia; [2]University of Zagreb, Croatia

Knowledge visualization can provide a narrative for understanding the dynamics of knowledge dissemination, synthesis and redistribution. The interactions between various knowledge instances is not cumulative, but spawns new knowledge instances. These knowledge instances can then spawn new knowledge instances. This is a process which cannot be controlled, but its dynamics can be understood through visualization. Using visualization, patterns of knowledge asset interactions that can lead to innovation and success, or conflict and failure, can be identified. In today's knowledge economy, organizations that operate in highly competitive market conditions have a need for up-to-date knowledge of emerging technologies. This research attempts to provide insight into a technology fields evolution by analysing how the content of patent claims changes over time. This is achieved by analysing keywords that occur in patent claims and using this data to create topics of interest addressed by patents.

## Framework of mechanical design knowledge representations for avoiding patent infringement

**Pingfei Jiang, Mark Atherton, David Harrison, Alessio Malizia**

Brunel University, United Kingdom

Nowadays companies strive to stay competitive in the market by introducing innovative products and protecting their Intellectual Property by filing patents. However, with an increasing number of patents granted each year, designers face challenges in producing novel designs and patentable inventions such that early identification of potential patent infringement can help them to steer their design away from future litigation and towards a patentable novel solution. This paper presents a framework for representing mechanical design working principles contained in existing patents by developing the Function Analysis Diagram (FAD) and a domain-specific ontology. The developed FAD, named FAD+, provides design insights including device architecture, design features and the functional interactions amongst them. The ontology formulates patent knowledge representation and conceptualisation, which contributes to comparison of an emerging design to existing patents. Overall, the framework enables designers to obtain in-depth understanding of patents, increase their qualitative IP awareness and help them to identify potential patent infringement during the product development process.

### Product description in terms of advantages and drawbacks: Exploiting patent information in novel ways

**Filippo Chiarello, Gualtiero Fantoni, Andrea Bonaccorsi**
Università di Pisa, Italy

Patents are an enormous source of valuable information. Unfortunately only a limited number of elements are targeted in them (mainly legal) and most of the design knowledge is lost or not exploited. Advantages and drawbacks belong to such a group. The paper presents a method to automatically extract advantages and drawbacks from patent texts and proposes a classification framework to organize the gathered knowledge. The organization of advantages and drawbacks follows the evolution of energy material and signal flows, typical of the functional analysis, and allows to organize them in structured documents where the designer can find useful triggers to avoid failures or hints to conceive a more appealing product.

### Definition and support of differentiation and integration in mechanical structure using S-curve theory and wavelet transform

**Takahiro Ishii, Victor Parque, Satoshi Miura, Tomoyuki Miyashita**
Waseda University, Japan

The differentiation and the integration of products are the essential procedures for product innovation. To understand the product innovation, the approaches using S-curve theory, which explain the evolution of a technological system, have been effective. However, the S-curve theory has the disadvantage that the validity of the analysis depends greatly on the number of data. In this paper, we propose a novel method for measuring and predicting the technological innovation and the product evolution based on the S-curve and wavelet transform to solve the problem. In order to confirm the effectiveness of the proposed method, we will conduct a case study using patents of air purifiers. Furthermore, we will define and support the differentiation and the integration of the mechanical structure using the proposed method. Our analysis shows that the differentiation and the integration of the mechanical structure occur as a life cycle extension after the main technologies enter the declining phase. Therefore, the incidental technologies should be introduced at the beginning of the declining phase of the main technologies.

**WEDNESDAY, AUG 23**

## D5.8

**2:00 pm – 3:00 pm**
**2506**

CHAIR
*Joaquim Lloveras*

# Additive Manufacturing Case Studies in Industry 2

WEDNESDAY, AUG 23

D5.9

2:00 pm – 3:00 pm

2514

CHAIR

*Georges Fadel*

## Performance monitoring and control for an additive manufacturing factory – A case study in the aerospace industry

**Nicolas Judalet[1], Akin Kazakçi[1], Emmanuel Le Gouguec[2], Arnaud Balvay[2]**

[1]MINES ParisTech, France; [2]ManzaConsulting, France

Additive Manufacturing (AM) is a promising technology that opens many new perspectives for design, logistics and production. A few state-of-the art industrial companies are beginning to industrialize this technology, i.e. shifting AM applications from prototyping to the production of end-user parts, and optimizing the production process under standard operational constraints. This shift requires to build and manage high-performance AM-based factories, yet few studies are available about the specificities of managing operations in such kind of contexts. Based on a case study with a leading company in the aerospace industry, we argue that the performance of such AM factories relies mainly on their ability to learn quickly how to control the quality of the parts that are produced and that this requires a customized information system. We then provide detailed descriptions of several operational issues AM factory managers and operators will have to face, as well as corresponding measures and metrics to control the learning process towards designing efficient solutions to these new constraints.

## Additive manufacturing and the product development process: Insights from the space industry

**Angelica Lindwall, Christo Dordlofva, Anna Öhrwall Rönnbäck**

Luleå University of Technology, Sweden

With Additive Manufacturing (AM), manufacturing companies have the potential to develop more geometrically and functionally complex products. Design for AM (DfAM) has become an expression implying the need to design differently for the AM process, compared to for conventional, usually "subtractive" manufacturing methods. There is a need to understand how AM will influence the product development process and the possibilities to create innovative designs, from the perspective of the product development engineer. This paper explores the expected influence of AM on the product development process in a space industry context. Space industry is characterized by small-scale production, and is increasingly cost-oriented. There is a general belief that AM could pave the way for more efficient product development. Three companies have been studied through interviews, observations and workshops. Results show that engineers' expected implications of introducing AM in the space industry are: the involvement and influence of customers and politics on innovativeness; the need for process understanding and usage of new tools for DfAM-thinking; the need for qualification of AM processes.

### Using additive manufacturing to design adaptive user interfaces – Lessons learned from a DfAM process

**Florian Weiss, Benedikt Janny, Hansgeorg Binz, Thomas Maier, Daniel Roth**
University of Stuttgart, Germany

The use of Additive Manufacturing (AM) is not limited to non-functional mock-ups, but can also serve to produce fully functional prototypes and end products. This paper outlines the development of a user-adaptive physical human-machine interface (HMI) to examine influencing factors of a Design for AM. For the development of the HMIs, an iterative design approach has been pursued using AM prototypes of shape-changing control elements in end user usability testing for the ergonomic development of the adaptive interface. With a systematic derivation of ergonomic and functional aspects, different shapes of the adaptive HMI are determined. Based on the compiled requirements of the user regarding the control element and the resulting requirements of using AM, four adaptive prototypes were developed. The prototypes are discussed and compared based on ergonomic, functional and manufacturing-related aspects and the conclusions of the process for designing the HMIs for AM are presented. Finally, statements are made concerning the findings for future development projects for AM and aspects that ought to be considered using AM for the design of physical human-machine interfaces.

### Democratisation of design for functional objects manufactured by fused deposition modelling (FDM): Lessons from the design of three everyday artefacts

**Mark Goudswaard, Ben Hicks, James Gopsill, Aydin Nassehi**
University of Bristol, United Kingdom

The purpose of this paper is to explore how the democratisation of design can be achieved for useful items manufactured by Filament Deposition Modelling (FDM). This is achieved through a design study that involves the identification of typical functional objects manufactured by FDM and then performing and mapping the design process for these items. Through analysis of the respective difficulties contributed by different categories of actions, four areas of the design process are identified as requiring improvement in order to democratise design. The study also finds that it is easier to amend models than it is to generate them from scratch. This leads to the consideration of democratising design through amending existing models in design repositories, such as Thingiverse. The discussion examines the consequences of these findings and how they impact the requirements and possible functionality of a system that could meet the challenge of democratising FDM design.

## Break

**3:00 pm – 3:15 pm Level 2**

**WEDNESDAY, AUG 23**

# D5.9

**2:00 pm – 3:00 pm**
**2514**

CHAIR
*Georges Fadel*

WEDNESDAY, AUG 23

D6.1

**3:15 pm – 4:15 pm**
**Performance Theatre**

CHAIR
*Cecilia Berlin*

# User Feedback

### Exploring the persona model as a tool to generate user insight through co-creation with users in the early phase of a design project

**Jane Holm Hansen, Louise Møller Nielsen**
Aalborg University, Denmark

The persona model is a widely know tool for synthesizing user research. A persona is a hypothetical archetype based on actual users, which is typically created to create a shared understanding of the user in the design team. Previous research has focused on the personal model as a consensus-making tool. However, in this paper the aim is to explore, whether the persona model can also be useful and valuable for collecting user insights. More specifically, the paper investigates the potentials and challenges of using the persona model as a generative tool to achieve user insight, when co-creating with the user in the early phase of a design project. A modified persona template with fixed parameters has been introduced to users in two co-creation workshops. The users were asked to fill in the persona template based on their own experiences. This study is a first endeavor into exploring the persona model as a generative tool and so far the empirical study includes only two co-creation-workshops, which is too few to make any solid conclusions. Still, the study indicates some interesting insights about the potentials and challenges the persona model has, when used as a generative tool.

### Evaluation and management of customer feedback to include market dynamics into product development: Satisfaction Importance Evaluation (SIE) model

**Ravi Kumar Gupta, Farouk Belkadi, Alain Bernard**
École Centrale de Nantes, France

Customer's requirements fluctuate across geographical regions and type of use context for a product. In order to address dynamic market's needs, it is important to maintain an open communication channel between the users and the product design department. This communication allows customers to evaluate released products and express their opinion through in production and after-sales feedback gathering. Designers can use this pool of knowledge as a reference for future product design, so as to support frugal product design, creating product that can be adjusted to different market needs. A new SIE model is proposed for the evaluation of customer feedback to identify whether modules and attributes in a product are designed perfectly according to the market's needs. A methodology based on modular approach (modular organization of a product, product-service and product system) is proposed for the feedback formalization for a product development perspective. The product modules and attributes are evaluated to compute improvement indicators for the product in development and for the future product. The effects of these evaluations on the product development and delivery time are analyzed.

## Exploring the integration of social media feedback for user-oriented product development

**Quan Deng[1,2], Marco Franke[1,2], Karl Hribernik[1,2], Klaus-Dieter Thoben[1,2]**
[1]BIBA – Bremer Institut für Produktion und Logistik GmbH, Germany; [2]University of Bremen, Germany

Product designers thrive on designing products to fulfil various expectations and needs from customers. To understand the customer expectation and needs, it is crucial to have the information on customer feedback that is generated during product usage phase. For this purpose, social media has attracted strong interest, as increasing amount of information is published daily by customers. This information is related to a wide range of products and contains product specific feedbacks. To make use of the feedbacks, different approaches were developed and described in literature. Most of them focused on the extraction of limited information to support specific tasks, which is however not flexible and general enough. Little research has provided a practicable and flexible solution to support different design tasks in various domains. This article suggests a social media wrapper approach, which can be flexibly configured to address this issue. It provides designers a holistic view of the feedbacks that widely distributed in different social media channels as well as in diversity data sources. This holistic view of feedbacks can be analyzed to earn necessary knowledge for design tasks.

## Employing design representations for user-feedback in the product design lifecycle

**Samantak Ray, Young Mi Choi**
Georgia Institute of Technology, United States of America

The product design lifecycle is dependent on user-feedback to deploy products with the highest rate of market success. User-feedback informs a product design to cater to the needs of the consumer. Feedback can come at any stage of the design lifecycle but earlier feedback leads to more significant impact in design decisions/direction. This study seeks to make use of design representations — like sketches — to represent a real product and consequently elicit early feedback. In this study, 5 different design representations of a heater product were created and validated for the purpose of exploring their capabilities. 36 feedback-sessions were conducted to gather data on the representations and this data was coded to distill the feedback and discover the representation's shortcomings compared to the real product. The results informed a plan to update the representations to more accurately represent the real product. The trends observed while coding shed light on common oversights made by designers in creating representations of a concept product — this will contribute to developing a system for producing design representations optimal for acquiring feedback in the design-lifecycle.

**WEDNESDAY, AUG 23**

# D6.1

**3:15 pm – 4:15 pm**
**Performance Theatre**

CHAIR
*Cecilia Berlin*

# Computational Design Cognition Studies

WEDNESDAY, AUG 23

D6.2

**3:15 pm – 4:15 pm**
**Art Gallery**

CHAIR
*Jonathan Cagan*

## Building a computational laboratory for the study of team behaviour in product development

**Marija Majda Perišić[1], Mario Štorga[1], John Gero[2,3]**
[1]University of Zagreb, Croatia; [2]UNC Charlotte, United States of America; [3]George Mason University, United States of America

As the result of the first phase of building a computational laboratory which is aimed to enable detail study of the emergent team properties and team behaviour in product development, this paper focuses on the design of a computational representation of a member of product development team. Since team members are often faced with the necessity to adjust to changes in their environment, the emphasis was put on modelling of human adaptive capacity. Specifically, the paper brings together the theoretical findings on mechanisms individuals use when faced with disruptions and introduces the architecture of an adaptable agent that can be used for studying adaptation of product development team. Building on the findings from psychology, sociology and cognitive science, the proposed agents are defined as cognitive, situated, affective and social. The proposed computational workbench is aimed to augment understanding of team processes prior, and in response to adaptation triggers in the context of product development projects, and should enable anticipation of possible pitfalls, enhance the development of design methodologies and tools, and provide guidelines for design education.

## Learning by migrating: A computational study of diversity and team-level decision-making

**Russell Thomas[1], John Gero[1,2]**
[1]George Mason University, United States of America; [2]UNC Charlotte, United States of America

How does previous experience and learning influence a team's ability to successfully agree on a system architecture, team roles and responsibilities, and design method? Migration of team members leads to diversity in past experiences and beliefs, which might have a positive or negative affect on team decision-making. Using computational modeling of self-managed teams across multiple project life cycles, we perform controlled experiments to evaluate performance and decision-making patterns of migrating vs. non-migrating teams. We find that there is no difference in mean performance, indicating that neither approach is intrinsically better. However, statistical tests of paired trials shows a meaningful an advantage for migrating (diverse) teams. Examining patterns of decision-making over time reveal that migrating (diverse) teams explore a wider range of team-level decisions, which makes them more adaptable in specific circumstances.

## Using crowdsourcing to provide analogies for designer ideation in a cognitive study

**Kosa Goucher-Lambert, Jonathan Cagan**
Carnegie Mellon University, United States of America

Analogical reasoning is a prominent method for human creative design. The design research community has invested significant effort into understanding the process of design by analogy, including the impact of different types of analogies on design thinking and solution characteristics. Yet, generating those analogies is a challenge. The present work investigates whether it is possible to obtain useful analogies from individuals with no domain knowledge. To do this, individuals in a crowd workforce were asked to provide solutions for design problems previously explored in the literature. A text mining approach was used to extract commonly used words from these responses, which then served as analogies for problem solvers with design expertise. Finally, 111 participants were recruited for a cognitive study in which they were asked to solve four design problems using some subset of crowd-sourced analogical inspiration. Results indicate that it is feasible to gather impactful analogies from a crowd workforce. The usefulness of analogies at different analogical distances is highly dependent on the problem itself, highlighting the utility of obtaining analogies using the crowd.

## Calculation of design cognitive features based on complex linkography-network

**Jiang Xu[1], Ying Chuai[1], Xiuyue Wang[2], Gang Sun[1]**
[1]Tongji University, People's Republic of China; [2]Southeast University-Monash University Joint Graduate School, People's Republic of China

In view of the complexity of multi-disciplinary team collaborative innovation design process, the quantitative design of cognitive research can be realized by putting forward to deconstruct design complex cognitive space based on the complex linkography-network model. This thesis builds a complex linkography-network model for the complexity of the design of cognitive forms, and describes complex design cognition from the perspective of process and content, and then extracts the characteristics of cognitive process based on the essence of the cognition, and uses a rational analysis to structural decomposition of cognitive complexity. Cognitive instances are used to analysis and verify the validity of the characteristics of expression. This study provides the possibility for manifesting the complex relationship of implicit cognition and the intelligent diagnosis for design cognitive research.

**WEDNESDAY, AUG 23**

# D6.2

**3:15 pm – 4:15 pm**
**Art Gallery**

CHAIR
*Jonathan Cagan*

# Design Process – Supporting Tools

WEDNESDAY, AUG 23

D6.3

**3:15 pm – 4:15 pm**

**2301**

CHAIR

*Eric Rebentisch*

## Introducing constraints to enhance integration at the design-manufacturing interface of new product development

**Susanne Bix**

University of Wuppertal, Germany

Enhancing integration at the design-manufacturing interface in new product development is increasingly important for industrial players to keep up with shorter product lifecycles and innovative dynamics. While abundant research addresses the topic, industrial adoption remains incremental. The paper identifies insufficient recognition of organizational factors and over-emphasized complexity as possible hindrances in industrial application of existing theory. A new approach is outlined that introduces constraints as stimuli to consider manufacturability aspects in the design process. Recent observations in new venture creation and the psychological nature of design processes serve as inspiration. The approach is developed in the empirical context of electrified powertrain systems; initial analyses indicate significant potential for enhanced integration. Explorative case studies are planned to identify constraint designs and forms of organizational embedding that are able to influence product and process engineering. CAD software add-in, motion-time system analyses and manufacturing cost projections are developed as proxies to be introduced as constraints in the design process.

## Parameter control assisting morphological product conceptualization of multi-technology-machine-tools

**Alexander Schmid, Georg Jacobs, Manuel Löwer, Tim Katzwinkel, Walter Schmidt, Justus Siebrecht**

RWTH Aachen, Germany

Product conceptualization is an essential part of each product emergence process. A valid and context-sensitive selection and validation of appropriate product concepts in early stages of product development is challenging. The major reference for subsequently synthesizing overall out of individual solutions represents the morphological analysis, for a systematic heuristic generation of product concepts. This paper addresses a multi-stage design process for a holistic and quantitative morphological analysis and synthesis based on relation-oriented functional modelling. General object is to manage complex problems which do not necessarily suffer by combinatorial explosion. A similarity based product conceptualization is carried out by a Euclidian distance measure for the selection of well-balanced and robust overall concepts. Therefore, various target systems including functionality, economic efficiency and innovation potential are considered during assessment for a systematic combination. A validation and evaluation is performed by an integrative sheet metal forming center.

## An exploratory study into the impact of new digital design and manufacturing tools on the design process

**Lucia Corsini, James Moultrie**
University of Cambridge, United Kingdom

The study aims to understand the impact of new digital design and manufacturing tools on the design process. Digital manufacturing technologies are having far reaching impacts on design, however there is currently little understanding about how this is affecting the design process. The paper reports on an interview study with twelve designers who use new digital manufacturing tools, in architecture, ceramic design, product design and jewellery design. Data is gathered and analysed using a grounded theory approach. The study shows that the design process is defined by the relationships between digital design tools, digital manufacturing tools and digitally manufactured objects. The nature of these relationships vary in direction and degree of formalisation, and they are discovered to influence three key factors in the design process: (1) emergence and control; (2) creativity and, (3) design skills. The study provides new insight into the design process, as well as providing an integrated view of digital design and digital manufacture, identifying areas for further research.

## A tool to support project time evaluation

**Nenad Bojcetic[1], Dragan Zezelj[1], Damir Salopek[2], Filip Valjak[1]**
[1]University of Zagreb, Croatia; [2]KONČAR – Power Transformers Ltd., Croatia

The paper describes the development of a tool to support the project management process. The developed application enables project managers to estimate completion time for process of creation of CAD models. Application use real data retrieved from PLM system about previous projects so more accurate time could be make. The developed application was embrace by the project managers as the very valuable tool.

**WEDNESDAY, AUG 23**

# D6.3

**3:15 pm – 4:15 pm**
**2301**

CHAIR
*Eric Rebentisch*

# Risk Management 2

WEDNESDAY, AUG 23

D6.4

**3:15 pm – 4:15 pm**
**2306/2309**

CHAIR
*Warren Seering*

## Breakthrough technologies: principle feasibility debates

**Andreas Makoto Hein[1], Marija Jankovic[1], Hélène Condat[2]**
[1]CentraleSupélec, Université Paris Saclay, France; [2]Initiative for Interstellar Studies, United Kingdom

Designing new technologies involves creating something that did not exist before. In particular, designing technologies with a low degree of maturity usually involves an assessment of its feasibility or infeasibility. Assessing the feasibility of a technology is of vital importance in many domains such as technology management and policy. Despite its importance, few publications actually deal with the fundamentals of technological feasibility such as feasibility proofs or proposing different feasibility categories. This paper addresses this gap by reviewing the existing literature on the feasibility of low-maturity technologies, proposes a framework for assessing feasibility issues, and reconstructs past and ongoing feasibility debates of four exemplary technologies. For the four technologies analysed, we conclude that sufficient expected performance is a key feasibility criteria to all cases, whereas physical effects and working principles were issues for more speculative technologies. For future work, we propose the further development of feasibility categories for different technologies of different degrees of maturity.

## Identifying product development crises: The potential of adaptive heuristics

**Christopher Muenzberg[1], Verena Stingl[2], Joana Geraldi[2], Josef Oehmen[2]**
[1]Technical University of Munich, Germany; [2]Technical University of Denmark, Denmark

This paper introduces adaptive heuristics as a tool to identify crises in design projects and highlights potential applications of these heuristics as decision support tool for crisis identification. Crises may emerge slowly or suddenly, and often have ambiguous signals. Thus the identification of a project crisis is often difficult. Yet, to allow fast crisis response, timely identification is critical for successful crisis management. Adaptive heuristics are successful judgement strategies when limited and ambiguous information is available. This article presents a theoretical proposition for the application of heuristics in design sciences. The paper compares crises to 'business as usual', and presents sixteen indicators for emerging crises in product development. These indicators are suggested as cues for adaptive heuristics. Specifically three heuristics are found to be well suited to support design practitioners to make robust inferences about the situation: 1. One-single-cue, 2. Fast-and-Frugal-Trees, and 3. Tallying. The paper presents application scenarios for these three heuristics and provides an outlook on further research on adaptive heuristics in design sciences.

## Neural network-based survey analysis of risk management practices in new product development

**Andreas Kampianakis, Josef Oehmen**
Technical University of Denmark, Denmark

The current study investigates the applicability of Artificial Neural Networks (ANNs) to analyse survey data on the effectiveness of risk management practices in product development (PD) projects, and its ability to forecast project outcomes. Moreover, this study presents the relations between risk management factors affecting the success of a PD project, such as cost. ANNs were chosen due to the fact that hidden inherent relations can be revealed through this type of quantitative analysis. Flexibility in terms of analysis and adaptability on the given dataset are the great advantages of Artificial Neural Networks. Dataset used is a filtered survey of 291 product development programs. Answers of this survey are used as training input and target output, in pattern recognition two-layer feed forward networks, using various transfer functions. Using this method, relations among 6 project practices and 13 outcome metrics were revealed. Results of this analysis are compared with existent results made through statistical analysis in prior work of one of the authors. Future investigation is needed in order to tackle the lack of data and create an easy to use platform for industrial use.

**WEDNESDAY, AUG 23**

D6.4

**3:15 pm – 4:15 pm**
**2306/2309**

CHAIR
*Warren Seering*

# Design of Mechatronic Systems

WEDNESDAY, AUG 23

D6.5

3:15 pm – 4:15 pm

2311

CHAIR

*Beate Bender*

## Assessment of dependencies in mechatronics conceptual design of a quadcopter drone using linguistic fuzzy variables

**Ugo Chouinard, Sofiane Achiche, Cédric Leblond-Ménard, Luc Baron**

École Polytechnique de Montréal, Canada

The multi-disciplinary nature of Mechatronic Systems (MeSy) results in a highly complex design task, and it is believed that using an integrated approach to design would help reduce this complexity. However, integrated design is hard to implement due to the existing interactions between the components of MeSy. Some of these interactions are referred to as dependencies, and can affect the performance of MeSy while increasing the design task complexity. It is thus necessary to deal with them as early as possible. Although there are some methods to model dependencies, no methods exist to deal specifically with negative effect dependencies. Therefore, we propose a method that enables the identification and assess negative dependencies that exist within a mechatronic system. We first define negative dependencies between two components through four dimensions (affecting level, affected level, effect attenuation and functional closeness) and then assess these dimensions using fuzzy linguistic variables. We then demonstrate the effectiveness of the method by using a quadcopter drone as a case study which shows that it is possible to gain knowledge regarding potential design problems early on.

## Design for Control

**Ralf Stetter[1], Avery Simundsson[2]**

[1]University of Applied Sciences Ravensburg-Weingarten, Germany; [2]University of Manitoba, Canada

Currently, a large series of helpful guidelines for the design of products in the more concrete stages of design and product development were generated and published under the notion design for X, such as Design for Manufacture and Assembly (DFMA), Design to Cost (DtC), and Design for Sustainability (DfS). Until now, little attention has been given to design guidelines aiming to supporting designers in creating products that enable and ease control — no special attention has been given to Design for Control (DfC) guidelines. Some researchers have started to investigate DfC, but until now, the more conceptual stages of design were not the focus of their research. Additionally, recent research in the direction of Design for Diagnosis (DfD) has been initiated, which shares some common elements with DfC. In this paper, a first attempt is made to formulate hypotheses for how mechanical and electrical products can be designed in order to enable and to ease effective and efficient control.

## An approach to handle uncertainty during the process of product modelling

**Jan Würtenberger, Julian Lotz, Tillmann Freund, Eckhard Kirchner**
Technische Universität Darmstadt, Germany

Product models are the results of product modelling and are used for decision making during the development process. They are based on assumptions by the designer, which are made under a lack of information, so the designer has to make assumptions under uncertainty. This paper systematizes the process of product modelling to assist understanding of what the designer do during that process. With the help of that, a methodical support is developed which the designer can use to define a viewing frame for the product model. It is based on the function-process relationship and the question, in which way the product behaves if identified influencing factors occur.

## Integrated modeling of behavior and reliability in system development

**Julian Hentze[1], Thorben Kaul[2], Iris Graessler[1], Walter Sextro[2]**
[1]Paderborn University, Heinz Nixdorf Institute, Germany; [2]Paderborn University, Mechatronics and Dynamics, Germany

The integrated modeling of behavior and reliability in system development delivers a model-based approach for reliability investigation by taking into account the dynamic system behavior as well as the system architecture at different phases of the development process. This approach features an automated synthesis of a reliability model out of a behavior model enabling for the closed loop modeling of degradation of the system and its (dynamic) behavior. The approach is integrated into the development process following Systems Engineering. It is based on standard models used in model-based development methodologies i.e. SysML or Matlab/Simulink. In addition to the theoretical description of the necessary steps the procedure is validated by an application example at two stages of the development process.

**WEDNESDAY, AUG 23**

# D6.5

**3:15 pm – 4:15 pm**
**2311**

CHAIR
*Beate Bender*

# Resource-Conserving Methods

WEDNESDAY, AUG 23

D6.6

3:15 pm – 4:15 pm

2314

CHAIR

*Weston Baxter*

## Design for complex product rebirth or how to protect resources

**Christian Mascle**

École Polytechnique de Montréal, Canada

This paper presents research conducted on a new design method for rebirth of complex products. Design for rebirth is a thinking method for protecting resources. Reuse, remanufacturing, upgrading and controlled recycling are effective ways to reduce costs, social impact and the consumption of energy and materials for equipment that has finished its service life. Other benefits include reduced pollution, transport, etc. Several issues are studied: existing end-of-life (EOL), selection methods for environmental fasteners and materials, modularization, design adequation. Subsequently, we describe a proposed method that allows the designer to select EOL, environmental fasteners and materials, and use modularization effectively during preliminary design. This integrated method is based on fuzzy logic data processing. Case studies are presented to demonstrate the method's validity. One way of solving rebirth of complex products is to optimize the product design process to include EOL. EOL options must be properly chosen from the beginning by the product developer with the aim of minimizing environmental impact and respecting laws, while at the same time maximizing economic profit.

## Is this system eco-innovative? A case-based workshop

**Flore Vallet[1,2], Benjamin Tyl[3], Olivier Pialot[4], Dominique Millet[5]**

[1]CentraleSupélec, Université Paris-Saclay, France; [2]IRT SystemX, Université Paris-Saclay, France; [3]APESA, France; [4]Seatech USTV, France; [5]LISMMA Seatech USTV, France

Eco-innovation is a challenging topic for companies that are expected to promote the design of products and services for a sustainable society. Early phases of eco-innovation processes and more specifically eco-ideation (the generation phase of promising ideas) still needs efficient supportive methods. This paper empirically challenges a previous proposition of eight eco-ideation stimulation mechanisms (ESMs) thanks to a case-based activity. An explorative workshop on the examination of 16 supposed eco-innovative cases was conducted with four groups of 30 environmental experts. One objective of this workshop for participants was to define, individually and collectively, a way to label eco-innovation cases. This paper presents (1) the selection and characterization of top and flop cases in groups (2) an inductive characterization of eco-innovation regarding cases (3). This arises new perspectives for eco-innovation practice, for instance the consideration of systemic and mass effects.

## Teaching systemic design for sustainability in engineering by building eco skis

**Tobias Luthe[1,2,3], Thomas Lumpe[1], Jonas Schwarz[1], Martin Schütz[1], Kristina Shea[1]**

[1]ETH Zurich, Switzerland; [2]Grown Outdoor Creativity Lab, Switzerland; [3]University of Applied Sciences HTW Chur, Switzerland

Resource limitations are drivers for engaging in sustainability. Systemic design approaches to address complex sustainability challenges need to be implemented more in education curricula, especially in design and engineering programs. Innovative and adequate didactic concepts should be effective in the long-term learning outcomes, and motivate students to engage in systemic design thinking and practice. The main objective of this paper is to deliver and evaluate an innovative format for teaching systemic design in an engineering program at the ETH Zurich, that is effective both in direct learning outcomes and long-term motivation to embrace and apply its theory and practice. We evaluate the effectiveness of the course with self-reflective material and process matrices, and with a final questionnaire. The combination of lectures and a ski-building workshop led to highly engaged and motivated students who experienced simplifications to complexity and trustable, aesthetic eco-design solutions to incorporate in their skis. The majority wished to study further in systemic design and to apply such practice more in their engineering design work.

## Building a business case for ecodesign implementation: A system dynamics approach

**Vinícius Rodrigues, Daniela Pigosso, Tim McAloone**

Technical University of Denmark, Denmark

Several potential business benefits obtained from ecodesign are consistently reported by academic studies and companies. These benefits comprise increased innovation potential, development of new markets and business models, reduction in risks and costs, improvement of organizational brand, among others. However, there are still significant challenges for adopting ecodesign, specially concerning the capture and measurement of the expected business benefits. To address such gap, this paper proposes an exploratory concept of a simulation-based business case for ecodesign implementation, grounded on a System Dynamics approach. The study builds upon the Ecodesign Maturity Model (EcoM2) and the related capabilities of ecodesign managements practices, offering an integrative outlook into how ecodesign capability building can potentially affect corporate performance outcomes over time. Preliminary results point towards the potential for managers and key organizational decision-makers to use the business case simulator to assessing ecodesign benefits and testing multiple implementation scenarios (e.g. what-if questions).

**WEDNESDAY, AUG 23**

# D6.6

**3:15 pm – 4:15 pm**

**2314**

CHAIR

*Weston Baxter*

# Materials and Design 1

WEDNESDAY, AUG 23

D6.7

3:15 pm – 4:15 pm

2504

CHAIR

*Thomas Vietor*

## Fiber-reinforced composite design within a lightweight and material-oriented development process

**Jerome Kaspar, Michael Vielhaber**

Saarland University, Germany

The need for lighter, stronger and stiffer structures has long been of central importance for the product development of (high-tech) lightweight systems across several industries. Accordingly, apart from the today's extensive gain in constructive and technological engineering skills, particularly new high-strength materials lead to satisfy the present rigorous requirements (e.g. mandatory national CO2 regulations in automotive industry) for lightweight engineering in a much deeper dimension. Nevertheless, advanced composites such as fiber-reinforced plastics (FRP) are often used as "black metal" by simply keeping the geometry of a metal component and replacing the material, even though the predicted performance will rarely match expectations. As a consequence, and to address hitherto untapped potentials in terms of lightweight design, there is an urgent need for a systematic approach of a (intelligent) topology-optimized methodology focused on a detailed, but also integrated constructive and technological procedure to specify and optimize composite structures within nowadays requested multi-material systems. Therefore, a corresponding approach is presented in this contribution.

## Experimental and simulative assessment of crashworthiness of mechanically aged short-fibre reinforced thermoplastics

**Christian Witzgall, Sandro Wartzack**

Friedrich-Alexander-University Erlangen-Nuremberg, Germany

Short-fibre reinforced thermoplastics (SFRT) are increasingly used in 21st century's automotive construction. Besides statically loaded parts, SFRT are also used for safety-relevant components such as door modules and crash absorbers. Temperature, chemically aggressive media as well as mechanical loading lead to aging effects within the plastic, which generally, weakens the material's mechanical properties. Thus, within the present paper, a series of tests is introduced in order to investigate the effect of mechanical ageing on the material's crashworthiness behaviour. Furthermore, a concept for consideration the effects of ageing within numerical simulation is introduced.

## A qualitative study to identify the need and requirements on further development of design guidelines for fibre-reinforced composites

**Viktoriia Butenko, Jürgen Wilwer, Markus Spadinger, Albert Albers**
Karlsruhe Institute of Technology (KIT), Germany

This paper describes the methodological approach and results of a qualitative study used to identify the needs and requirements on the further development of design guidelines for fibre-reinforced polymers. To this purpose the method of the semi-structured interview was chosen. A total of 16 industry representatives from different countries, industries and departments took part in the interview study. The results have shown that the necessary information in design guidelines depends very much on the requirements placed on the product, the field of activity of participants and their experience level as well as the industry sector. Apart from this the requirements for desirable content to be found in design guidelines was much the same in North America as in Germany. Furthermore, the results have shown that the current solutions available these days to support the design engineers during the product development with fibre composite materials are no longer contemporary. There is a need to rethink the classical concept of design guidelines and to adapt these to the requirements of the industry.

**WEDNESDAY, AUG 23**

D6.7

**3:15 pm – 4:15 pm**
**2504**

CHAIR
*Thomas Vietor*

# Information and Knowledge Management – Extracting knowledge

WEDNESDAY, AUG 23

D6.8

3:15 pm – 4:15 pm
2506

CHAIR
*Hansgeorg Binz*

## Design space visualization for efficiency in knowledge discovery leading to an informed decision

**Audrey Abi Akle[1], Bernard Yannou[2], Stéphanie Minel[1]**
[1]ESTIA, France; [2]CentraleSupélec, Université Paris-Saclay, France

Design space exploration refers to the systematic activity of discovery and evaluation of the elements in the design space in order to identify optimal solution by reducing the design space toward an area of performance. Designers sample thousand design points iteratively, explore the design space, gain knowledge about the problem and make design decision. According to the literature, Design Space Exploration results in a decision of quality called informed decision which is supported by information visualization. Indeed, the representation of design points is seen as primordial to gain understanding of the problem and make an informed decision. Thereby, in our work, we try to identify which graph is the most suited to the discovery phase and allows designers to make an informed decision. We designed a web platform with four design problem and carried out an experiment with 42 participants. It results one graph more suited to make a decision of quality and to gain the most understanding: the Scatter Plot Matrix.

## Development of a knowledge-based system for help in decision making: A medical application

**Justine Coton, Guillaume Thomann, François Villeneuve**
Université Grenoble Alpes, France

A part of the work of a physiotherapist consists on analysing its patients' motion capacities. In the case of motion analysis, some difficulties can hinder the evaluation process: attention can be diverted, situations can be delicate to evaluate. The consequence is an inter-individual variability and uncertainty during the evaluation. New motion sensors make it possible to record and analyse the motions with another point of view. Those tools can be used to help in the capture, but the restitution of the recorded information needs to be adapted to the user knowledge with the aim to be interpreted. In this paper, the authors propose to put the user at the center of this tool in an application of the UCD principle by proposing a method to return information based on a Knowledge Based structure. The restitution modules and tools are constructed on different levels of knowledge represented in a knowledge-based expert system. The knowledge has been structured into 4 levels (from the most factual to the most abstract) and were linked to 4 levels of restitution (from the most textual to the most graphical). A case-study using the assessment scale "Motor Function Measure" is presented.

### The difficulties reported by engineers in searching information

**Shuai Zhang, Aylmer Johnson**
University of Cambridge, United Kingdom

Efforts have been made by researchers in the area of knowledge management to understand engineers' information searching behaviors, such as the types of information searched by engineers, and the sources and tools they use to address their information needs. However, few studies pay attention to the difficulties that engineers are experiencing in fulfilling their information needs. This paper presents an exploratory study that investigates the problems of information searching in engineering design development. In this research, eight engineers with different level of experience were interviewed to identify the difficulties they deal with in searching required information. The reported problems that participants are experiencing include: 1) formulating information queries; 2) hesitation in consulting others; 3) the limitations of existing retrieval tools.

### Modularization: Exploring opportunities for knowledge transfer between the mechanical engineering and construction industry

**Markus Kohl[1], Julian Wilberg[1], Iris Tommelein[2], Ergo Pikas[3], Udo Lindemann[1]**
[1]Technical University of Munich, Germany; [2]UC Berkeley, United States of America; [3]Aalto University, Finland

Lean thinking is an example that shows how innovation in the manufacturing industry also leads to improvements in the construction industry. Modular product design is common in mechanical engineering, enabling companies to reduce costs and development time. Various methods and tools exist to design modular products. Modular design is not new to the construction industry, but a conducted literature survey reveals that the number of available methods and tools is limited in comparison with mechanical engineering. Therefore, this paper systematically searches for learning opportunities between both industries in terms of modularization. Firstly, the two sectors are compared on a high-level basis. Following this, the objectives for modularization are compared. Finally, existing methodologies are analyzed. Overall the findings indicate that the construction industry would benefit from process models that help to systematically modularize buildings based on different module drivers. Additional research is required to develop a modelling approach for the various dependencies and flows in buildings. The paper proposes further research steps to push modular design in construction.

**WEDNESDAY, AUG 23**

# D6.8

**3:15 pm – 4:15 pm**
**2506**

CHAIR
*Hansgeorg Binz*

# Computational Design Optimisation

WEDNESDAY, AUG 23

D6.9

3:15 pm – 4:15 pm

2514

CHAIR

*Panos Papalambros*

## The role of multidisciplinary design optimization (MDO) in the development process of complex engineering products

**Athanasios Papageorgiou, Johan Ölvander**

Linköping University, Sweden

The work presented in this paper explores several concepts related to the design of complex engineering products and emphasizes on the effects of considering Multidisciplinary Design Optimization (MDO) in the development process. This paper is by no means a comprehensive literature review, but instead, the aim is to discuss some key points through theory and references to common MDO applications. In this respect, the central topics which are addressed herein are the enhancement of the generic product development process, the road towards a better integration of the organization's functions, the methods to manage complex system architectures, and finally, the shortcomings of the MDO field. As a link to more tangible industrial applications, Unmanned Aerial Vehicles (UAVs) are chosen as an illustrative example due to their technical complexity as well as the demanding requirements of the corresponding market. Overall, the paper shows that despite the current state-of-the-art limitations, MDO can be a valuable tool within the "traditional" design process that has the potential to enable products of better quality while simultaneously reducing the total development time and effort.

## A rapid algorithm for multi-objective Pareto optimization of modular architecture

**Roozbeh Sanaei[1], Kevin Otto[2], Kristin Wood[1], Katja Hölttä-Otto[2]**

[1]Singapore University of Technology and Design, Singapore; [2]Aalto University, Finland

Assigning components and functions to modules early can facilitate faster and higher quality results in the latter stages of development and manufacturing. Methods have been developed to suggest suitable architectures using a variety of metrics that measure the ideality of the modularity. However, different modularity criteria considered are often in conflict with each other and improving one is not achievable without a compromising effect on another. To investigate this, we explore using multiple metrics such as defined in the modular function deployment and consider modularization as a multi-objective optimization problem. We develop here a new multi-objective search algorithm that is able to quickly find non-dominated Pareto-optimal architectures. The algorithm is demonstrated for a cordless vacuum cleaner. We further compare the performance of the algorithm with previous work using the IGTA+ algorithm for multiple-objective clustering. The results show the new algorithm improved the computation time of generating the Pareto-optimal surface by more than two orders of magnitude, reducing the 54 component vacuum cleaner modularization search from 192 hours to 24 minutes.

## An optimization-based approach for supporting early product architecture decisions

**Visakha Raja[1,2], Ola Isaksson[2], Michael Kokkolaras[3,2]**

[1]GKN Aerospace Sweden, Sweden; [2]Chalmers University of Technology, Sweden; [3]McGill University, Canada

An important aspect in designing the product architecture of turbo fan engine structural components is the load path and flow path of the components. We present an approach for deciding the preliminary load carrying configuration or LCC (arrangement of structural elements to carry loads) for a generic, static engine structure during early design phases. The LCC, which is a part of the load path aspect, withstands multiple load cases during engine operation. Each such load case for the LCC can be represented as an interface stiffness optimization problem. Our approach for deciding the preliminary LCC involves individual consideration of a number of problems (load cases), down-selecting a small number of interesting problems, and running a coordinated optimization for the down-selected problems using the non-hierarchical coordination. The optimization yields a compromise solution that can be considered as a starting point for detail design of the integrated product. This approach may allow better design resources allocation, as the obtained solution satisfies a number of load cases on the structure.

## Integrated structure-control design optimization of an unmanned quadrotor helicopter (UGH) for object grasping and manipulation

**Abolfazl Mohebbi[1], Colin Gallacher[2], James Harrison[3], John Willes[2], Sofiane Achiche[1]**

[1]École Polytechnique de Montréal, Canada; [2]McGill University, Canada; [3]Stanford University, United States of America

In this study, the problem of integrated system-level design optimization for a quadrotor equipped with a robotic arm and gripper is addressed and thoroughly discussed. First, the operational objectives and the mission of the system are defined and main components are introduced. Then the system level analysis is described in such a way that for the robotic gripper, manipulator and the quadrotor structure, a mechanical system-level optimization is formulated and in a bigger design integration loop, the overall mechanical-control system optimization is solved which guarantees an optimal system solution after a number of iterations. At the end, more detailed numerical results are discussed and analyzed.

**WEDNESDAY, AUG 23**

# D6.9

**3:15 pm – 4:15 pm**

**2514**

CHAIR

*Panos Papalambros*

## Design Society General Meeting

**4:30 pm – 5:30 pm Great Hall & Foyer**

The Design Society will hold a General Meeting on the afternoon of 23rd August 2017 at The University of British Columbia, Vancouver, Canada during the ICED17 Conference. All members of the Society are invited and encouraged to attend the Meeting, which will have the following provisional Agenda:

1. Welcome and Introduction

2. Minutes of Meeting of July 2015

3. Report of the Board of Management

4. Elections – ratification of the election results

5. Any Other Business

## Gala Dinner

**6:30 – 10:00 pm Museum of Anthropology**

Join us at the stunning Museum of Anthropology, renowned for its displays of world arts and cultures, in particular First Nations works. Explore the over 40,000 artifacts at your leisure, as the Museum and its sculptured grounds are reserved exclusively for you! Name badge is required for admission.

# THURSDAY AT A GLANCE

## THURSDAY, AUG 24

| Location | 9:00 am – 10:30 am | 11:00 am – 12:30 pm | 2:00 pm – 3:00 pm | 3:15 pm – 4:15 pm | 4:30 pm – 5:15 pm | 5:15 pm – 6:00 pm | 6:00 pm – 8:30 pm |
|---|---|---|---|---|---|---|---|
| Great Hall & Foyer | | | | | Keynote Ron Britton | Closing Session | Farewell |
| Performance Theatre | **P3.1:** CAD and PDM Insights for Knowledge Management | **P4.1:** Digitalization in Systems Engineering | **D7.1:** Cost Analysis and Optimization | **D8.1:** Knowledge Centric Modeling | | | |
| Art Gallery | **P3.2:** User and Customer Experience | **P4.2:** Multisensory Product Experience | **D7.2:** Healthcare Systems Design | **D8.2:** Systems Design for Special Needs | | | |
| 2301 | **P3.3:** Design for X/ Design to X | **P4.3:** Sustainability | **D7.3:** Sustainability Assessment | **D8.3:** Circular Economy | | | |
| 2306 / 2309 | **P3.4:** TRIZ-Related Methods | **P4.4:** Explorations in New Design Methods | **D7.4:** Engineering Change Management – General Studies | **D8.4:** Engineering Change Management – Costing | | | |
| 2311 | **P3.5:** Design to Embrace Resource Limitations | **P4.5:** Biomimetic and Bioinspired Design | **D7.5:** Engineering Research Applications | **D8.5:** Computational Methods for Engineering Applications | | | |
| 2314 | **P3.6:** Materials and Design 2 | | **D7.6:** Robust Design 1 | **D8.6:** Robust Design 2 | | | |
| 2504 | **P3.7:** Design Education – Case Studies | **P4.7:** Developing Competencies | **D7.7:** Maker Spaces – Activity Based Learning | **D8.7:** Design Learning | | | |
| 2506 | **P3.8:** Visual Facilitation | **P4.8:** Design Thinking | **D7.8:** Designers' Personal Attributes and Skills | **D8.8:** Effective Design in Industry | | | |

# CAD and PDM Insights for Knowledge Management

THURSDAY, AUG 24

P3.1

9:00 am – 10:30 am
Performance Theatre

CHAIR
*Joshua Summers*

## Functional surfaces as initial product design concept in 3D-CAD-Systems

**Tim Katzwinkel, Georg Jacobs, Manuel Löwer, Alexander Schmid, Walter Schmidt, Justus Siebrecht**
RWTH Aachen, Germany

Finding an initial shape design for innovative product concepts is one of the most challenging and most creative parts in product design processes. To support design engineers during that particular phase, knowledge based design automation tools can be used. This paper proposes an enhancement of existing design methodologies in terms of initial shape design of innovative product concepts.The presented approach consolidates PLM and parametric 3D CAD technologies into one integrated method. A concept of parametric working surfaces as an institutionalized feature embedding product lifecycle knowledge is described and briefly demonstrated with a software example. The approach intends to support the product designer with additional information from different company departments as well as giving the designer a tool to explicitly declare the design intent of its design concept in the very early phase of geometric shape definition.

## A new "knowledge-based engineering" guideline

**Thomas Luft[1], Daniel Roth[2], Hansgeorg Binz[2], Sandro Wartzack[1]**
[1]Friedrich-Alexander-University Erlangen-Nuremberg, Germany; [2]University of Stuttgart, Germany

It is necessary to enable product developers to use specific engineering knowledge in an efficient and fast way during the product development process. However, existing procedures supporting the development of products are not strictly convenient to meet this challenge. This is the reason why already in the 1980 various research approaches in the area of knowledge-based engineering (KBE) have been developed. Nevertheless, there is still no uniform and universally applicable description for the industrial environment, with which a KBE application can be implemented and operated. Therefore, the aim is empowering designers to use design-related knowledge in CAD-systems as a central engineering workbench. The main research question in this paper is: How to formulate a universally applicable procedure to conduct KBE-projects with all relevant roles as well as necessary instructions and recommendations regarding specific KBE-methods and -tools? By answering this question, this contribution offers insights in general adapted definitions and perspectives, a procedure for the implementation of KBE-projects, a classification of knowledge-based engineering and a first exemplary solution.

## Automatic design structure matrices: A comparison of two formula student projects

**James Gopsill[1], Chris Snider[1], Lia Emanuel[2], Sian Joel-Edgar[2], Ben Hicks[1]**
[1]University of Bristol, United Kingdom; [2]University of Bath, United Kingdom

Design Structure Matrices have become a fundamental tool to support engineers in their handling and management of interactions across product & organisational architectures. Recent work in the field has exploited the opportunity afforded by Product Lifecycle Management systems, which capture the digital footprint of engineering projects to generate Design Structure Matrices in real-time through the co-occurrence of edits to product models. Given the systematic and more objective nature of the generation of these DSMs as well as being able to monitor their evolution throughout engineering projects, there now lies an opportunity in comparing projects/products using DSMs. To investigate this and the potential insights that could be generated, this paper presents the automatic generation of DSMs for two Formula Student projects. These have then been compared with respect to the end-of-project, change propagation characteristics and evolution of the DSMs. From this analysis, six insights have been generated that map the characteristics of the DSMs to the performance of the project/product and highlights the potential of automatic DSMs to further support engineering project management.

## Knowledge based support for the designer at the interface of CAD/CAE

**Rene Andrae, Peter Köhler**
University of Duisburg-Essen, Germany

The extensive possibilities of modern CAD-software turn the classic approach into a more dynamic one. This opens up the possibility to take into consideration influences from the production and computation at an early stage of the design process. The content of this paper is a three-stage approach for the developing of support systems for a knowledge-based safeguarding in the design process. This method has been developed as part of researches of supporting methods for simulations during the design phase. Accordingly, the focus is still on the interface of CAD-CAE. The method is divided into three parts: the knowledge acquisition, the system design and the knowledge implementation into the CAD System. The approach will be applied in a case study, which focuses on an integrated simulation strategy for injection moulded parts.

**THURSDAY, AUG 24**

# P3.1

**9:00 am – 10:30 am**
**Performance Theatre**

CHAIR
*Joshua Summers*

# CAD and PDM Insights for Knowledge Management, cont'd

**THURSDAY, AUG 24**

P3.1

**9:00 am – 10:30 am**
**Performance Theatre**

CHAIR
*Joshua Summers*

## Structuring information in technical inheritance with PDM systems

**Wieben Scheidel, Iryna Mozgova, Roland Lachmayer**
Leibniz Universität Hannover, Germany

Nowadays a product development process is often based on experience and collected product lifecycle information. The communication between machines and equipment and a consistency throughout the whole product lifecycle are enabled by Industry 4.0. In the Collaborative Research Center (CRC) 653 several aspect for communicative and intelligent products are developed. The CRC aims to develop smart products, so-called gentelligent products, which collect and store their lifecycle information inherently and give feedback to the development and production. In this publication it is shown how the development process is supported by the experience and information of gentelligent components supplied by Technical Inheritance. To provide relevant life cycle information for the development process the need of a product data management (PDM) system is shown. At the example of the Formular Student racing car RP09 the necessity of PDM for Technical Inheritance is shown to support the next generation development and its advantages discussed.

# User and Customer Experience

THURSDAY, AUG 24

P3.2

9:00 am – 10:30 am
Art Gallery

CHAIR
*Filippo Salustri*

### Prototyping shape-changing interfaces – An evaluation of living hinges' abilities to resemble organic, shape-changing interfaces

**Matilde Bisballe Jensen, Jørgen Blindheim, Martin Steinert**
Norwegian University of Science and Technology, Norway

This paper presents an evaluation of nine laser cut living hinges in terms of their ability to resemble earlier defined properties of mechanical shape-changing interfaces. Such interfaces are expected to become more prominent in future human-machine-interactions. However, there is a lack of empirical research regarding how users respond to such interactions since the actual interface can be difficult to build. The project therefore aims to prototype the user experience of a shape-changing interface through more simple methods yet with convincing, robust and organic appearance. Based on previous research we define nine criteria to evaluate the patterns ability to imitate a shape-changing interface. Grounded on those criteria we select the pattern with flexibilities resembling organic behaviour the most. This pattern is used to build the Breathing Box, utilizing a computer-controlled actuator that is able to alter the shape of the surface. Hence, we illustrate how designers can move from low-fidelity prototypes to functional prototypes allowing repeatable experiments. Such controllable experiments in turn allow a quantitative evaluation of user experience of shape-changing interfaces.

### From customer experience to product design: Reasons to introduce a holistic design approach

**Silvia Ceccacci, Luca Giraldi, Maura Mengoni**
Università Politecnica delle Marche, Italy

In the recent years, the creation of a good Customer Experience has become one of means to help companies in competing in the arena of retail. This have led to a focus shift from product design to the customer services' design and customer marketing with the aim to elicit a unique experience able to improve customer satisfaction, influence customer's decision-making and foster repurchasing. In this context, the present paper investigates the close interplay between Customer Experience and User Experience and describes an experiment to give evidence of the effects of the customer journey on the user experience. It discusses the necessity of considering the whole Customer Experience in product/service design and proposes a new holistic approach centred on CX to support the design of all elements characterising the company's offering.

# User and Customer Experience, cont'd

THURSDAY, AUG 24

P3.2

9:00 am – 10:30 am
Art Gallery

CHAIR
*Filippo Salustri*

### User-driven segmentation of design data

**Alex Maynard, Alexander Burnap, Panos Papalambros**
University of Michigan, United States of America

Design data is used to inform decisions during the design process, and must often be segmented for tasks such as customer segmentation, design benchmarking, and market preference segmentation. Qualitative data segmentation methods are accurate but not scalable due to being human-intensive, while quantitative segmentation models are scalable but often inaccurate due to mathematical assumptions. We propose Pangaea as an approach of combining human intelligence and computational algorithms, using an interactive 2D interface for user-driven segmentation on the frontend with both n-dimensional clustering and 2-dimensional reduction algorithms on the backend. We conduct an experiment segmenting automobile exterior color preferences. Our results show that users are able to find consistent data segmentations both between algorithms and between users, suggesting Pangaea may be a promising approach for combining human intelligence with computational algorithms for design data segmentation.

### User experience journeys

**Simon Kremer, Thilo Krahl, Udo Lindemann**
Technical University of Munich, Germany

The emergence of positive User Experience (UX) is gaining in importance for convincing and satisfying customers with technical products. But User Experience Design brings along new characteristics that have to be considered — making the assessment of products more difficult. Hence, designers have to anticipate complex user product interactions and subjective user judgements. In industrial practice of product development the overwhelming complexity of influencing UX factors often leads to focus on single traditional aspects like usability — disregarding the holistic picture, especially temporal aspects, and making it difficult to analyze and consistently develop an intended UX. Therefore, we developed User Experience Journeys — aiming at comprehensive analysis and communication of UX in product development processes. This paper defines the matrix structure of UX Journeys — dissecting the interaction into relevant development information. Furthermore, we present an analysis process that accompanies the journey — identifying and analyzing the emotional experience curve. This methodology is based on theoretical findings about psychology and UX and applicable for industrial practice.

## Design for relaxation: A model for understanding stress for designers

**Michèle Stoop, Dirk Snelders**
Delft University of Technology, The Netherlands

Stress is negatively affecting a large part of society. Knowledge on treating stress is available in the literature even though the phenomenon has yet to be fully explained. Designers could transform these insights into useful products and services that could support people affected by stress. Based on a study of the literature, a model is created called Design for Relaxation. The model is validated using an analysis of the work of design students addressing work related stress. The conclusion is that the model can be used by designers to develop future products and services to counter excessive levels of (work related) stress.

**THURSDAY, AUG 24**

P3.2

**9:00 am – 10:30 am**
**Art Gallery**

CHAIR
*Filippo Salustri*

# Design for X/To X

THURSDAY, AUG 24

P3.3

9:00 am – 10:30 am

2301

CHAIR

*Michael Kokkolaras*

## From privacy by design to design for privacy

**Guilda Rostama[1], Alexandre Bekhradi[2], Bernard Yannou[2]**

[1]Independent author, France; [2]CentraleSupélec, Université Paris-Saclay, France

Privacy by design is a method that places in the early stages of the design and decision-making process the user's privacy and the protection of his/her personal data as a basic principle. In 2018, Privacy by Design will become a mandatory provision for any entity across the world which collects and processes European residents' personal data. In other words, more than a method, Privacy by Design is soon to become a legal requirement, the infringement of which may be subject to fines up to 2% of a company's total worldwide annual turnover. However, we argue in this article that Privacy by design is not another legal requirement that solution designers and providers need to comply with, but that the lack of respect for users' privacy is increasingly becoming a pain for users, with the aid of the pain-driven Radical Innovation Design (RID) methodology. Thus, we will show that Privacy by design may increase the value creation of a solution and that integrating privacy as a default setting in the design of a solution is becoming an essential factor for success on the market. This paper is a proposal and first attempt to evolve from Privacy by Design to a Design for Privacy.

## Design for privacy in public space

**Kwangmin Cho, Chajoong Kim**

UNIST Ulsan National Institute of Science and Technology, Republic of Korea

The role of public space in contemporary society is important to a person's well-being as it provides useful function. However, privacy issues is problem when user use the public space. This study aims at investigating the relationship between elements of privacy and the types of public space in order to better user experience in public space. A total 40 participants (21 males and 19 females, aged from 22 to 25) were invited to participate. This study used user picture interview and value mapping to investigate relationship between privacy and public space. There were differences of privacy important in public space and each privacy elements had different meaning according to public space type. Designers could utilize this framework to develop public space in terms of privacy. The privacy elements are interpreted by user's voice to elaborate specific meaning to protect privacy in public space.

## New ways of hygienic design – A methodical approach

**Jean-Paul Beetz, Hermann Kloberdanz, Eckhard Kirchner**
Technische Universität Darmstadt, Germany

Hygienic design is a necessary topic in developing food processing machinery. Designers have access to plenty of guidelines that support embodiment design and detailing of certain equipment. Earlier phases receive little attention in terms of Hygienic Design. Furthermore, developing products that are not covered by any guideline is a laborious challenge. This paper presents an extended approach of Hygienic Design in order to consider earlier product developing phases. Analysing use phase processes and the investigation with regard to their categorization lead to formalised Hygienic Design requirements. Allocating over 70 existing guidelines to fundamental damage processes "adhesion", "accumulation", "intrusion" and "abrasion" offers a new systematic scheme of a guidelines categorisation, which provides an extended understanding of Hygienic Design. In order to illustrate benefits of using Hygienic requirements in early phases, influencing possibilities are illustrated by an example.

## An assembly-oriented product design methodology to develop similar assembly operations in a mixed-product assembly line

**Narges Asadi[1], Mats Jackson[1], Per Augustsson[2], Anders Fundin[1]**
[1]Mälardalen University, Sweden; [2]FlexQube, Sweden

With the growing demands for product variety, Mixed-Product Assembly Lines (MPALs) as an effective means of creating product variety are recently increasing in manufacturing companies. However, handling different products from distinct product families creates high complexity in performing assembly operations in an MPAL. The elevated complexity, calls for increased similarity between assembly operations in an MPAL which requires product design changes accordingly. Hence, the objective of this paper is to suggest an assembly-oriented product design methodology to increase similar assembly operations for various products cross-product families. The proposed methodology uses Interface Diagram, a product architecture modelling tool, for comparing assembly operations cross-product families, suggesting an assembly-oriented design, and communicating it to designers. The methodology has been developed by conducting a case study in heavy vehicle manufacturing industry. The results highlight a visual approach towards establishing a common language between assembly and design teams to consider the requirements of an MAPL in product design.

**THURSDAY, AUG 24**

# P3.3

**9:00 am – 10:30 am**
**2301**

CHAIR
*Michael Kokkolaras*

# Design for X/To X, cont'd

**THURSDAY, AUG 24**

P3.3

**9:00 am – 10:30 am**

**2301**

CHAIR

*Michael Kokkolaras*

### Towards real-time feedback on manufacturability for engineering designers directly from manufacturers

**Paul Weißenbach, Detlef Gerhard**

TU Wien, Austria

An approach to provide automatically generated feedback on manufacturability for engineering designers without breaking their flow of thought is presented. The origin of the feedback should be knowledge bases maintained by manufacturers. Therefore, the feedback provider is from the perspective of the engineering designer behind a network. This "remote design checks" introduces additional aspects regarding latency and intellectual property protection, which are incorporated into a proposed distributed software architecture. Feedback is provided directly in engineers authoring tools (CAD software). A proof of concept implementation was created. Architecture and proof of concept are evaluated and discussed on the basis of a use case based on aluminium extrusion.

# TRIZ-Related Methods

THURSDAY, AUG 24

P3.4

9:00 am – 10:30 am
2306/2309

CHAIR
*Gaetano Cascini*

## An approach to analyse the potential of tailored forming by TRIZ Reverse

**Tim Brockmöller, Iryna Mozgova, Roland Lachmayer**
Leibniz Universität Hannover, Germany

Within the "Collaborative Research Centre" 1153 a new technology called Tailored Forming (TF) is developed. With TF load adapted hybrid high performance components which consist of two different materials can be manufactured. The subproject "Configuration and design" aims to design optimized TF components to derive design guidelines. Therefore a computer aided optimization environment is developed. To reduce the optimization time a method to determine the feasibility to develop and manufacture components by means of the TF technology is required. To determine the potential of the TF Technology the new method TRIZ Reverse, which is based upon the "Theory of Inventive Problem Solving" (TRIZ) has been created. TRIZ Reverse uses the traditional process of contradiction solving in reverse. At first it has to be analysed for which of the 40 Inventive Principles TF provides a solution. Subsequently, the contradiction matrix is reduced according to the identified principles for TF and important parameters for the optimization can be determined. This paper describes the scheme of an optimization process for the development of TF components and demonstrates the TRIZ Reverse method.

## From simulation to inventive problem resolution, a global method

**Sebastien Dubois[1], Roland De Guio[1], Ivana Rasovska[2], Fatima Zahra Ben Moussa[3], Rachid Benmoussa[3]**
[1]INSA Strasbourg, France; [2]University of Strasbourg, France; [3]ENSA of Marrakech, Morocco

In order to formalize and automatize the use of TRIZ based patterns, and in particular, the use of contradictions, a Generalized System of Contradictions (GSC) has been proposed. The model has been defined to always satisfy the existence of a GSC for unsolvable problems. It has also been stated that for a given problem, many systems of contradictions can be formulated. And so the question of the choice of the GSC to consider for resolution has to be tackled. In this article, a method will be proposed to illustrate that classical TRIZ contradictions do not exist systematically, but that in this case, Generalized Contradictions could be formulated. The hypotheses to hierarchize the contradictions will be proposed. The problems related to the use of the GSC will be detailed and a method to go from simulation until inventive problem resolution will be proposed. Finally, the existence of particular contradictions, contextual contradictions, will be illustrated, as they enable the application of TRIZ resolution principles.

# TRIZ-Related Methods, cont'd

THURSDAY, AUG 24

P3.4

9:00 am – 10:30 am

2306/2309

CHAIR

*Gaetano Cascini*

## Designing new concepts for household appliance with the help of TRIZ

**Christoph Baur, Christopher Muenzberg, Udo Lindemann**

Technical University of Munich, Germany

This paper presents a case study of the application of TRIZ in an industrial development project. The study focusses on the TRIZ method "Trends of Engineering System Evolution" to develop innovative ideas for future household appliance. The paper starts with an introduction of TRIZ and the fundamentals of Trends of Engineering System Evolution. Building up on this theory the application of the method follows a five-step approach. First, four Main Parameters of Value are identified: Noise, Drying Result, Water Consumption, and Speed. In the second and third step, these parameters are evaluated and allocated on the Technology-S-Curve. Finally, in the fourth and fifth step TRIZ trends and sub-trends are used to develop ideas for household appliance based on their position on the S-Curve. Overall 44 ideas were developed. The result part presents three conceptual ideas. The paper closes with a conclusion of the project work and results. Main findings are: TRIZ trends are applicable in industrial project work, internal knowledge is needed for detailed application, and time-consuming application.

## Knowledge management and eco-innovation: Issues and organizational challenges to small and medium enterprises

**Ahmed Cherifi[1], Mickaël Gardoni[1], Patrick M'Bassègue[2], Jean Renaud[3], Rémy Houssin[3]**

[1]L'École de Technologie Supérieure de Montréal, Canada; [2]École Polytechnique de Montréal, Canada; [3]INSA Strasbourg, France

At the design stage of a product or process, the environmental dimension is becoming a major issue, but designers are poorly equipped to handle it. The design or re-design expected in the product cycle is done with resources that are combined, which are associated, leading to the generation of new knowledge. To help SMEs in the development of their product, we propose a methodological approach that will allow to respect eco-innovative goal. As a starting point, a qualitative multi-criteria matrix will allow prioritization of all impacts for environment. A customized application of the inventive TRIZ principles (Russian acronym for theory of solving inventive problems Teorija Reshenija Izobretateliskih Zadatch) will help to choose eco-innovative solutions. To this aim, we have created a new approach: Eca TRIZ, based on new contradiction matrix. It was tested in various situations presented during the "24 Hours of innovation" competition. Some of them are presented in this research paper.

## Advanced innovation design approach for process engineering

**Didier Casner, Pavel Livotov**
Offenburg University of Applied Sciences, Germany

Process engineering focuses on the design, operation, control and optimization of chemical, physical and biological processes and has applications in many industries. Process Intensification is the key development approach in the modern process engineering. The proposed Advanced Innovation Design Approach (AIDA) combines the holistic innovation process with the systematic analytical and problem solving tools of the theory of inventive problem solving TRIZ. The present paper conceptualizes the AIDA application in the field of process engineering and especially in combination with the Process Intensification. It defines the AIDA innovation algorithm for process engineering and describes process mapping, problem ranking, and concept design techniques. The approach has been validated in several industrial case studies. The presented research work is a part of the European project "Intensified by Design® platform for the intensification of processes involving solids handling".

# Design to Embrace Resource Limitations

THURSDAY, AUG 24

P3.5

9:00 am – 10:30 am

2311

CHAIR

*Bernard Yannou*

## Challenges and preconditions to build capabilities for sustainable product design

**Jesko Schulte, Sophie Hallstedt**

Blekinge Institute of Technology, Sweden

Sustainable product innovation has previously been found to be positively correlated to competitiveness. However, in order to build capabilities for sustainability integration one must first understand companies' current state. The overall aim is therefore to identify common preconditions and challenges for sustainability integration in product innovation. A questionnaire study, targeting employees with roles in product development, was conducted at four medium-sized to large product development and manufacturing companies in Sweden. Results show that capabilities for sustainability integration are perceived as decisive for future company success, but are not considered to be correspondingly high prioritized today. Decision making is focused on material selection and energy efficiency, so no full socio-ecological sustainability perspective is covered. Formal decision support tools are only used by half of respondents and are a main area for improvement. Identified challenges include short-term economic thinking, lack of sustainability criteria and vague management commitment. Based on these findings, seven recommendations for companies are presented and validated.

## Overdesign in building services: the hidden energy use

**Darren Jones, Claudia Eckert**

The Open University, United Kingdom

This paper categorises and describes the various types of margins that are applied during building services design, and highlights the various stakeholders involved, from the early specification of requirements, through to the engineering design specification and installation. Using a case study of a hospital boiler upgrade, the paper differentiates between margins built into the to regulatory, clinical, and contractual requirements, and the margins applied through the engineering design choices that allow for various contingencies and uncertainties. To meet energy targets, hospitals invest in products that use less energy. Whilst such interventions, such as lighting upgrades and control improvements provide some efficiencies, over-design of core systems often negate the savings. The over-specification and over-design of building service systems often results from the cumulative addition of various design margins. It is quite possible that sometimes margins are added as a matter of habit with no real thought as to whether they are really applicable to a particular situation, calling into question the issue of design procedures.

## Mindfulness and resource-sensitive design: A literature overview and an agenda for research

**Wing Mui Helen Chan, Cees de Bont**
The Hong Kong Polytechnic University, Hong Kong S.A.R. (China)

Mindfulness has aroused great interests in the past few decades and researches on mindfulness conducted have suggested that it is related to increase in awareness, creativity, quality decision-making, and sustainable behaviour in addition to many other benefits associated with it. As design is largely about decision-making and creativity and resource-sensitive design is related sustainability, there seems to be some correlation between mindfulness and resource-sensitive design. This paper presents a theoretical study on how mindfulness can be instrumental in resource-sensitive design and provides a research agenda on this topic.

## A process for designing lean- and sustainable production

**Yasmeen Jaghbeer, Yvonne Motyka, Sophie Hallstedt**
Blekinge Institute of Technology, Sweden

Today's trends such as globalization, increased customer demands, and increased sustainability challenges have caused a paradigm shift, where the importance of designing lean- and sustainable modern manufacturing systems is realized by many companies. This study proposes a process of action steps using Value Stream Mapping method integrated with sustainability life cycle analysis and sustainability compliance index to assist in designing lean- and sustainable production systems. The developed process was validated through a case study to test the adopted tools and how they can capture and improve the lean- and sustainability levels. The current sustainability and lean levels were explored first, followed by analyzing and developing the future improved state. A roadmap of about 40 actions was suggested to the case company distributed on a one year time plan. The key contribution of this study is an applicable and generic process of action steps including several adopted tools from the lean-and sustainable product development fields to help manufacturing companies in creating roadmaps for more lean- and sustainable production systems.

**THURSDAY, AUG 24**

# P3.5

**9:00 am – 10:30 am**

**2311**

CHAIR

*Bernard Yannou*

# Design to Embrace Resource Limitations, cont'd

**THURSDAY, AUG 24**

P3.5

**9:00 am – 10:30 am**

**2311**

CHAIR

*Bernard Yannou*

### What green design activities and mindsets drive innovation and sustainability in student teams?

**Jeremy Faludi, Alice Agogino, Sara Beckman, Alastair Iles**

UC Berkeley, United States of America

What sustainable design practices can also drive innovation, and what practices do people value? Previous analysis of sustainable design methods, and the opportunism of designers generally, has suggested that design methods should actually be examined at the level of their component activities and mindsets, as each of these provides different advantages that designers could mix and match. This study performed workshops of three sustainable design methods for a total of 327 students, then surveyed students about which activities or mindsets within each design method drove innovation value, sustainability value, and any other value. The design methods tested were The Natural Step, Whole System Mapping, and Biomimicry. Qualitative and quantitative analyses of surveys found that some activities and mindsets were valued more than others for sustainability, innovation, or both, and to some extent revealed why. Some results were surprising and suggest new research directions.

# Materials and Design 2

## Material selection – A qualitative case study of five design consultancies

**Charlotte Asbjorn Sorensen[1,2], Anders Warell[2], Santosh Jagtap[3]**
[1]Malmö University, Sweden; [2]Lund University, Sweden; [3]Blekinge Institute of Technology, Sweden

This qualitative case study aims at understanding when and how industrial designers, working in design consultancies, engage in activities that will influence material selection in the design process. While the extant literature presents material selection processes as a sequence of activities aimed at finding candidate materials, there is paucity of research on material criteria activities. Formulating material criteria is an activity that is performed during all design phases and they become clearer and more complete throughout the project. For the case studies, explorative semi-structured interviews were conducted with five industrial designers with 10 years of work experience or more. The results suggest (a) that risk management has a major influence on the material selection process, (b) that negotiations of project boundaries in the 'fuzzy' pre-design phase has crucial influence on the risk management aspect of the material criteria activities, and (c) a lack of awareness that design briefs usually outline material criteria expressed as sensorial characteristics, which are later translated by engineering into final material criteria used for the material selection process.

## A semi-formal approach to structure and access knowledge for multi-material-design

**Sebastian Kleemann, David Inkermann, Benjamin Bader, Eiko Türck, Thomas Vietor**
Technische Universität Braunschweig, Germany

In recent years multi-material-design has been of broad interest. There has been a great deal of literature on how multi-material-design has support realisation of lighter, cheaper products with lower impact to the environment. However, there has been no general approach to name the essential potentials of multi-material-design as a first guideline to support suitable use of the technologies. On the basis of an extensive literature survey, this paper proposes a method to systematically derive these potentials. Moreover, we found that these potentials, such as "reducing weight", "improving mechanical performance" or "easing manufacture and assembly" can serve to structure the design knowledge required for multi-material-design. Therefore, we propose a model to link the specific potentials to measures and guidelines to support decision-making and knowledge application. This structuring may lead to finding suitable design guidelines for specific development goals more quickly. This could accelerate product development and make the benefits of multi-material-design more transparent, which will promote the dissemination of multi-material-design in industry.

**THURSDAY, AUG 24**

P3.6

**9:00 am – 10:30 am**

**2314**

CHAIR

*Sandro Wartzack*

# Materials and Design 2, cont'd

THURSDAY, AUG 24

P3.6

9:00 am – 10:30 am

2314

CHAIR

*Sandro Wartzack*

### Multi-criteria analysis of multi-material lightweight components on a conceptual level of detail

**Tim Fröhlich, Sebastian Kleemann, Eiko Türck, Thomas Vietor**
Technische Universität Braunschweig, Germany

Multi-material design offers higher degrees of freedom in designing a component due to different design options and material combinations. However, both cause a more complex component design. In addition many development goals — such as weight, costs and environmental impact — and outer conditions — such as restricted installation spaces — have already to be considered in the early stage of development. Otherwise the most suitable design option might not be considered and concepts are no longer pursued after design in detail since they did not fit the requirements from the beginning. As a result, the designer needs assistance in analysing different design options to find those that are able to fulfil the development goals best possible within an appropriate effort. A suitable approach to solve this issue is to represent the considered component by an abstract definition and calculate the component's properties analytically inside an automated tool. Thus the general behaviour of a design option and specific variations can be evaluated by the designer. Consequently components can be designed more purposeful considering a big solution space and a variety of development goals.

### Reverse natures: Design synthesis of Texture-Based Metamaterials (TBMs)

**Sayjel Vijay Patel[1], Paul John Mignone[1], Mark Kam-Ming Tam[1,2], David Rosen[1]**
[1]Singapore University of Technology and Design, Singapore; [2]Massachusetts Institute of Technology, United States of America

We describe a new approach for generating micro-structures for 3-D printing called 'Texture-based Metamaterials'. Current micro-structure synthesis methods jump to install a performance goal from the outset. This is not useful in conceptual design when design goal are not yet well-defined. In order to fully realize 3-D printing design spaces, requires new exploratory methods. Using 3-D scans of natural textures as components, we can expand the catalog of 3-D printed microstructures. To do this, we introduce a new modelling procedure to generate new unit-cell geometries. Unit-cells can be repeated or combined with other structures to provide performance behavior at the macro-scale. To apply these structures in a design, we then simulate and characterize their mechanical behavior. Finally, we present a case study example to show the process and tool-chain.

# Design Education – Case Studies

## Engineering design education in time-sensitive environments

**Majed Jarrar, Hanan Anis**
University of Ottawa, Canada

The engineering design education has been undergoing reform for more than half a century. It was marginalized in the second half of the twentieth century mostly due to the proliferation of sciences and mathematics in engineering programs. Then, engineering design was restored through capstone projects as well as freshmen-level design required courses, after the outcome-based accreditation emerged. Due to the limited time of these design courses, students often end up rushing towards demonstrating a working prototype before the end of the course, and because of that, end up missing several important elements in process of prototyping. There is a new trend to build a 'design spine' throughout the engineering program as means of reform. We'd like to explore the impact of entrepreneurship on engineering design education because of its efficiency in solving time-sensitive problems through means such as rapid prototyping, lean startup, and customer discovery iteration. We used the course Technology Entrepreneurship at the University of Ottawa to test the design skills of the students who took it. We demonstrate positive results and discuss the possible contributing factors.

## A descriptive study of the effect of K-12 design education on changes in self-esteem

**Kaylin Broussard, Lauren Murphy, Katherine Kai-Se Fu**
Georgia Institute of Technology, United States of America

This research explores the hypothesis that introducing K-12 students to design education has the potential to introduce students to skills that are integral and vital to being a strong designer, with particular attention to self-esteem. A new K-12 design curriculum has been developed to explore this hypothesis. This paper presents an assessment of the impact of the design education curriculum on K-12 students' self-esteem, both presented and self-reported. Self-reported and presented student self-esteem measurements indicate no correlation with one another. Over the course of the curriculum, self-reported self-esteem increased slightly overall. Indicators for high presented self-esteem showed overall increases in individuals. The presented low self-esteem measurements stayed nearly constant over the course of the study. These preliminary results suggest formalized methods for assessing student outcomes in the context of design education research. Providing evidence that shows a correlation between design education and self-esteem builds a case for design education as a valid teaching tool, and opens the discussion for design as mechanism to address new educational demands.

**THURSDAY, AUG 24**

P3.7

**9:00 am – 10:30 am**
**2504**

CHAIR
*André Liem*

# Design Education – Case Studies, cont'd

THURSDAY, AUG 24

P3.7

9:00 am – 10:30 am

2504

CHAIR

*André Liem*

## Navigating the common approaches to product development

**Julia K. Vance, Jack Giambalvo, Steven Hoffenson**

Stevens Institute of Technology, United States of America

Many design approaches are used and taught in industry and academia, and it is difficult even for seasoned design professionals to know which to use. These design approaches were developed in different disciplines with a unique purpose or application in mind. To help practitioners, educators, and students navigate these approaches, a new way to communicate the similarities and differences and the strengths and weaknesses of common design environments, processes, and methods is needed. This study presents a review of some common approaches used in product development: design thinking, systems thinking, total quality management, agile design, waterfall process, engineering design process, spiral model, Vee model, axiomatic design, value driven design, lean manufacturing, six sigma, theory of constraints, and decision based design. This review revealed a set of key criteria for differentiating these approaches from one another, and a visual representation is proposed to identify the key characteristics of each approach and how they compare and overlap with one another. This analysis and representation can be used to help designers and students choose the best approach for a project.

## Shifting paradigm: Towards a comprehensive understanding of quality

**Björn Falk[1], Konstantinos Stylidis[2], Casper Wickman[2], Rikard Söderberg[2], Robert Schmitt[1]**

[1]RWTH Aachen, Germany; [2]Chalmers University of Technology, Sweden

The development of competitive products is not a question of unique and expensive features but of best quality for money. Yet, defining quality from a customer's perspective and realizing it throughout the product development process is complex. The elicitation of customers' perception and correlating product attributes is recently subject to studies and research projects in industry and science. The common aim is to identify the product parameters responsible for a costumer's judgement. Still, these efforts are scattered and examining individual cases. A common understanding as well as a framework for distinct research and application is still missing. Besides its history, current research and arising challenges, the paper at hands shall emphasize the need for a change in the understanding of product quality and propose a comprehensive framework to handle quality perception especially on an industrial level. This will help to define the relevant attributes and specifications, form a common platform for parties involved in product development and, hence, guide further research.

## Discursive vs. intuitive – An experimental study to facilitate the use of design catalogues

**Selin Üreten, Dieter Krause**
Hamburg University of Technology, Germany

Though shown to be of support to the designer, design method acceptance is still an issue to the design society today. Requirements and concepts in general derived from fundamental learning principles have been developed to enhance learning. This study is an experimental study to collect impressions about design method acceptance based on predefined criteria for facilitated use of design catalogues. Two workshops in sequence were conducted with students of advanced integrated product development courses to teach and train them in design catalogues. The control group applied twice a discursive solution finding process with design catalogues whereas the test group first worked intuitively with the brainstorming method and just in the second stage with a discursive solution finding process. Results have shown differences in the perception of both groups and revealed an improved method acceptance for groups who worked discursively twice. The groups working intuitively first and then discursively claimed that the design catalogues rather restricted their creativity but were considered useful as an additional tool. Implications for enhancing the learning experience could be deduced.

**THURSDAY, AUG 24**

P3.7

**9:00 am – 10:30 am**
**2504**

CHAIR
*André Liem*

# Visual Facilitation

THURSDAY, AUG 24

P3.8

9:00 am – 10:30 am

2506

CHAIR

*Elies Dekoninck*

## Fostering ideation in the very early design phases: How textual, pictorial and combined stimuli affect creativity

**Yuri Borgianni[1], Federico Rotini[2], Marco Tomassini[2]**

[1]Free University of Bolzano-Bozen, Italy; [2]University of Florence, Italy

Creativity is critical to the success of design outcomes. Several research contributions investigate the effects of different stimuli on the creativity of conceptual solutions. Studies still lacks dedicated to early New Product Development activities focused on the definition of new product ideas in terms of unprecedented benefits and product attributes. The paper deals with the forms through which stimuli are delivered to support ideation for the recalled design activity. The objective of the paper is to assess if and how different stimuli affect designers' ideation performance. An experiment was performed, in which participants were asked to produce new ideas or product attributes for an existing product category, by exploiting textual, pictorial and combined stimuli as source of inspiration. The results show that the inspiration fashions play a limited role on the outcomes of the ideation process, if the latter are assessed through the most acknowledged creativity metrics. However, the experiment reveals that significantly different ideas have emerged in groups using diversified forms of stimuli.

## Can visual facilitation beat verbal facilitation?

**Roché Boedhoe[1], Petra Badke-Schaub[2]**

[1]Build & Beyond, The Netherlands; [2]Delft University of Technology, The Netherlands

This paper analyzes the effect of visual and verbal facilitation in an interdisciplinary design setting. The depending variables were (the process of gaining) cross and shared understanding in the group, the outcome variable was design creativity. Based on literature research and a field study, a visual facilitation protocol materialized as a set of rules has been developed which guides a facilitator. The protocol has been tested by conducting twenty between-group experiments with (non-design) Master students following visual and verbal facilitation. In the visual facilitation condition, the groups were guided by means of sketching and in the verbal condition the groups were guided verbally. The results show significantly higher shared understanding when working with the visual facilitation protocol. However, visual facilitation resulted in lower creativity—in particular, novelty. These findings suggest that visual facilitation might be an effective method for constructing shared understanding during interdisciplinary design collaboration, but at the same time the high level of sharedness between team members negatively relates to design creativity.

## The idea mapping board: A tool for assessing design concepts and visualizing a team's use of the design space

**Kevin Helm[1], Daniel Henderson[1], Kathryn Jablokow[1], Shanna Daly[2], Seda Yilmaz[3], Eli Silk[4], Daniel Sevier[3]**

[1]Pennsylvania State University, United States of America; [2]University of Michigan, United States of America; [3]Iowa State University, United States of America; [4]Rutgers, The State University of New Jersey, United States of America

This paper introduces the Idea Mapping Board, a visualization tool that supports the formation of shared mental models within design teams during concept generation and assessment. The Idea Mapping Board is intended for small teams of two to four practicing engineers or engineering students. It incorporates multiple dimensions for concept assessment based on cognitive level and cognitive style. We also present results from two pilot studies used to evaluate the effectiveness and ease of use of the Idea Mapping Board and its impact on the ideation flexibility of its users. This research is part of a larger project funded by the National Science Foundation (NSF) that investigates the impact of multiple factors, methods, and tools on the ideation flexibility of engineering students and practitioners. The Idea Mapping Board was created as part of our investigation of teaming as an intervention to help users expand their exploration of the design space.

## Show me the pictures: The effect of representational modalities on abductive reasoning in decision making

**Sarah Arntz, Ruben Verbaan, Boris Eisenbart, Carlos Cardoso**

Delft University of Technology, The Netherlands

This paper describes a study designed to investigate the effect of concept representation types on the use of abductive reasoning by decision makers when selecting early stage innovation concepts for further development. According to prior research, abductive reasoning can be instrumental to decision makers in terms of generating testable hypotheses about an innovation concept's future developments into concrete, viable product or service offerings. It has furthermore been linked with an increase in project acceptance rates. Here, an experiment is described testing whether visual concept representations promotes higher levels of abductive reasoning than textual concept representations or a combination of visuals and text. The results show that when purely visual concept representations were used, the participants showed a significant higher level of abductive reasoning than when this visual representation was complemented with text. This has managerial implications pertaining to how innovation concepts could/should be presented to selection committees or individuals in companies seeking to increase the amount of innovation projects that pass through a first screening process.

**THURSDAY, AUG 24**

# P3.8

**9:00 am – 10:30 am**

**2506**

CHAIR

*Elies Dekoninck*

# Visual Facilitation, cont'd

**THURSDAY, AUG 24**

## P3.8

**9:00 am – 10:30 am**
**2506**

CHAIR
*Elies Dekoninck*

### Investigating effects of stimuli on ideation outcomes

**Srinivasan Venkataraman, Binyang Song, Jianxi Luo, Karupppasamy Subburaj, Mohan Rajesh Elara, Lucienne Blessing, Kristin Wood**
Singapore University of Technology and Design, Singapore

This research investigates the effects of using stimuli, such as patents, on ideation outcomes, through the research questions: (a) What is the effect of stimuli on ideation outcomes? and (b) What is the effect of stimuli distance on ideation outcomes? An experiment to address these questions entails an ideation exercise involving 105 participants generating 226 concepts without or with patents and other resources. Significant findings are: (a) more concepts are generated with patents than without patents, (b) more concepts are generated with patents identified by participants on their own than using pre-chosen patents, (c) more concepts are generated using both patents and other resources than other degrees of stimulation, (d) concepts developed using both patents and other resources have higher novelty and quality than concepts generated without any stimuli, and (e) no significant correlations are observed between the proximity of stimuli to problem domains with novelty and quality of concepts. These results have practical implications on using stimuli to improve ideation outcomes for designers, design teams, and organisations, and motivate investigation into the stimuli used.

## Break

**10:30 am – 11:00 am  Atrium Lower Level**

# Digitalisation in Systems Engineering

## Towards a digital twin: How the blockchain can foster E/E-traceability in consideration of model-based systems engineering

**Dominik Heber**[1,2], **Marco Groll**[1,2]
[1]Daimler AG, Germany; [2]University of Twente, The Netherlands

Complexity of electric/electronics (E/E) in automobiles increases tremendously due to more connectivity and real-time data processing. Hence, huge volatility of E/E artifacts is the consequence. In order to keep track of all changes made from early systems engineering to late after sales, a permeable traceability in data management systems has to be achieved. Therefore, this elaboration adapts the blockchain technology to achieve traceability of E/E development artifacts from early model-based systems engineering (MBSE) till after sales. By this, MBSE is linked to product data management and the automobile's configuration is known at each instant of time. The Digital Twin, a digital, domain-specific representation of the physical vehicle in one front end tool, makes the complexity still feasible to handle and is empowered by the blockchain. Hence, traceability of E/E artifacts over an automobile's lifecycle including MBSE is fostered in a manageable manner.

## Design principles of wearables systems: an IoT approach

**Anastasia Stelvaga, Clement Fortin**
Skolkovo Institute of Science and Technology (Skoltech), Russian Federation

Wearable technologies comprise a large variety of electronic devices that are suitable to wear on the human body. These technologies were considered initially as an isolated consumer product but are now more and more designed as a component of a set of systems based on the Internet of Things (IoT) concept, where the design of the user experience based on high connectivity, is so critical. The aim of this paper is to formulate a set of new design principles specifically for highly connected wearables. This research work focuses on the conceptual design phase, specifying a set of activities devoted to new product concepts generation, testing, and selection. An overview of technological challenges in wearables design is first presented. Based on these features and challenges, 9 Design Principles were developed. Practical guidance aimed at providing a fluent human-device interaction are proposed. A methodology, describing the order of application of the Principles is also proposed. An analogy of the given Design Principles with an existing design model for the IoT domain is also presented.

**THURSDAY, AUG 24**

**P4.1**

**11:00 am – 12:30 pm**
**Performance Theatre**

CHAIR
*Dieter Krause*

# Digitalisation in Systems Engineering, cont'd

THURSDAY, AUG 24

P4.1

11:00 am – 12:30 pm
Performance Theatre

CHAIR
*Dieter Krause*

## Integration of MBSE into existing development processes – Expectations and challenges

**Johannes Kößler, Kristin Paetzold**
Universität der Bundeswehr München, Germany

The development of technical products is faced with an increasing amount of data of different domains. The communication between them is becoming more difficult. Additionally the dependencies between this data is getting more and more unclear. MBSE is an approach trying to improve this situation with the use of system models. The use of this models instead of a document-based storage allows a better consistency of the data and supports the visualization and understanding of the complete system. But the application of MBSE and its integration into existing environments is a difficult task. The integration of domain specific data causes a high effort while the benefit is often unclear or arises later on. Based on selected data from the industry the application is often started within a wide field of the company and often focusing on SysML trying to find a method to adapt it to the needs. This paper suggests to clearly define goals that have to be achieved with the use of MBSE. The goals serve as measurable criteria to evaluate the success of MBSE. Additionally they define the content that has to be integrated into the system model of MBSE as well as the addressees and operators.

## mecPro² – A holistic concept for the model-based development of cybertronic systems

**Martin Eigner[1], Thomas Dickopf[1], Marc Schneider[2], Tim Schulte[3]**
[1]Technische Universität Kaiserslautern, Germany; [2]em engineering methods AG, Germany; [3]Schaeffler AG, Germany

While today's products are increasingly developing into high-tech products in the meaning of Industrie 4.0, Internet of Things or Industrial Internet, the processes, methods and concepts for the development of such Cyber-Physical Systems or Cybertronic Systems are adapting very slowly to the new requirements. This paper introduces a holistic concept for the development of such cybertronic systems. The focus here is on the integration of two important partial results of the German research project mecPro², the mecPro² Process Framework and the mecPro² Architectural Framework. While the process framework designates the development process for cybertronic systems, the architectural framework defines how the system information required in the process is created, further processed and represented in a system model including its interrelations. Based on methods of Model-based Systems Engineering this concept especially helps to improve solution finding process as well as the consistency and collaboration in the early development phases.

## Mechatronic modularization of intelligent technical systems

**Andre Lipsmeier, Thorsten Westermann, Harald Anacker, Roman Dumitrescu**
Fraunhofer Institute for Mechatronic Systems Design IEM, Germany

A successful transformation of mechanical engineering products toward Intelligent Technical Systems (ITS) requires an interdisciplinary and modular system architecture as well as an interdisciplinary understanding of the system for all stakeholders. Different approaches for the development of modular product structures as well as for generating interdisciplinary understanding of the system for all stakeholders exist. There is, however, a lack of a method which is consistent with the approach of Model-Based Systems Engineering (MBSE) and takes the aspects of all the disciplines involved in the ITS context into account.This contribution shows an approach for improving the development processes of Intelligent Technical Systems with modularization combined with MBSE. The approach is divided into five phases: Target Definition (Phase 1), System Modelling (Phase 2), System Analysis (Phase 3), Identification of mechatronic Modules (Phase 4) and Restructuring of mechatronic Modules (Phase 5). In addition, the results are validated by an industrial separator. The results clarify the benefits of modularization combined with MBSE to improve the development processes of ITS.

**THURSDAY, AUG 24**

P4.1

**11:00 am – 12:30 pm**
**Performance Theatre**

CHAIR
*Dieter Krause*

# Multisensory Product Experience

THURSDAY, AUG 24

P4.2

11:00 am – 12:30 pm
Art Gallery

CHAIR
*Monica Bordegoni*

## Multisensory product development

**Antonia Fels, Björn Falk, Robert Schmitt**
RWTH Aachen, Germany

The sensory design of products plays an important role in the customer's overall assessment of quality. While sensory design comprises of visual, acoustic and haptic aspects, the combination of these aspects and hence the multisensory product design becomes increasingly important. However, for a successful realization of a multisensory design, the human cognition and multisensory perception has to be considered. In this paper, the phenomenon of multisensory enhancement as well as dissonance owing to sensory mismatch was examined by means of an empirical study with 98 test persons. The use case of aged products was investigated. It was hypothesized that (1) products are perceived older if aged equally regarding all primary senses and (2) the perception of harmony suffers from sensorially dissimilar aged products. Using a Maximum-Likelihood-Estimation as a reference value for the multisensory product age, the first hypothesis could be confirmed through a statistical analysis. However, the second hypothesis had to be rejected for this empirical setup, i.e. sensorially mismatching products were not perceived less harmoniously.

## Kansei modeling methodology for multisensory UX design

**Hideyoshi Yanagisawa[1], Chihiro Miyazaki[1], Carole Bouchard[2]**
[1]The University of Tokyo, Japan; [2]Arts et Métiers ParisTech, France

Through a time-series of user experience(UX), multiple senses, such as vision, hearing, and touch, interact with a product. Cross-modal studies have shown that multiple senses interact each other and change their perceptions. In this paper, we propose a Kansei modeling methodology by considering multisensory interactions of UX. In this methodology, we structure the user's Kansei as a cognitive process involving four layers: physical quantity, perceived features, delight factor, and delightful experience. We extract the layered structure for each scene of the user experience. Each scene consists of the user's senses and action. With our modeling methodology, we extract cognitive components involving multimodal integration from comprehensive cognitive structures of the UX. Based on expectation theory as a principle of contextual cross-modal interactions, we identify the tolerance of a perceived feature that satisfies multiple delight factors, involving attractive and must-be qualities in the Kano model. We demonstrate the validity of the methodology with an experiment using of a hair dryer multisensory design.

### Design of a smart alarm clock to foster sustainable urban mobility

**Dario Monici, Serena Graziosi, Francesco Ferrise, Monica Bordegoni**
Politecnico di Milano, Italy

In this paper we describe the design of a smart alarm clock, conceived as a persuasive system to foster a sustainable urban mobility. Automatically retrieving and elaborating information available on the web, such as means of transport and weather forecast, the device is able to suggest to the user the most sustainable travelling solution, to help him/her to wake-up and reach the destination on time. Following a user-centered design approach the elaboration of the best travelling solution takes also into account, together with his/her next day appointments, user's needs and habits such as: the time he/she needs to get ready in the morning; his/her travelling preferences. A functional prototype has been built to test the effectiveness of the device using as a context the city of Milan.

### Material perception and material identification in product design

**Jessica Dacleu Ndengue, Mihaela Juganaru-Mathieu, Jenny Faucheu**
MINES Saint-Étienne, France

What makes designs intuitive? One essential part of it has to do with perception. The human body retrieves and processes information about its immediate surroundings at two levels: physical and perceptual. From the material engineer point of view, when a person interacts with a product, he (or she) interacts with the product and the materials simultaneously. The understanding of the perception mechanism of material's surfaces provides leverage for the perceived quality of products. Our study focuses on the influence of the object identification context on the perception of materials, i.e. a context where the materials are embedded in an identified object or a context where the materials are presented as anonymous parts. These findings can be used in product design in that user experience can be tuned by promoting congruity between function, materials and object identity to favor understandability of the product. On the contrary user's surprise can be promoted by favoring incongruity between these parameters.

**THURSDAY, AUG 24**

## P4.2

**11:00 am – 12:30 pm**
**Art Gallery**

CHAIR
*Monica Bordegoni*

# Sustainability

THURSDAY, AUG 24

P4.3

11:00 am – 12:30 pm

2301

CHAIR

*Sophie Hallstedt*

## An exploration of company personas to support customized DfS implementation

**Faheem Ali[1,2], Casper Boks[1], Niki Bey[2]**

[1]Norwegian University of Science and Technology, Norway; [2]Technical University of Denmark, Denmark

The increasing discussion on DfS implementation in companies has shifted the focus to effectiveness of the implementation process. Literature shows that there are certain barriers and challenges that impede the success of such efforts. This paper tries to explore whether companies — similar to product users — have certain personas that play a determining role in the implementation process. The paper draws its theoretical foundation from academic literature on human persona in user-centred design and DfS and from environmental management system literature on company characteristics. This is supplemented by insights from interviews with a case company trying to identify dimensions of a company persona in a DfS implementation context. These results are used to propose an initial framework to define persona of a company.

## Is it sustainable? A conceptual exposition of sustainability in technical artefacts

**Laura Hay, Alex Duffy**

University of Strathclyde, United Kingdom

Design is increasingly viewed as a key driver of global sustainability improvement. Accordingly, a range of sustainability-oriented design approaches have emerged over the past decades, all sharing the same high-level goal: the delivery of sustainable artefacts. Developing a shared vision of sustainability is positioned as a crucial first step in sustainability-oriented design processes; however, there is a lack of clarity regarding what the terms sustainable and sustainability fundamentally mean when applied to technical artefacts. To address these issues, we present a conceptual exposition of sustainability, beginning with three fundamental theoretical viewpoints on the concept and translating these to engineering design. Using the first generic model of systems sustainability (the S-Cycle) and an industrial case study, we then explain the basic constitution of sustainability of technical artefacts and discuss goals and metrics for sustainability-oriented engineering design. Some implications of the work for future research are briefly discussed, highlighting that sustainable design is not inherently 'good' and should therefore be conducted with caution and responsibility.

## Codesign of sustainable performance objectives in a food value chain

**Gaëlle Petit[1], Gwenola Yannou-Le Bris[1,2], Gilles Trystram[1]**

[1]AgroParisTech, France; [2]CentraleSupélec, Université Paris-Saclay, France

Food value chains actors market products to the end-consumer but most of the time their goals and are strategies not aligned, in particular on sustainability. Today in a context of global warming, resources depletion, and social struggles, it has a special importance for a value chain to prove its commitments and reevaluate its brands image towards the end-consumer and citizen. This case is about the French pork value chain, spanning feed production to food consumption. The study shows that assessing the sustainability performance is a first step in order to then enhance the value chain sustainability and the importance of actor negotiation in finding trade-offs among solutions proposed. From an average value chain, the authors designed and envisioned several improvement scenarios at various steps of the value chain that can be assessed thanks to various sustainability-specific tools. The set of retained sustainability indicators was tested as a support with the actors of the value chain and the results can be the starting point of a reflection to go towards a joint arbitration and a will to share the potential added value brought by the new scenarios.

## Design challenges in energy conservation strategies for shared spaces

**Chathura Withanage, Lucienne Blessing, Kristin Wood**

Singapore University of Technology and Design, Singapore

Business and service buildings, mainly consisting of shared spaces, account for 38% of the total Singapore energy consumption. However, compared to energy use studies in private spaces (i.e., apartments, houses, etc.), there are far fewer studies on shared spaces. This paper describes the results of a user study conducted in four cohort classrooms at Singapore University of Technology and Design (SUTD). The user study was designed to gain insights into students' attitudinal and behavioural changes in response to energy feedback displays placed in their classrooms, and an inter-cohort classroom energy competition with monetary incentives. The research questions: (RQ1) which factors shape energy use behaviour and (RQ2) which factors shape energy users' responses to interventions aimed at sustainable behaviour, were formulated to explore shared space energy use behaviours. The results show that social dynamics, contextual forces such as policies on resource usage, and personal capabilities are playing roles in shaping energy use behaviours as well as shared space users' responses to interventions.

**THURSDAY, AUG 24**

# P4.3

**11:00 am – 12:30 pm**

**2301**

CHAIR

*Sophie Hallstedt*

# Explorations in New Design Methods

THURSDAY, AUG 24

P4.4

11:00 am – 12:30 pm
2306/2309

CHAIR
*Yoram Reich*

## Ekphrasis as a design method

John Gero[1,2]
[1]UNC Charlotte, United States of America; [2]George Mason University, United States of America

Ekphrasis is the expression of a concept that is represented in the medium of one domain in the medium of another domain. This paper presents the results from exploring the concept of ekphrasis as the foundation for a computational design method. It presents a formalization of design by ekphrasis before describing its application in in a simple engineering design task involving the design of the cross-section of a beam to optimize multiple criteria. The new domain is as genes in an evolutionary domain that includes the introduction of new operators within that domain beyond the standard evolutionary operators of crossover and mutation. This generates a space of genomes beyond those that were there at the commencement of the process. Designs, i.e., cross-sections, produced in this new domain not only look different but have performances that are better than the Pareto-optimal designs produced by the original genetic operators. Design by ekphrasis can be considered as a framework for designing that involves transforming any design space in one domain into another design space in a new domain with contingent processes in the new domain.

## The beginning of a new era: Using design thinking to identify dimensions for product assessment

Danielly de Paula[1], Axel Menning[2], Benedikt Ewald[2], Kathryn Cormican[1]
[1]National University of Ireland Galway, Ireland; [2]Hasso-Plattner-Institut, Germany

A careful user needs assessment is one of the essential factors in the successful development of new products and services. Strategies for need assessment are often used to assess and select ideas during the idea generation phase of the new product development process. However, there is still a large gap between evaluating ideas and evaluating the performance of a product according to the user's needs. To address that gap, this paper aims to formulate propositions and identify key insights on how to evaluate the performance of new products according to the user's needs from a design perspective. Towards our aim, we conducted 10 in-depth interviews with design thinking professionals from Hasso Plattner Institute (HPI) in order to identify relevant concepts that could be used for product assessment. The findings provide preliminary results of how to link need assessment in product performance and idea selection in design thinking. This research intends to contribute to the literature by advancing the discussions on need assessment in new product performance by adding new perspectives from design.

## Decision design and re-ordering preferences: The case of an exploration project in a large firm

**Mario Le Glatin[1,2], Pascal Le Masson[1], Benoît Weil[1]**
[1]MINES ParisTech, France; [2]Zodiac Aerospace, France

Decision theory has been long applied to project management for risk and uncertainty reduction. Among the foundations, the manager is considered following axioms describing his rationality; the most prominent ones being transitivity and independence. The order in preferences is not supposed be reversed yet unknown events of nature may perturb our understanding and may require designing new decisions going against decision theories, hence increasing uncertainty. In this paper we propose a model of decision making in the unknown whose hypotheses are tested on an industrial case in order to show that traditional decision making is not able to grasp the natural phenomenon of expansion and generativity as a manager senses the unknown in an innovation project. Bayesian Nets with Abraham Wald's foundations are used to sense the re-ordering preferences and the benefits of designing one's playground and being intransitive. The purpose is also to contribute to the idea that design theories, theories studying generative processes, by opposition to optimisation (decision theory) and ideation (creativity theory) can help extend the underlying logic of innovation management.

## A category of design steps

**Spencer Breiner[1], Eswaran Subrahmanian[1,2]**
[1]National Institute of Standards and Technology (NIST), United States of America; [2]Carnegie Mellon University, United States of America

In this paper we critique the interpretation of Concept-Knowledge theory in terms of logical decidability. We argue instead that concepts and knowledge should be regarded as logical language and axioms, the two main components of a logical theory. Based on this proposal and using tools from the mathematics of category theory, we propose a category of logical designs to act as a formal interpretation for the dynamic operators which define the design processes of C-K theory.

# Explorations in New Design Methods, cont'd

THURSDAY, AUG 24

P4.4

**11:00 am – 12:30 pm**
**2306/2309**

CHAIR
*Yoram Reich*

### Enhancing the balancing while synthesizing-process – a method development project

**Dennis Noubarpour**
Chalmers University of Technology, Sweden

There exist many different product and concept development methods. Many of these do not target the performance and cost-balance between sub-solutions in a concept. The management of properties between sub-solutions do yield value in a cost-effective way since not all solutions for a concept is investigated. Moreover, there is a risk of conflicts between sub-solutions which can lead to costly loops. A concept development method, Balancing While Synthesizing-process was developed in the purpose to support balancing activities. Results from research projects showed one step in the process not being intuitive enough and further development was needed. A method development project was conducted to make the particular step more intuitive. The project also includes a digitalization of the process with the goal to achieve further improvements. This paper describes the enhanced version of the Balancing While Synthesizing-process and the benefits achieved realized by the method development.

# Biomimetic and Bioinspired Design

## Design guidelines for shoulder design of an anthropomorphic robotic arm

**Martin Leroux, Sofiane Achiche, Dominique Beaini, Maxime Raison**
École Polytechnique de Montréal, Canada

The development of biomechanically-accurate robotic arms is of high interest; in this paper we investigate an actuated spherical mechanism for biofidelic shoulder design. Given the high inertia of an extended arm, serial mechanisms were quickly discarded in favour of a parallel design. One particular design, the agile eye, was studied in depth due to multiple intrinsic advantages. However, no work was done regarding its capacities with higher inertia loads. Our objective is to characterise the behaviour of the agile eye in terms of speed, precision and input efforts when there is a load on the end effector. We developed the dynamic model of the robot to implement torque control with a PD controller. The system was then simulated for a few point to point trajectory conditions. The characterisation of the behaviour of the robot with a load on its end effector revealed that it reaches similar precision, with slightly slower speed depending on design choices but requires motors with power proportional to the expected load in comparison to when there is no mass on the end effector. These results can serve as design guidelines for anthropomorphic robotic arm/shoulder development.

## Do biomimetic students think outside the box?

**Torben Anker Lenau**
Technical University of Denmark, Denmark

Biomimetics is a recognized method in ideation for getting access to new and — for the designer — novel knowledge, which hopefully will result in more novel and useful products. But do designers actually find new knowledge, i.e. think outside the box or do they stick to well-known biological phenomena? If they concentrate on animals and plants, which they beforehand have knowledge about, it could be expected that solutions will remind of what they would have found without using biomimetics. To investigate this question, the empirical results from a university course in biomimetics have been analysed. The empirical material comprises 111 students working on 28 different functional design problems. On average teams identify 9.0 relevant biological phenomena and manage to produce a physical proof-of-principle for the selected biological analogy. 39% of the analogies can be characterised as well-known phenomena and 51% are from the animal kingdom. These numbers indicate a tendency of fixating on well-known knowledge. The authors propose that applying a simple constraint during the search process can counteract the tendency.

**THURSDAY, AUG 24**

P4.5

**11:00 am – 12:30 pm**

**2311**

CHAIR

*Torben Anker Lenau*

# Biomimetic and Bioinspired Design

THURSDAY, AUG 24

P4.5

11:00 am – 12:30 pm

2311

CHAIR

*Torben Anker Lenau*

## Detection and splitting of constructs of SAPPhIRE model to support automatic structuring of analogies

**Sonal Keshwani, Amaresh Chakrabarti**
Indian Institute of Science, India

The objective of this work is to structure a natural language description of analogies into a common causal language — which is chosen here to be SAPPhIRE model of causality. The motivation is to create a database of analogies that is structured so as to support focused search for analogies across the database. This should provide the benefit of utilizing the enormous data available on the Internet, while also providing relevant analogies to the designers as search results. This objective is achieved by implementing the following three steps: Firstly, detection of SAPPhIRE constructs in a document, achieved with an F-Measure of 0.834 using a text-classification approach; secondly, splitting sentences containing multiple SAPPhIRE constructs, achieved with an accuracy of 76.5% using a rule based approach; Thirdly, prediction of SAPPhIRE constructs for each text-input, implemented using the method proposed in literature. With these three steps, the time required to structure analogies into a common causal language can be reduced, thereby supporting population of the database and hence enabling designers in retrieving relevant analogies for novel idea generation.

## Biomimicry design tooling

**Laura Stevens[1,2,3], Marc de Vries[2], Jos van den Broek[3], Dick Rijken[1]**
[1]The Hague University of Applied Sciences, The Netherlands; [2]Delft University of Technology, The Netherlands; [3]Leiden University, The Netherlands

The demand for a focus on nature-oriented design education and the improvement of 21st century teaching skills has grown exponentially in recent years. Biomimicry addresses these needs but the lack of scientific research on didactic methodologies leaves teachers and students utilizing examples with little knowledge on how to start efficiently within the design process. This research structurally assesses how biomimicry is currently taught and learned, which difficulties arise and which applications are most useful, so that effective educational strategies are developed, evaluated and implemented. This ultimately increases the number of successful sustainable, circular designs produced by multi-disciplinary student teams.

# Developing Competencies

## Examining entrepreneurial motivations in an education context

**Matthew Lynch[1,2], Kristoffer Slåttsveen[1], Federico Lozano[1], Martin Steinert[1], Gunnar Andersson[2]**

[1]Norwegian University of Science and Technology, Norway; [2]University College of Østfold, Norway

Entrepreneurial skills are receiving greater attention as engineering departments realise the value of having their graduates receive an education that goes beyond just technical skills. In Norway, one particular education method is to have engineering students start a business. Little is known about what motivates students who set out to start a business, and how feasible they perceive this task. This article sets out to explore students' motivations around entrepreneurship. The paper finds that students are largely motivated by intrinsic factors such as the challenge of working on their own business, and learning to use their skills and competence. While extrinsic motivations such as money do not seem to play a large motivating role. The article reveals students' have negative perceptions regarding their own skills and competence to pursue an entrepreneurial career. The article is based on empirical data gathered from a joint workshop held between two similar universities who educate their engineers in entrepreneurship.

## Competences for the development of smart products

**Michael Herzog, Beate Bender**

Ruhr University Bochum, Germany

Within the concept of Industry 4.0 the expansion of mechatronic products towards smart products is key. Whereas the discussion about smart products in the context of production is more prominent, the shift towards the paradigm of smart products also suggests that the current way of product development needs to be adapted fundamentally. It becomes obvious that besides technological topics like big-data or IT-infrastructure, the human factor is of major importance for a successful realization of industry 4.0. Especially new concepts for training and further education for product development are needed to cope with the emerging challenges. In order to design new educational concepts, instructional goals are key. Nowadays these goals are described in a competence oriented way. Until now, there are now competence models available that consider both the specificity of product development as well as the context of Smart Products. Hence this paper aims at deriving this competence model in a conceptual way. Therefore, a multistaged approach is conducted that synthesizes competence models for product development and engineering for industry 4.0 as well as design methodologies in the field.

**THURSDAY, AUG 24**

**P4.7**

**11:00 am – 12:30 pm**

**2504**

CHAIR

*Ian James de Vere*

# Developing Competencies, cont'd

**THURSDAY, AUG 24**

P4.7

**11:00 am – 12:30 pm**

**2504**

CHAIR

*Ian James de Vere*

### Exploitation of micro-learning for generating personalized learning paths

**Zoltan Rusak**

Delft University of Technology, The Netherlands

Personalization of learning experience in engineering courses is a key to successfully engage students in any type of learning activity. Personalization is needed to achieve optimal learning experiences taking into account the pace of learning influenced by the background and capability of the learners, their personal interest, and optimal timing of learning exercises. This paper presents the development of an algorithmic solution to personalize learning content and learning paths for teaching Android software development to design students. Our solution recommends micro-learning sessions to students based on their background knowledge, their preferences and ranking of alternative learning contents, and their performance of completing the tests of micro-learning sessions. The recommender algorithm has been applied in an e-learning environment by 68 students of an elective course and the goodness of recommendations was evaluated with the goal to further tune the learning content and the recommendation mechanism. Our results show that ca. 60% of the learning content of the course requires personalization, while the remaining 40 % is suitable for all students without any adjustment.

### An educational method for enhancing the ability to design innovative products

**Kaori Yamada[1], Akira Tsumaya[1], Toshiharu Taura[1], Kenji Shimada[2], Toshiya Kaihara[1], Yasuyoshi Yokokohji[1], Ryuta Sato[1]**

[1]Kobe University, Japan; [2]Carnegie Mellon University, United States

In the modern era, what we produce is important, and synthetic design thinking is strongly needed to create innovative products that bring qualitative changes to users' lifestyles. This paper proposes an educational method for creative design that can enhance a person's ability to generate a new concept of ground-breaking products that are not merely extensions of existing ones. This approach is unique due to its process, which starts with a person coming up with a concept based on 'intuitive synthesis' in which the metaphor of a 'product like a living thing' is instinctively created; then, details are confirmed by 'analyzing and investigating' the concept's characteristics, followed by a 'representation' of the product and the scene in which it will be employed using a virtual reality device. Based on this educational method, the International Design Engineering School was carried out in 2016. Students enthusiastically joined this program, and their design outcomes were found not to be improvements of existing products, but rather, were pioneering previously non-existent products.

# Design Thinking

THURSDAY, AUG 24

P4.8

11:00 am – 12:30 pm

2506

CHAIR

*Petra Badke-Schaub*

## Design thinking vs. systems thinking for engineering design: What's the difference?

**Melissa Greene[1], Richard Gonzalez[1], Panos Papalambros[1], Anna-Maria McGowan[2]**

[1]University of Michigan, United States of America; [2]NASA Langley Research Center, United States of America

Design thinking (DT) and engineering systems thinking (EST) are two complementary approaches to understanding cognition, organization, and other non-technical factors that influence the design and performance of engineering systems. Until relatively recently, these two concepts have been explored in isolation from one another; design thinking methods have been applied to industrial design and product development, while engineering systems thinking is used in professional systems engineering practice and large-scale, complex systems design. This work seeks to explore the relationship between these two concepts, comparing their historical development, values, applications, and methods. The primary contribution of the work is a set of four concept models that depict plausible relationships between design thinking and systems thinking for engineering design.

## Design thinking – a paradigm

**Linda Nhu Laursen, Christian Tollestrup**

Aalborg University, Denmark

Design thinking has received an increasing amount of attention in both practice and academia. Previous research has successfully pointed out design thinking is vaguely and diversely defined, presenting eight different discourses. Although design thinking has been viewed from different perspectives with diverse results, much current research use the terms of design thinking without clarification of the relation to one another; this creates confusion. With this paper we clarify design thinking. Through a review of key literature and a conceptual synthesis, we show design thinking is not merely a process or either of eight suggested discourses — but all of them. Thinking like a designer is a paradigm, which may materialize in various forms. It is a way of seeing and interacting with the world. It is a world-view. By categorising central themes from key literature, we add to the current discussion with a coherent conceptual framework of design thinking. A taxonomy of the design thinking paradigm, which provide clarity of levels, since there in current literature are no clear distinction between the fundamental paradigm, methods and practical tools and techniques of design thinking.

# Design Thinking, cont'd

THURSDAY, AUG 24

P4.8

**11:00 am – 12:30 pm**

**2506**

CHAIR

*Petra Badke-Schaub*

## A corpus-led approach on guidelines extraction from design thinking methodologies

**Maiara Rosa, Giovana Nogueira, Henrique Rozenfeld**
University of São Paulo, Brazil

Target of criticism and enthusiastic expressions in literature, design thinking (DT) as spread by IDEO has been popularized and practitioners' literature has been growing. However, this DT strand lacks further theoretical characterization. This work is part of a wider research that aims to provide a proper characterization of DT to allow its integration into product-service system (PSS) design process models. This wider research has already provided the 46 most recurrent activities on DT. Besides activities, one of the elements that is also essential on a proper DT application is the mindset assumed by the design team, which is commonly framed by guidelines proposed on methodologies in literature. The goal of this work is to identify the generic and specific guidelines that complement DT recurrent activities, towards a more complete characterization of DT. This goal was achieved by means of a corpus-led approach based on corpus linguistics and frame semantics applied to eight DT methodologies. It resulted into nine generic guidelines and about ten specific guidelines per DT recurrent activity, which can be classified into agent, duration, manner, place and time.

## Integrated approach to the agile development with design thinking in an industrial environment

**Michael Grashiller[1], Tobias Luedeke[1], Michael Vielhaber[2]**
[1]csi entwicklungstechnik GmbH, Germany; [2]Saarland University, Germany

The aim of this paper is to investigate the arrangement of creative techniques and flexible project management methods to enable innovative product development in one single process. Because innovation had become key factor, creative and agile methods — such as Design Thinking and Scrum — are interesting to combine. But contemporary methods of such integration to existing structures often fail and today no further applications are known. This paper challenges the implementation of the combined processes focussed to the modern product development. In a second stage, the authors present a methodology to overcome the deficits and introduce the EIVAmode process. As basis, there is a conflated Design Thinking process combined with a Scrum framework afterwards. The approach is designed for producing industries with the requirement of an accessible innovation process in product-related search fields. Finally, it was applied to the product development within an 8-month testing phase. It brought remarkable results by comparison with a project using static project management. The presented approach will provide a contribution to enhance the innovativeness in an industrial environment.

### Towards a DT mindset tool evaluation: factors identification from theory and practice

**Marco Paparo, Clio Dosi, Matteo Vignoli**
University of Modena and Reggio Emilia, Italy

Several studies identify the Design Thinking mindset as the crucial aspect of the Design Thinking implementation in organisations. However, it is not clear how to measure the DT mindset in organisations, and its successful implementation. This paper aims at contributing at the development of a multidimensional scale of a Design Thinking mindset. This research in its first phase performs a structured literature review to identify what key elements define a Design Thinking mindset. We identified 40 characteristics clustered in 9 groups. The second phase of research identifies validated scales that could overlap with those groups and be used to measure them. Out of 9 factors, we managed to cover 5 factors with validated scales. A double panel of experts tested the validity of the survey: a first panel of 4 Design thinking experts and a second panel of 14 practitioners of different experiences of DT implementation. Results identify what elements of DT mindset should be measured, what domains (factors) could be measured with validated scales (from literature) and what domains will require ad-hoc development of new items from future research.

**THURSDAY, AUG 24**

## P4.8

**11:00 am – 12:30 pm**
**2506**

CHAIR
*Petra Badke-Schaub*

## Lunch

**12:30 pm – 2:00 pm Atrium Lower Level**

# Cost Analysis and Optimisation

THURSDAY, AUG 24

D7.1

2:00 pm – 3:00 pm
Performance Theatre

CHAIR
*Christian Weber*

## Interdisciplinary life cycle data analysis within a knowledge-based system for product cost estimation

**Stefania Altavilla[1], Francesca Montagna[1], Linda Newnes[2]**
[1]Politecnico di Torino, Italy; [2]University of Bath, United Kingdom

Product lifecycle has become one of the most relevant cost drivers for many manufacturing companies. Companies, in fact, are forced to reduce not only the costs that directly determine the price of the product, but they must also evaluate those costs that affect the entire lifecycle since customers are now considering after-sale services in their purchasing decision. However, implementing a product lifecycle perspective is challenging for an organisation if the uncertainty related to the duration of the life cycle process as well as the collection of a large amount of data are taken into account. Data, if correctly collected, contain valuable information that can be extracted and integrated into the analysis, to improve better design decisions and enhance product quality. For this purpose, this research proposed a knowledge-based system that uses empirical data, and information available across phases of product's lifecycle, and suggests how different qualitative and quantitative analyses can be performed, to transform the results in valuable feedback for future product development, while also providing a cost estimation.

## A design to cost method for electric cable harness

**Marco Mandolini, Paolo Cicconi, Vincenzo Castorani, Alessio Vita, Michele Germani**
Università Politecnica delle Marche, Italy

The Design to Cost method is a well-known methodology for developing cost-competitive products. In the context where the Industry 4.0 initiative is pushing the research on innovative systems for data exchange and analysis, the electric aspect of a product is becoming more and more important. The scientific and industrial literature contains several methods and tools for the cost estimation of electric cable harness, but they essentially calculate the cost by simply considering the Bill of Material and computing the cost of the raw material. The installation cost is not considered. The paper presents a Design to Cost method for electric cable harness, based on the analytic cost analysis of the raw material and routing process. The inputs of such a method are the electric Bill of Material and the 3D path of the cable harness. The cost consists of three items: purchasing, installation and cutting. The method, once implemented within a prototype software tool, has been applied for the cost optimization of the electric cable harness of an on-shore module for power generation. The average accuracy, measured comparing the results with experimental data, was 10.5%.

## Systematic approach to optimize cost drivers based on life cycle cost modeling

**Florian Johannknecht[1], Matthias Gatzen[2], Roland Lachmayer[1]**
[1]Leibniz Universität Hannover, Germany; [2]Baker Hughes Incorporated, United States of America

Optimizing cost drivers is one of the key success factors within product development. Approaches to develop cost-efficient products are deeply rooted in standard design methodology. However, in most instances manufacturing costs are in primary focus. Against the background of current trends in various industries, the life cycle of a product becomes more and more important, which results in the necessity of considering costs from the use phases as well. Designing a product with low life cycle costs poses a significant challenge. Various dependent influences lead to trade-off decisions with the involvement of subject matter experts. Focus on the most important cost influences in different life cycle phases is essential for a fast, efficient, and standardized process to optimize costs. This paper describes a holistic life cycle costing approach for cost management in product development. Based on cost modeling, a systematic way to optimize capital and operational cost drivers is explained. Relations and trade-offs between costs from different phases of the life cycle are presented. Also, a case study performed with an industry partner demonstrates the application of the model.

**THURSDAY, AUG 24**

D7.1

**2:00 pm – 3:00 pm**
**Performance Theatre**

CHAIR
*Christian Weber*

# Healthcare Systems Design

THURSDAY, AUG 24

D7.2

2:00 pm – 3:00 pm
Art Gallery

CHAIR
*Yong Se Kim*

## Designing mental health delivery systems: Where do we start?

**Alexander Komashie[1], Sarah Ray[2], Manaan Kar Ray[3], P. John Clarkson[1]**
[1]University of Cambridge, United Kingdom; [2]Cambridgeshire and Peterborough NHS Foundation Trust, NIHR CLAHRC for the East of England, United Kingdom; [3]Cambridgeshire and Peterborough NHS Foundation Trust, United Kingdom

Healthcare services that consistently meet the needs of service users have to be designed. The growing demand for better quality of care, together with an increasing awareness of limited resources, are bringing attention to the need for design in healthcare. In mental health, considered the largest cause of disability in the UK, the need is great. Existing services often fail to meet demands and do not consistently deliver good quality care for all service users. The design of better delivery systems has the potential to improve service user experience and care outcome. But, where do we start? This paper reports the first stage of an ongoing research to co-design a language for designing mental health services. This stage of the research identified, through focus groups and interviews with service users and clinicians, the key components of a mental health service. This paper argues that an appropriate concept of a mental health delivery service as a system, the identification of its key components and an understanding of the association between these components form an essential first step in designing such a system.

## Engineering value-effective healthcare solutions: A systems design perspective

**François Patou, Anja Maier**
Technical University of Denmark, Denmark

Our modern healthcare systems commonly face an important dilemma. While they depend on innovation to provide continuously greater healthcare value, they also struggle financially with the burden of adopting a continuous flow of new products and services. Although several disruptive healthcare models, i.e. decentralised, personalised, pervasive, connected, and stratified, promise to relieve some of this tension, they do not per se guarantee optimal value generation. We argue that systems thinking and engineering design can remedy this limitation. We support this claim by making the case of Design for Evolvability and by elaborating on two examples: MRI systems and Point-of-Care in-vitro diagnostics solutions. We specifically argue that Design for Evolvability can realign the agendas of various healthcare stakeholders, serving both individual and national interests. We finally acknowledge the limitations of current engineering design practices and call for new theoretical and empirical research initiatives taking a systems perspective on healthcare product and service design.

## A multimethodology for hospital process redesign

**Guillaume Lamé[1], Julie Stal-Le Cardinal[1], Oualid Jouini[1], Muriel Carvalho[2], Christophe Tournigand[3], Pierre Wolkenstein[4]**

[1]CentraleSupélec, Université Paris Saclay, France; [2]Pharmacie, Hôpital Henri Mondor, APHP, France; [3]Service d'oncologie, Hôpital Henri Mondor, APHP, France; [4]Service de dermatologie, Hôpital Henri Mondor, APHP, France

Hospitals are complex organizations, faced with major challenges. They are required to reach higher cost efficiency, while improving treatment quality and achieving patient-focused care. Yet, hospitals are still fragmented organizations, which prevents them from reaching these targets. In this article, we propose a multimethodology to achieve coordination and integration between different hospital departments involved in the same care process. Our proposition combines Soft Systems Methodology, Discrete Event Simulation, benchmarking and Service Blueprinting. It offers both qualitative and quantitative aspects, and takes into account both the logical/technical and the social/political dimensions of interventions and change management in organizations. The multimethodology is evaluated on a project in outpatient chemotherapy delivery within a partner hospital. Solutions are generated and refined for the problem of patient waiting times. The study makes a methodological contribution, by proposing this multimethodology. It also offers a practical solution concept for outpatient chemotherapy planning.

## Nurse-centred design: homecare nursing workarounds to fit resources and treat wounds

**Dawood Al-Masslawi, Sidney Fels, Rodger Lea, Leanne M. Currie**

The University of British Columbia, Canada

In recent years the number of patients referred to home and community healthcare units are increasing. Many in this population have chronic or difficult to heal wounds. Homecare nurses provide care for these patients. The resources available to nurses have not increased at the same rate. Observations made in this study indicate that nurses have to fit resources to work around barriers to their work. This is known as a workaround. To identify common workarounds data from 6 weeks of observation was topically coded and thematically analyzed. The findings were validated using a questionnaire. The results point to gaps and limitations in access to reliable, accurate, and consistent resources, especially in work nomadic in nature such as homecare nursing. Workarounds created and used by homecare nurses enable them to negotiate appropriate fits for resources and fill in the gaps. Many of the workarounds were found to be related to computational resources. It is possible that use of these workarounds to inform new design leads to nurse-centred design. This type of design will give homecare nurses access to resources that they need while supporting their nomadic work.

# Sustainability Assessment

THURSDAY, AUG 24

D7.3

2:00 pm – 3:00 pm

2301

CHAIR

*Daniela Pigosso*

## Sustainability integration in a technology readiness assessment framework

**Sophie Hallstedt[1], Daniela Pigosso[2]**

[1]Blekinge Institute of Technology, Sweden; [2]Technical University of Denmark, Denmark

In this paper, an approach to systematically include sustainability into the Technology Readiness Levels (TRL) is proposed. The aim is to answer the question "how can sustainability provide systematic guidance in technology development and early product development?". Results from a case study illustrate that the suggested approach can support i) the inclusion of sustainability into the early design stages, when only limited data and information is available; ii) the enhancement of the comprehensiveness of sustainability and ease of use in the day-to-day engineering working environment; and iii) simplified sustainability assessments without being too simplistic and/or reducing the sustainability scope. The proposed approach is being co-developed in collaboration with a case company, and tests on an actual technology development project are planned. The next steps are related to the application of the proposed approach in other companies to test its robustness and enhance its generalization for application in diverse contexts.

## Product sustainability assessment in conceptualisation phase

**Victor Gerardo Martinez**

Kwantlen Polytechnic University, Canada

Along the design process many decisions and compromises are made in order to reach a final design solution. In literature is commonly accepted that tackling sustainability issues at early stages provides a better opportunity to make a positive contribution. Nevertheless, designers face a paradigm, how can they assess the sustainability of something that is not yet conceptualised? Another important constraint for addressing sustainability issues at early stages is that most tools supporting in this task are designed to assess once the product is defined; there is very little to no tools at all addressing the needs and culture of designers at early stages of design. This paper presents a series of test where designers were asked to follow a design process and given a novel "soft modelling" tool to assess concepts. The results show that designers' primary reaction is to deny the assessment of something they have not defined yet. Nevertheless, if used, the tool was found that it is possible for them to reflect on the options and future decisions. This results show that the "soft modelling" approach if developed could provide important aid to designers at early stages.

## Why choose one sustainable design strategy over another: A decision-support prototype

**Rachael Gould, Patricia Lagun Mesquita, Cecilia Bratt, Göran Broman**
Blekinge Institute of Technology, Sweden

Sustainable design strategies provide tangible ways for integrating sustainability into early phase product design work. Examples include design for remanufacturing and design for the base of the pyramid. There are many such strategies and it is difficult to choose between them. Sustainable product design activities also need to be tailored to business priorities. We therefore designed a decision-support prototype to aid project teams to choose strategies based on relevance to the project in terms of both business and sustainability value. To design the prototype, we first identified potential strategies from sustainable product development literature. We then used literature on each of six selected strategies to identify potential business and sustainability benefits. We developed a way to compare sustainability value based on a scientifically established definition of sustainability and a lifecycle perspective. The prototype is designed to be usable by practitioners who are not necessarily sustainable design experts. The prototype was created to enable future work to test ways to integrate the selection of sustainable design strategies into the early phases of product design.

## Complexity theory as an epistemological approach to sustainability assessment methods definition

**Marianna Nigra**
Politecnico di Torino, Italy

It is since the last thirty years that the world community has formally recognized the necessity of approaching the changes occurring to the social environmental and economic structure of society. Yet, the fact itself that sustainability has to represent a crucial shift for the architectural and urban design practice is still object of a debate characterized by contrasting positions. Despite since 1992, when UN released the Agenda 21 and called for 'better measurement tool' to assess the sustainable practice, the definition of an assessment method able to gauge the complexity of the changes that are occurring in our societies and to suggest management strategies is as well a subject of an open discussion and work by both the academic and the industrial world. This paper proposes the application of the complexity theory as an epistemological approach to overcome limits in the current sustainable assessment methods, and proposes a system to gauge and to value the complexity of sustainable architectural and urban projects and development processes.

# Engineering Change Management – General Studies

THURSDAY, AUG 24

D7.4

2:00 pm – 3:00 pm
2306/2309

CHAIR
*Claudia Eckert*

## Matrix-based system modelling to predict properties change propagation

**Tobias Luedeke[1], Jerome Kaspar[2], Philip Meiser[2], Jan-Henrik Schneberger[1], Hans-Georg Herrmann[3,4], Michael Vielhaber[2]**
[1]csi entwicklungstechnik GmbH, Germany; [2]Saarland University, Institute of Engineering Design, Germany; [3]Saarland University, Chair of Lightweight Systems, Germany; [4]IZFP Fraunhofer Institute for Nondestructive Testing, Germany

A significant shorter pre-development time in the automotive industry without physical prototypes due to a quicker generation of concepts is key to reduce development cost and to reach a higher product maturity much faster. However, especially appropriate product property changes have to be considered and can be handled better while reducing the number of macro-iterations and, instead, fostering micro-iterations in order to support a more agile development process. Consequently, it is inevitable for the application of an agile development and change management process to apply a holistic system consideration and to widen the range of consideration along the complete development process and not to stick in the determination of details. In this contribution, an approach towards a matrix-based system model is presented which applies both a systemic and systematic process upon the modelling of a whole system. The multi-dimensional mathematical description of the system elements and the hierarchical system decomposition support the calculation in a top-down / bottom-up procedure. Special attention is given to the product property changes and their propagation throughout the system.

## Change propagation management by active batching

**Gyesik Oh, Yoo S. Hong**
Seoul National University, Republic of Korea

Incremental design causes changes to an existing product by modifying or adding sub-systems. In the perspective of development process management, changes prolong duration and raise cost with increasing design change jobs. The change management of a complex product is challenging since changes are stochastically propagated to multiple sub-systems. The present study proposes the novel change management method, active batching, to accommodate the complex and uncertain characteristics of change propagation. Active batching composes multiple probable change requests as a batch, based on the prediction of change propagation. It saves cost by eliminating multiple setups and redundant execution. It also avoids unnecessary waiting to compose a batch, which accelerates development process. Numerical study on software development project validates that active batching moves Pareto frontier line of project performance into the direction of less cost and short duration.

## A method for the expert-based identification of engineering change propagation

**Niklas Kattner, Jan Mehlstäubl, Lucia Becerril, Christoph Hollauer, Dominik Weidmann, Udo Lindemann**
Technical University of Munich, Germany

Handling engineering changes effectively becomes more and more important for the performance of the overall design process. Therefore, it is crucial to assess the propagation of engineering changes precisely to prevent unexpected workload. However, the detailed analysis of technical systems to predict possible change propagation is often time consuming. Furthermore, the effort needed for the analysis highly increases with a growing number of system elements. Hence, methods for the application in the industry have to be both precise in the prediction of change propagation and extremely time efficient. This paper therefore presents a new approach to identify change propagation by combining a matrix-based approach of modeling interrelations with the implicit available knowledge of an expert familiar with the system. Additionally, the system understanding is expanded by introducing artefacts. It remedies the problem of having preliminary development results, e.g. feature specification or preliminary part lists, which also have to be considered in the change propagation analysis. Finally, the approach is evaluated within an industrial use case.

## Decentralized handling of conflicts in multi-brand engineering change management

**Carsten Hesselmann[1], Stefan Kehl[1], Patrick Stiefel[2], Jörg Müller[1]**
[1]Clausthal University of Technology, Germany; [2]Volkswagen Group, Germany

Changes on components that are commonly used in different products in multi-brand product development, cause various types of conflicts. This paper considers conflicts of interest among individuals that are caused by differing payoffs each brand would realize if a specific change request were accepted. Following an analysis of requirements on multi-brand engineering change management processes, we propose an approach to model these conflicts using methods from the field of agreement technologies. In particular, we propose voting games as a model and mechanism to represent and reconcile opposing interests and conflicting requirements. In this initial paper, we describe such a mechanism from a conceptual perspective and illustrate our model by using an example agreement process, where commonly used components are defined by different brands and changes on them are voted on in order to determine the set of components that combines the different interests at best. A core element of our approach is a micro-meso-macro coordination architecture that allows to express and reconcile different value systems (e.g. from corporate group, from different brands, down to individual designers).

**THURSDAY, AUG 24**

# D7.4

**2:00 pm – 3:00 pm**
**2306/2309**

CHAIR
*Claudia Eckert*

# Engineering Research Applications

THURSDAY, AUG 24

D7.5

2:00 pm – 3:00 pm

2311

CHAIR

*Kilian Gericke*

## On the design of Len Lye's Flaming Harmonic

**Angus McGregor[1], Shayne Gooch[1], Evan Webb[2]**

[1]University of Canterbury, New Zealand; [2]Len Lye Foundation, New Zealand

Len Lye (1901–1980) was an artist who wanted to build kinetic sculptures at a monumental size however he was constrained by the availability of resources and technology. This paper examines the structural design of a vertical cantilever beam which is a key element in the monumental version of Lye's 'Flaming Harmonic'. In 'Flaming Harmonic' the vertical cantilever vibrates at resonant bending and whirling frequencies due to a reciprocating harmonic ground movement which is provided by a mechanical drive. Lye produced a 1.3m tall model of a similar work called 'Harmonic'. Design rules developed in this paper show that 'Flaming Harmonic' can be produced at a height of 14m. Similarity between 'Harmonic' and 'Flaming Harmonic' ensures that while the artwork is produced posthumously, artistic integrity for the larger work will be preserved. The vibratory mode shapes and corresponding stresses are established for 'fixed' and 'pivot' clamp designs. It is shown that while a slightly different vibrating shape is achieved using each method the 'pivot' clamp design results in a lower bending stress and hence a longer life for the vertical cantilever.

## Application of product development process (PDP) in the construction of vertical axis wind turbine with movable blades

**George Santiago[1], Willmari Hernandez[2], Ana Cláudia Costa de Araujo[1], Marcela Rosa[1], Mario González[1]**

[1]UFRN Federal University of Rio Grande do Norte, Brazil; [2]UNIFEI Universidade Federal de Itajubá, Brazil

This article, through an approach of Product Development Process (PDP), characterizes the development phases of a new concept of vertical axis wind power turbine. The conceptual model used serves as a guide in the design, management and implementation of product research and development (R&D). The use of a model facilitates the replication, evolution and error handling of a new concept. Product development methodologies were applied in UNIFEI laboratories and the results prove the efficiency of the proposed prototype in comparison to existing technologies.

### Selective pre-load generation: Finding manufacturing-integrated solutions for linear guides

**Michael Roos, Christian Wagner, Sebastian Gramlich, Jannik Reichwein, Eckhard Kirchner**
Technische Universität Darmstadt, Germany

Pre-load is important for a linear guide's precision but can adversely affect its longevity. The idea of selectively adjusting pre-load for specified track sections of a linear guide is starting point for an innovative product design. Key challenge of realising linear guides with a selective pre-load generation is to integrate this additional function with low manufacturing effort. A continuous flow production with linear flow splitting has a high potential for realising a function integrated product design at low costs. Based on linear flow split linear guides, these potentials are extended towards manufacturing-integrated solutions (MIS) for linear guides with integrated selective pre-load generation. The design pattern matrix (DPM) aids the designer in systematically developing MIS based on generally applicable function carriers. Several MIS for linear flow split linear guides with a selective pre-load generation have been developed and two prototypes produced. The solutions are characterised by a comprehensive utilisation of the continuous flow production's design possibilities, resulting in products with high functionality and low manufacturing and assembly effort.

### Measuring frugality – application to a solar water distiller

**Serge Rohmer, Abdelatif Merabtine, Youcef Bouzidi**
University of Technology of Troyes, France

This paper explores the concept of frugality to help designers in optimizing the resources needed for the design of products. A metric proposes to integrate the geographical origin of the components which participate at the achievement of the product's functions. The resulting profile gives a global notation of the frugality, and suggests ways of improvement by targeting functions that are less frugal. A case study on a solar water distiller supports the proposal in order to prove the efficiency of the methodology.

**THURSDAY, AUG 24**

## D7.5

**2:00 pm – 3:00 pm**

**2311**

CHAIR

*Kilian Gericke*

# Robust Design 1

THURSDAY, AUG 24

D7.6

2:00 pm – 3:00 pm

2314

CHAIR

*Tobias Eifler*

## A method for the tolerance analysis of bearing seats for cylindrical roller bearings in respect to operating clearance and fatigue life

**Alexander Aschenbrenner, Sandro Wartzack**
Friedrich-Alexander-University Erlangen-Nuremberg, Germany

Roller bearings are used in a vast variety of mechanical applications and are often highly stressed machine elements. Therefore the fatigue life of roller bearings can determine the reliability and service life of these mechanical systems. The fatigue life of a roller bearing is greatly affected by its operating clearance and the design of the adjacent components (namely shaft and housing). Especially the geometric dimensioning and tolerancing of the bearing seats can have great influence on the operating clearance and therefore the fatigue life of a roller bearing. In this article a method for the statistical tolerance analysis of the operating clearance of cylindrical roller bearings is presented. The method uses a discrete geometry representation coupled with contact detection algorithms for the determination of the operating clearance. The results are thereafter coupled with the calculation of the fatigue life. Statistical analysis of the results assists an engineering designer when choosing a robust design for the bearing seats.

## A geometric approach to tolerance analysis: Contribution to the robust design of flexible assemblies

**Christoph Schluer, Peter Gust, Frank Mersch, Falko Diepschlag, Alina Sersch**
University of Wuppertal, Germany

Tolerance analysis is an important element for virtual product development. It makes it possible to record the effects of permissible deviations for the complex assemblies. The component deviations will only be represented by a significantly simplified structure in commercially available 3D tolerance analysis programs and elastic deformations in the components, as well as complex contact regions, can only be partially represented. The objective of this paper is therefore to present a geometric-based approach for tolerance analysis. This already represents the tolerance-related deviations for components in a 3D data set as realistic imperfections. The assertion, that the geometric imperfections have a significant impact, will be verified on the basis of a bolted articulated joint assembly. The numerical results will be subsequently validated experimentally. A test bench will be designed for this purpose and various test sequences with realistic bolted articulated joints will be examined. The results indicate the relevance of realistic consideration of tolerances in product engineering processes and therefore create an element for the robust design of flexible assemblies.

## Applying robust design methodology to a quadrotor drone

**Charles Coulombe, Jean-Francois Gamache, Abolfazl Mohebbi, Ugo Chouinard, Sofiane Achiche**
École Polytechnique de Montréal, Canada

Optimization of mechatronics system often rely on optimization of the controller, while treating the structural part of the system as a fixed constraint. The research work presented in this paper has the goal of obtaining a robust design for a quadrotor drone, focusing on the structural parameters of the drone, such as mass and dimensions. A robust design method is a design that focuses on minimizing the effects of the variations of the design parameters, here structural parameters, on the response of the system. In this paper, the system's response is represented by its energy consumption. Using a MonteCarlo simulation, the most influential design parameters are first determined, and then a designer-defined objective function is minimized to obtain a robust mechanical design for the quadrotor at hand. The optimized drone is then shown consuming less energy than a comparable drone, while also being more robust to variation of design parameters.

## A function– and embodiment-based failure analysis method for an in-depth understanding of failure mechanisms

**Bartosz Gladysz, Lukas Spandl, Albert Albers**
Karlsruhe Institute of Technology (KIT), Germany

Research studies have shown that there is an industry demand for improved failure analysis as well as failure documentation and this could be accomplished by model-based failure analysis methods. Furthermore, it is shown that the embodiment of design is an important aspect, which supports the product developer during the design process. Motivated by these findings, the authors combine the Failure Mode and Effect Analysis (FMEA) method and Contact and Channel Approach (C&C$^2$-A). The resulting function- and embodiment-based method focusses on failure mechanisms, thereby improves the analysis and documentation of failures. The results are exemplified and discussed based on two real use cases: the development of a pneumatic gear shift actuation system for a race car and the development of an inline quality control system for a CNC turning machine.

**THURSDAY, AUG 24**

# D7.6

**2:00 pm – 3:00 pm**

**2314**

CHAIR

*Tobias Eifler*

# Maker Spaces – Activity Based Learning

THURSDAY, AUG 24

D7.7

2:00 pm – 3:00 pm

2504

CHAIR

*Stanko Škec*

## Differences between the discerning and opportunistic mind-sets in design learning

**Basyarah Hamat[1,2], Boris Eisenbart[1], Jan Schoormans[1], Petra Badke-Schaub[1]**

[1]Delft University of Technology, The Netherlands; [2]Universiti Teknologi Malaysia, Malaysia

Design learning can be improved by understanding the differences between individual characteristics of students and its connection with their learning processes and outcomes. This paper focusses on the differences between discerning and opportunistic mind-sets. 91 students from industrial, product or automotive design courses participated in a quasi-experiment where they were required to generate solutions for a design problem, answer a Q&A survey and fill in a questionnaire. The obtained data were analysed using qualitative and quantitative metrics. We found evidence of individual characteristics, processes and outcomes that differentiate the discerning and opportunistic mind-sets. Based on these findings the paper proposes and discusses potential implications for design education.

## Makerbox: Introducing a low threshold maker experience for everyone — An online facilitation platform for problem based projects

**Kristoffer Slåttsveen[1], Truls Nygaard[1], Georgina Seviour[2], Martin Steinert[1], Knut Einar Aasland[1]**

[1]Norwegian University of Science and Technology, Norway; [2]University of Glasgow, United Kingdom

This paper presents an online facilitation platform for project based education workshops, where the task formulations and solution methodology is based on engineering design methods. As design engineers, we are trained to see failure as lesson for future improvement and learn to identify the underlying cause for a problem. We want to contribute to the educational system, and expose children to design and decision-making problems before they reach college. We are also inspired by the maker communities around the world, and the great work they do towards inspiring and educating the engineers and designers of tomorrow. Most of the learning activities this community offers, is however based on step-by-step tutorials. In addition to the skills such projects train, we would like to add an element of ill-structured problems. The need for this perspective has been confirmed by teachers and maker-associations in our community. As a result, we present the Makerbox, an online facilitation platform for project based workshops. Usable by teachers and other engaged organisers. The paper also presents and discusses results from pilot tests exploring how the projects should be presented.

## Providing a conducive environment to integrate design and production: Assessing the potentials of university-based fablabs (Ub-Fablabs)

**Vomaranda Botleng, Stéphane Brunel, Philippe Girard**
Université de Bordeaux, France

While design plays an important role in economic growth, the unanticipated high output of wastes during a product's lifecycle puts to question the current practice of design and production. According to Siefried Dais (Tscheiesner & Loffler 2016 Interview), the current design and manufacturing sectors operate in isolation. The design sectors formulate product solutions and design specifications while the manufacturing sectors produce for the customers. This gap needs to be bridged so that, not only will customers be empowered to design and produce, but also responsiveness to resource conservation and sustainability. This paper discusses findings into a potential platform that can integrate design and production- the Digital Fabrication Laboratories. A mixed method of participant observation and online content analysis was carried out on 53 university-based fablabs. Results revealed the following strengths of four criteria: i) digital technological infrastructures — 97%, ii) constructionist pedagogical approach — 84%, iii) collaboration through networking — 58%, iv) sustainability- 41%. This proposes a potential platform for the integration of design and production.

## Experiences of product engineering conceptual design with patent drafting

**Joaquim Lloveras**
Universitat Politècnica de Catalunya, Spain

This paper reports an education experience on product engineering conceptual design and its relation to patent drafting conducted in a technical university. Students have been required to draft patents since the 1993/94 academic year. The experience shows that drafting a patent is a good help to improve product designs and also to obtain new alternative solutions. This teaching system is contrasted upon completion of courses with anonymous student opinion polls. This long research work has resulted in a Product Engineering course in product innovation through a structured process in order to obtain a patentable Conceptual Design and to draft a patent. The present paper summarises this process. A case study of an old patent shows several items that serve to improve the design and are frequently repeated in every new patent draft. Several patent applications were made with students. The Conclusions section provides a list of characteristics that improve this general process of conceptual design when including the drafting of a patent.

**THURSDAY, AUG 24**

# D7.7

**2:00 pm – 3:00 pm**
**2504**

CHAIR
*Stanko Škec*

# Designers' Personal Attributes and Skills

THURSDAY, AUG 24

D7.8

2:00 pm – 3:00 pm

2506

CHAIR

*Philip Cash*

## Designer's identity: Development of personal attributes and design skills over education

**Kamila Kunrath, Philip Cash, Jason Li-Ying**
Technical University of Denmark, Denmark

Designers' Professional identity (DPI) is a social- and self-perceptive construct through which designers are able to identify themselves. To understand the development of DPI, not just as a profession but also as an educational process, there is a need to consider the designer as both individual and trained professional. These interactions become also a necessary foundation for professionalism that is especially important for design activity. For this study, a psychometric survey was developed by taking in consideration both aspects of DPI, making use of a set of elements distilled from literature as conceptual parameters for Personal Attributes and Design Skills. The survey evaluated professional self-awareness of design students at bachelor and master level; also providing a first profile model of the two groups. The dynamics of the relations between the DPI elements changes and develops very slowly due to the process of identity consolidation over the educational period. Further, DPI consolidates through a lifelong learning process. These results provide an initial insight into the development of DPI and the challenges of measuring this subjective aspect over education.

## Types of people in communal development projects in construction sector: Are they effective together?

**Marika Latvala, Vishal Singh**
Aalto University, Finland

Several issues in the real estate sector require communal development projects, where stakeholders need to self-organize and voluntarily take the responsibilities to realize the goals. The challenge is that such projects remain no one's, but everyone's responsibility. This paper investigates the group dynamics in such projects, focusing on creating a typology of the participants. The findings are part of a larger project that aims to understand who should be part of such projects, and what is needed to realize the desired change. The effective change management for these projects is critical so as to be lean with organization and management of these workshops such that we create more value for participants despite of the limited resources. The research data is collected from six workshops organized by an association of real estate owners in Finland. The research data is analysed using a coding scheme developed on the basis of literature review. Findings reveal five types of people in the workshops: opinionated leaders, empathetic leaders, critics, passive respondents, and listeners. The significance of these findings for management and planning of such projects is discussed.

### Evaluating the influences of heterogeneous combinations of internal/ external factors on product design

**Stefano Filippi, Daniela Barattin**
University of Udine, Italy

Several factors could affect the effectiveness of product design activities. These factors can be internal to the designers like skill, knowledge and personality traits, as well as external like instructions and examples provided. Up to now, researchers and designers in the academic and industrial fields analysed the effects of at most two factors at the same time, always of the same type (internal or external). This paper describes the activities and results of the preliminary stage of a wider research that aims at understanding the relationships among heterogeneous factors (internal and external together) and at defining the best combinations of any number of them to maximize the effectiveness of product design activities. This preliminary stage aims at verifying the possibility of overcoming the limits in the number of the factors to consider as well as in their membership to the same type (internal or external). To implement this verification, some heterogeneous combinations composed by more than two factors are defined and tested. The results of the tests show that the limits can be overcome; this, in turn, allows the wider research to be carried on.

### Exploring human behaviour in design education: Supporting sustainable decision-making with a tabletop activity

**Amanda Willis, Alyssa Wise, Alissa Antle**
Simon Fraser University, Canada

This paper explores the behaviour of learners engaging with a sustainable tabletop activity. Fitting with the theme of Resource-Sensitive Design, this paper takes the viewpoint that the early educational experiences of future designers can shape how they conceive the complex issues of resource scarcity, and therefore design education using technology can support learning and behaviours for sustainable decisions. Videos of twenty pairs of students playing the land planning game "[Blinded]" were qualitatively analyzed using a speech-act theory framework to identify emergent themes on collaboration and decision-making. The findings showed that learners used tools with speech acts in many ways that enhanced collaborative behaviours: 1. advocating for issues using evidence, and 2. sharing values to convince a partner and 3. engaging a non-attentive partner. The implications for design include supporting: informed decision-making, highly visible information, buy-in processes, and encouraging learners to express their values. These findings provide new avenues for exploring spaces for negotiation about the environment and decision-making about difficult trade-offs.

## Break

**3:00 pm – 3:15 pm Level 2**

**THURSDAY, AUG 24**

## D7.8

**2:00 pm – 3:00 pm**
**2506**

CHAIR
*Philip Cash*

# Knowledge Centric Modeling

THURSDAY, AUG 24

D8.1

3:15 pm – 4:15 pm
Performance Theatre

CHAIR
*James Gopsill*

## Concept for a simulation model to analyze knowledge conversions within the product development process

**Alexander Laukemann, Hansgeorg Binz, Daniel Roth**
University of Stuttgart, Germany

Business Process Management (BPM) has been established in industrial environments for decades. In the course of progressive information technology support, the research of BPM benefits from the advantages of digital process modeling and its tools. The results are complex and unclear process models, which should rather increase process transparency and be analyzable. Nevertheless, digital process models remain indispensable, particularly when information and knowledge-intensive processes are to be analyzed. The modeling language "Knowledge Modeling and Description Language" provides different views and objects to establish a valid digital process model. The advantage as well as disadvantage — is the modeling of information flows and knowledge conversions, which are interlinked and complex. The presented concept for a simulation model aims to overcome this contradiction and provide quantitative analyses of digital process models. The analytical results can be compared with existing qualitative analyses and used for a holistic investigation of the simulated process. In this way, target-oriented support from suitable knowledge management solutions can be purposefully compiled.

## A clustering and word similarity based approach for identifying product feature words

**Dedy Suryadi, Harrison Kim**
University of Illinois at Urbana-Champaign, United States of America

Product designers need to capture feedback from customers in order to assess how the product performs and is perceived in the market. One such example of publicly available source of customer's feedback is the online reviews in an e-commerce website. Two main difficulties in dealing with the reviews are finding relevant words related to a product and grouping different words that represent the same product feature. To overcome these difficulties, both lexical and distributional approaches are utilized in the paper. Using distributional information, words are embedded into real vector space using word2vec and then clustered. Using lexical information from WordNet, the head word for each cluster is identified by considering the similarity with the head words of other clusters. A comparison is made between using X-means and iterative c-means clustering with added word similarity information when breaking a cluster. In the case study of wearable technology products, starting from a large number of words, the approach is shown to identify relevant product feature words.

### Supporting development teams in the early stages of product development through DfX-based knowledge management system and communication platform

**Sinan Ugurlu, Detlef Gerhard**
TU Wien, Austria

In the product development, many aspects such as usability, safety, ergonomics, and recycling have to be taken into account. Development companies are required to make more robust and accurate decisions than in the past, as well as simultaneously promoting rapid innovation. In this, knowledge transparency and effectively sharing knowledge within the company are essential factors in reducing uncertainty and redundancy, which in turn can have a significant impact on firm competitiveness. This paper presents a concept, which combines a DfX-based knowledge management system and planned communication platform to assist development teams in more effectively communicating and accessing knowledge throughout the development process. This work considers to organize and access information through the use of key words, and also to retrieve knowledge via queries based on deep learning such as IBM Watson technology. This planned system aims to gather the implicit knowledge of experts and specialists in various areas of expertise based on DfX-aspects, which can later be accessed and used in order to reduce the time demanded for knowledge search and implementation in future development processes.

### Information rich mapping requirement to product architecture through functional system deployment: The Multi Entity Domain Approach

**Dagný Hauksdóttir, Niels Henrik Mortensen**
Technical University of Denmark, Denmark

Successful transformation of design information from customer requirements to design implementation is critical for engineering design. As systems become complex the tracking of how customer requirements are implement becomes difficult. Existing approaches suggest so called domain modelling for mapping requirements to architecture. These approaches do not fully support the steps and information created during product design synthesis. Design Specifications used to guide the design are often documented in text based documents, outside the design models. This results in lack of traceability which may impede the ability to evolve, maintain or reuse systems. In this paper the Multi Entity Domain Approach (MEDA) is presented. The approach combines different design information within the domain views, incorporates both Software and Hardware design and supports iterative requirements definition. The results suggest that it is possible to present design information in structural domain views, presenting more elaborate information of the design synthesis than provided by previous approaches. However, further validation in a practical project setting is required to validate the approach.

# Systems Design for Special Needs

THURSDAY, AUG 24

D8.2

3:15 pm – 4:15 pm
Art Gallery

CHAIR
*P. John Clarkson*

## Design opportunities in mutual support service for the elderly

**Yoonyee Pahk, Joon Sang Baek**
UNIST Ulsan National Institute of Science and Technology, Republic of Korea

As concerns about economic crisis and lack of human resource by rapid ageing population are growing, new models of social support service are required. One of alternatives for enabling sustained well-being life for elderly people is mutual support model. While there are high levels of interest in the research and enthusiasm for the concepts of mutual support in service sector, there are also low levels of awareness, understanding about this specific type of support based on reciprocity. With lack of knowledge, there is an ambiguity in designing or improving mutual support service. In this research, we conducted case studies exploring influential factors on building relation in mutual support service to know about what needs to be considered in designing mutual support service. Even though this research has limitations as preliminary study, the findings from case studies in this research still could be helpful to those who want to design mutual support model for elderly people or improve the relational quality of their service model.

## "Elderpersonas" adapting personas to understand the real needs of elderly people

**Arantxa Gonzalez de Heredia, Daniel Justel, Ion Iriarte, Ganix Lasa**
Mondragon Unibertsitatea, Spain

The population aged 65 and above is the most diverse of the age groups. This diversity is also growing due to longer life expectancy. To provide them with the right assistive products it is crucial to understand the real needs and goals of these new groups of people. The design tools that exist to date work well when designers work with average users. Nevertheless, it is not proved that these tools are effective when working with extreme or special user groups. With this study we aim to review the existing models of "personas" and to adapt it in order to provide designers with more effective inclusive design research tools. As a result of this adaptation, we developed "elderpersonas" which includes an ethical code and a description of the aging development that are necessary to ensure the quality of the research using few resources. We preliminarily tested on the elderly population in the Basque Country by interviewing 36 people aged over 65. Based on the results, we conclude that the "elderpersonas" enabled us to better understand elderly people as well as their needs and goals. In the future the new tool will be applied on design case studies to prove its real value in practice.

## Service design for people with disabilities using context-based activity modelling and international classification of functioning, disability and health

**Myung Joon Lim[1,2], Yong Se Kim[1]**

[1]Sungkyunkwan University, Republic of Korea; [2]National Rehabilitation Center, Republic of Korea

The core of the service is personalization, and personalized should be preceded by an understanding the individual, and the context surrounding the individual. People with disabilities want to use products, and have more services that are just right for him/her. However, since the developer of the product or service is often not the disabled, it is difficult to give insight into the problems of individuals with disabilities. Also, there is a lack of processes and framework in the development of products and services for the disability. Therefore, this paper will propose a framework for service design for people with disability according to Context-Based Activity Modelling (CBAM), Product Service System (PSS) methodology, and International Classification of Functioning, Disability, and Health (ICF) framework. Then the specific process of the kneeling bus for people with disability is explained using the proposed service design framework for people with disability. We hope that this framework for service design for people with disability will become available through much research.

## Sensing behaviour in healthcare design

**Julia Rosemary Thorpe[1], Birgitte Hysse Forchhammer[2], Anja Maier[1]**

[1]Technical University of Denmark, Denmark; [2]Rigshospitalet-Glostrup, Denmark

We are entering an era of distributed healthcare that should fit and respond to individual needs, behaviour and lifestyles. Designing such systems is a challenging task that requires continuous information about human behaviour on a large scale, for which pervasive sensing (e.g. using smartphones and wearables) presents exciting opportunities. While mobile sensing approaches are fuelling research in many areas, their use in engineering design remains limited. In this work, we present a collection of common behavioural measures from literature that can be used for a broad range of applications. We focus specifically on activity and location data that can easily be obtained from smartphones or wearables. We further demonstrate how these are applied in healthcare design using an example from dementia care. Comparing a current and proposed scenario exemplifies how integrating sensor-derived information about user behaviour can support the healthcare design goals of personalisation, adaptability and scalability, while emphasising patient quality of life.

**THURSDAY, AUG 24**

# D8.2

**3:15 pm – 4:15 pm**
**Art Gallery**

CHAIR
*P. John Clarkson*

# Circular Economy

**THURSDAY, AUG 24**

## D8.3

**3:15 pm – 4:15 pm**

**2301**

CHAIR

*Tim McAloone*

### How can design science contribute to a circular economy?

**Daniela Pigosso, Tim McAloone**
Technical University of Denmark, Denmark

Circular Economy is increasingly seen as a key approach to operationalising goals and supporting the transition to a sustainable society by enhancing competitiveness and economic growth. Creating a Circular Economy requires fundamental changes throughout the value chain, from innovation, product design and production processes all the way to end of life, new business models and consumption patterns. This paper explores how design science can support the transition from the traditional linear 'take-make-consume-dispose' approach, to a Circular Economy. By means of a systematic literature review, this paper discusses the role of a set of design topics in this transition.

### An end of life oriented framework to support the transition toward circular economy

**Marco Marconi, Michele Germani**
Università Politecnica delle Marche, Italy

Circular economy is recognized as the most effective economic model to face issues related to waste management and resource scarcity. This requires to efficiently manage the End of Life (EoL) phase, which represents the joining link to close the product lifecycle. The objective of this paper is the definition of a framework to monitor product EoL during the most affecting phases. It is founded on the concept that it is better to prevent issues, by designing optimized products and creating favourable operative conditions, other than solve problems related to EoL. The EoL-oriented framework integrates three innovative resources: (i) a Design for Disassembly Tool to identify product criticalities, (ii) a Disassembly Knowledge Database to support the redesign phase and (iii) a Collaborative EoL platform for the sharing of relevant data and materials. The final aim is to provide companies with a set of integrated methodologies and tools able to support the decision-making process at different levels (from conception to EoL management), in order to design product with improved performances in terms of disassemblability, maintainability, de-manufacturing and EoL.

## A review of key dimensions for designing environment-driven collaboration practices with external business partners

**Raphaëlle Stewart[1], Casper Boks[2], Niki Bey[1]**
[1]Technical University of Denmark, Denmark; [2]Norwegian University of Science and Technology, Norway

Environmental sustainability challenges are of growing interest in the business world and collaboration with external business partners is considered a key means to tackle them. Nevertheless, collaborating with external business partners to develop and deliver greener products and services is not straightforward for companies, and recommendations from academia, as well as industry practices remain scarce. Guidance is needed for designing collaboration practices and their implementation when developing and delivering greener products and services. Pursuing this aim, the present paper reviews environmental management literature fields and extracts indications regarding practices of such collaboration with external business partners. We outline three key dimensions affecting collaboration practices and their implementation and consolidate them in a framework. We suggest that tailored implementation approaches should be based on the clarification of the company's objective for collaboration, the company's organizational profile for collaboration and the company's value network context. As a final point, we derive needs for further research.

## Future-adaptability for energy and resource efficient vehicles

**Thomas Nyström[1], Lisbeth Svengren Holm[2], Patricia van Loon[1]**
[1]RISE, Viktoria Swedish ICT, Sweden; [2]University of Gothenburg, Sweden

In contrast to linear business models, circular business models (CBMs) assign the product value and its lifecycle responsibility to a manufacturer or service provider where customers get access to functionality and performance during multiple use cycles. A CBM requires (due to the increased business risk for product obsolescence) suitable products designed for long service life, changes in service content, repair, upgrades and remanufacturing. This paper illustrates drivers that can make three categories of vehicles obsolete in a circular business model. We propose a conceptual framework where drivers for obsolescence are used as enablers for future adaptable design, exemplified with industry cases. Future adaptable vehicles have the potential to be both profitable and energy and resource efficient during use and in end of life in a CBM. However, it will challenge today´s business models with a design logic that rewards longer and more flexible product life. Current barriers are legislation, standards and certification, and consumer acceptance. Besides organizations barriers and a general reluctance to changes.

**THURSDAY, AUG 24**

# D8.3

**3:15 pm – 4:15 pm**
**2301**

CHAIR
*Tim McAloone*

# Engineering Change Management – Costing

THURSDAY, AUG 24

D8.4

3:15 pm – 4:15 pm
2306/2309

CHAIR
*David Wynn*

## Predicting indirect process costs of engineering change based on a task characteristic perspective

**Marcel Gebhardt**
IPRI International Performance Research Institute, Germany

Today companies are capable to make precise predictions of engineering change costs incurred in producing departments. But implementing engineering changes is a work-sharing task. Besides production and assembly also non-producing departments are involved in engineering change management (ECM) processes. Activities performed in those departments lead to indirect process costs of engineering change (IPC). These costs result from planning, coordinating and supervising activities in ECM-processes and make up a huge share of total project costs. Today, there are no valid methods for estimating IPC. In practice, IPC are predominantly estimated on the basis of overhead rates. However, this does not lead to satisfying results. Hence, there is no transparency regarding IPC and IPC are frequently not considered in project calculations which may result in inadequate pricing decisions. In this connection particular attention must be paid to IPC. Therefore, we develop a model for predicting IPC in order to improve information and support managerial decisions.

## Predicting and visualizing cost propagation due to engineering design changes

**Alex Georgiades[1], Sanjiv Sharma[2], Timoleon Kipouros[1,3], Mark Savill[1]**
[1]Cranfield University, United Kingdom; [2]Airbus, United Kingdom; [3]University of Cambridge, United Kingdom

During product development changes in the initial design are ubiquitous. The ability to predict such changes, along with the expected costs, is a challenge on its own. This challenge increases exponentially when a single design change on one element of the system propagates to other components. As change propagates, so does the cost associated with it; where cost is more than just financial. A number of knowledge-based methods have been developed in the past that assist in the prediction of how change propagates through a system, and the impact that it can have on other components. None of the methods developed, however, considers how cost propagates due to design changes. This paper presents a novel methodology for predicting, visualizing, and assessing the propagation of change and the cost associated with it. As part of the methodology, a new method, CP2, has been developed to calculate the propagated costs. The methodology has been applied to a conceptual example of a simple system to demonstrate the procedure and the use of the methods. The visualization of the results arising from this methodology is also demonstrated as a mechanism for design decision-making.

## Assessment of changes in engineering design using change propagation cost analysis

**Eric Rebentisch[1], Günther Schuh[2], Michael Riesener[2], Stefan Breunig[2], Ferdinand Hoensbroech[2]**

[1]Massachusetts Institute of Technology, United States of America; [2]RWTH Aachen, Germany

Due to diverse customer demands, volatile markets, and dynamics in technology and innovation, the potential for engineering changes has significantly risen in product development projects as well as over the product lifecycle in recent years. Engineering changes can often lead to undesired change propagation effects. Thus, projects may overrun in both costs and schedule. Therefore, it is desirable to be able to predict the change impact caused by an engineering change and to estimate the cost impact on both product and production. This paper will present a multilayer network model to operationalize the dependencies among product requirements, product elements and production processes. Based on this, a change propagation analysis is presented. Initially, alternative technical solutions are generated to fulfill a specific change request. The change impact on both product and production is determined for each alternative. To identify the most cost-effective solution, the overall change costs of each alternative are calculated. Finally, the method is applied to the example of an asynchronous motor design to demonstrate the model's practical utility.

## Expert based approach to analyse and influence indirect cost of engineering changes

**Christian Schmied[1], Marcel Gebhardt[2], Markus Mörtl[1], Udo Lindemann[1]**

[1]Technical University of Munich, Germany; [2]IPRI International Performance Research Institute, Germany

Indirect cost of engineering changes represent increasing challenges for companies. Their high frequency and complex cost impacts makes it difficult to estimate and influence the cost outcomes. Currently direct cost (eg. changed material) are well mastered in industry, but indirect cost (e.g. engineering design, administration, testing, procurement) are not yet supported sufficiently. Early knowledge of amounts and effective measures to influence indirect costs can be crucial for the economic result on the market. Hence, fast and easy prediction and influence methods are needed in practice. The article describes an application-oriented approach to analyze systems behaviour of indirect cost based on expert estimation and weighted influence matrices. As multiple domains within the company at different times involve during change process, a flexible, customizable and open model structure is proposed for solution. This enables to represent the characteristics of company individual and change case-specific indirect costs. We also present a corresponding approach for company-specific derivation and application of indirect cost reduction measures.

**THURSDAY, AUG 24**

# D8.4

**3:15 pm – 4:15 pm**
**2306/2309**

CHAIR
*David Wynn*

# Computational Methods for Engineering Applications

THURSDAY, AUG 24

D8.5

3:15 pm – 4:15 pm

2311

CHAIR

*Pedro Parraguez Ruiz*

## Graph-based similarity analysis of BOM data to identify unnecessary inner product variance

**Michael Schmidt[1], Benedikt Gehring[1], Jan-Sebastian Gerber[1], Johannes Michael Stocker[1], Matthias Kreimeyer[2], Markus Lienkamp[1]**

[1]Technical University of Munich, Germany; [2]MAN Truck & Bus AG, Germany

This paper contributes to the fields of variant management and product family design. The focus lies on analysing historically grown product portfolios in order to reduce unnecessary inner variety. Such inner variety adds no value to the customer, yet it induces complexity costs within the whole company. Increasing transparency in documented product variants is key when applying standardisation or modularisation methods as part of variant management. Studies of literature and industrial practice at a major German truck manufacturer show that analysing product structure information from BOM data yields the potential to point out promising candidates in companies' portfolios for effective standardization or modularisation. For modelling and analysing highly variant and complex product structures, we employ graph-based modelling of BOM data in combination with a state-of-the-art tree matching algorithm for similarity calculations. Actual product data of a truck manufacturer serves as a case study. Thereby, we propose a generally applicable approach that enables intuitive handling of large amounts of product family data and that effectively supports variety reduction efforts.

## Engineering of assembly systems using graph-based design languages

**Theresa Breckle[1], Jens Kiefer[1], Stephan Rudolph[2], Martin Manns[3]**

[1]Ulm University of Applied Sciences, Germany; [2]University of Stuttgart, Germany; [3]The University of Siegen, Germany

Car Manufacturers are subject to continuous and fundamental changes. Already today increasing time pressure, rising complexity and a soaring cost pressure require a shorter time to market. As assembly planning is one of car manufacturers' core competence an innovative approach to adapt the processes is needed. This paper presents the early idea of a novel approach for an automated design process covering the early design phase of assembly systems. Integrating various input data as well as requirements leads to a are a base for this approach for designing an assembly system. Uncertain input data, which are fact within early planning phases, need to be considered in order to reach a holistic planning alternatives for evaluation, optimization and afterwards decision-making. With so-called graph-based design languages an automated and efficient design process will be implemented. This leads to a faster designing process in order to reduce planning time and planning costs and reach resilient and sustainable decisions.

## Digital representation of product functions in multicopter design

**Manuel Ramsaier[1], Kevin Holder[1], Andreas Zech[1], Ralf Stetter[1], Stephan Rudolph[2], Markus Till[1]**

[1]University of Applied Sciences Ravensburg-Weingarten, Germany;
[2]University of Stuttgart, Germany

In recent years the research concerning the representation of product functions has intensified again. Current studies exhibit a growing interest of design engineers to apply such representations in their daily practice. Simultaneously, a growing interest concerning graph-based methods for the digital representation of product models and the product logic in general can be observed. This paper seeks to combine these two research directions and to present a promising attempt to allow a sensible representation of product functions within a digital engineering framework based on graph based design languages. The main motivation for this research is to look for powerful methods and tools to overcome the limitations which result from the multitude of software tools along the product life cycle and heterogeneous data formats which are present in industrial companies and hinder integrated product development. This research seeks to expand the applicability of graph-based design languages into the domain of product functions. A rather simple product — a multicopter — is used as a basis for explanation and discussion.

## Generic approach to plausibility checks for structural mechanics with deep learning

**Tobias Spruegel, Tina Schröppel, Sandro Wartzack**

Friedrich-Alexander-University Erlangen-Nuremberg, Germany

The simulation of product behavior is a vital part in virtual product development, but currently there is no tool or method available that can examine the quality of FE simulations and decide automatically on whether a simulation is plausible or non-plausible. In the paper a method is presented that enables automatic plausibility checks on basis of empirical simulation datasets. Nodal simulation data is transformed to numerical arrays, of fixed size, using virtual spherical detector surfaces. Afterwards the arrays are used to train a Deep Convolutional Neural Network (AlexNet). The Neural Network can then be used for plausibility checks of FE simulations (structural mechanics). In a first application a Deep Convolutional Neural Network is trained with simulation data of a demonstrator part, the rail of speed inline skates. After the GPU training of the Neural Network, further simulations are evaluated with the net. These simulations were not part of the training data and are used to calculate the prediction quality of the Neural Network. This approach is to support development engineers during design accompanying FEA in virtual product development.

**THURSDAY, AUG 24**

# D8.5

**3:15 pm – 4:15 pm**

**2311**

CHAIR

*Pedro Parraguez Ruiz*

# Robust Design 2

THURSDAY, AUG 24

D8.6

3:15 pm – 4:15 pm

2314

CHAIR

*Tobias Eifler*

## Design procedures in the development of an electromagnetic manipulator

**Mohammad Al Mashagbeh, Thamir Al-Dulaimi, Mir Behrad Khamesee**
University of Waterloo, Canada

This paper addresses the conceptual design of and optimal dimensions for building a portable 3-DOF (Degree of Freedom) electromagnetic finger manipulator that can be used for many industrial applications. The overall design procedures are subdivided into the conceptual design, actuator design, configuration design, mechanical design, workspace design and the parametric design. The design procedures are developed based on a morphological chart, which combines the different functions used in the design. This chart allows us to select the best solution to satisfy our goals and objectives. We chose the electromagnetic actuation method to drive the manipulator. The manipulator workspace is 4 cm in the X and Z axes and the maximum swivelling angle in both axes is 30 degrees. The optimal dimensions of the electromagnetic coil are calculated. The magnetic force at 1 cm axial gap and 1 A excitation current is 8 N. This force can generate a 3 N force at the manipulator end-effector based on the manipulator dynamic model. The magnetic force versus the axial distance and versus the excitation current is calculated analytically and simulated using Finite element Methods.

## Design for robustness – Systematic application of design guidelines to control uncertainty

**Tillmann Freund, Jan Würtenberger, Julian Lotz, Carmen Rommel, Eckhard Kirchner**
Technische Universität Darmstadt, Germany

In Robust Design literature, the application of Robust Design guidelines is suggested as a measure to obtain a design that is more insensitive against variations. But it lacks a detailed and systematic overview of already existing design advice that can be transferred to robust design tasks. The authors provide a literature investigation of design advice in engineering design literature, derive criteria to assess its applicability for robust design tasks based on transfer functions and noise behaviour models. The research shows that almost half of the existing design advice is also suitable for robust design. To include the design advice catalogues into the development process, the authors suggest a procedure that is allocated within the integrated product and process development process. It consists of opportunistic analysis and synthesis steps and should be applied up from working principle level. To quantify the potential of robust design advice application, the robustness potential indicator is introduced. It represents the degree of robust design advice consideration.

## Empirical study of ill-supported activities in variation risk identification and assessment in early stage product development

**Kristian Bjarklev[1], Niels Henrik Mortensen[1], Martin Ebro[2]**
[1]Technical University of Denmark, Denmark; [2]Novo Nordisk A/S, Denmark

The purpose of this paper is to present findings from an industrial case study about the support of activities related to identifying and assessing variation-related issues in the design during the concept- and embodiment design stages. The case study investigates a large world-leading mechanical medical device company by interviewing six key employees that work in the variation risk identification and assessment process. It is found that there are several ill-supported activities, and that the project teams rely heavily on tolerance experts' assistance and experience in order to identify and assess the variation risk. Ill-supported activities are found to be: Balancing hardness of requirements and the screening; communicating mechanism understanding; predicting user input and internal component movement; documenting and communicating tolerance analysis; implementing robustness in the early definition of the projects; and implementing statistical information in the calculations. It is suggested these areas should be supported further.

## Identifying variability key characteristics for automation design – A case study of finishing process

**Angel Sanchez-Salas[1], Yee Mey Goh[2], Keith Case[2]**
[1]University of Toronto, Canada; [2]Loughborough University, United Kingdom

This paper describes an investigation of human interaction with process variability (i.e. variability not introduced by the humans themselves) in a manual manufacturing process. The process studied is grinding-polishing of high-value metal components, to evaluate the extent of the variability and how the operators applied their skills to overcome it. The research methods include analysis of documentation, observation and video recording and interviews. The results indicate that humans are able to adapt to variability in the parts and tools in order to deliver the product within specification. This suggests unconscious and automated behaviour meaning that the procedures executed are embedded in the minds of the operators. Vision and tactile senses were mainly used to check work progress and control critical features (Key Characteristics). Based on the findings of this and other case study, a framework will be developed to categorise variability in manual manufacturing processes to support the design of an automated solution.

**THURSDAY, AUG 24**

# D8.6

**3:15 pm – 4:15 pm**
**2314**

CHAIR
*Tobias Eifler*

# Design Learning

THURSDAY, AUG 24

D8.7

3:15 pm – 4:15 pm

2504

CHAIR

*Petra Badke-Schaub*

## Underlying design motivations in design methods and outcomes

**Cameron Turner, Malena Agyemang**
Clemson University, United States of America

Design teams approach design problems with a set of explicit requirements derived from the problem, but also bring a number of implicit design requirements to the problem through the culture within which they work. We hypothesized that these influences affect how design teams approach design problems, and in particular, how teams define requirements and apply analogies to develop their designs. In this paper, we used a multi-section senior design course to place teams working on similar design projects for real customers in a situation where they were subjected to a cultural bias between a Design for Manufacture and Assembly culture versus a Design for Environment culture by the instructors of each section. During the class, the emergence of design requirements related to these biases were noted during design reviews. End of semester surveys further measured the perceived student significance of these cultural differences, as well as differences in how students used design analogies throughout their design projects. Based on the data collected, differences in design culture affect the design process and methods used by the design teams.

## The practical side of engineering design

**Paul Martin Winkelman**
The University of British Columbia, Canada

In the minds of many, including engineers themselves, engineers are considered to be "practical". But what is "practical" and what values does it promote? Building on a simple search in engineering design literature, "practical" is shown to represent five values: ethical (consideration of needs and a call to action), non-cognitive (knowledge which is difficult to articulate), real (vs contrived, such as the world of education), deliberation (stressing the importance of context and the difficulty of choosing the best solution) and alignment (seeking a short, direct pathway from problem to solution based on what has gone before). The problem with alignment is that it necessarily leaves things out and, if politics and history are left out, engineers will likely find themselves working on projects in keeping with historical trends and dominant political values. And these values may not coincide with their own.

### Blow Bits: Creative playgrounds, gamification and virtuosity with hybrid design tools and environments (HDTE)

**Robert Wendrich**
University of Twente, The Netherlands

Playgrounds (real or virtual) are universal areas where most people learn to play, interact, engage, immerse to unlearn and relearn repeatedly in order to get more fundamental understanding and insights on their creativity, communication and collaboration patterns with others. Consequently, finding out more about oneself in the process. This paper connects research and development of hybrid design tool environments with play, gaming, and gamification strategies and methods for application in multiple domains. We present a playful tool, game environment and preliminary case study from our ongoing research and experimentation in hybrid design tools and environments (HDTE).

### Prototypical product shapes as a tool for aesthetic product design

**Jorge Maya, Daniel Betancur-Rodríguez**
Universidad EAFIT, Colombia

The use of prototypical product shapes allows to structure and support the intuitive aesthetic design process. Prototypicality, a cognitive variable, is the extent to which an object represents a category: it shapes our aesthetic feelings with products, affects usability, makes up the products' look, and affects products' aesthetic evaluations and preferences. A mental prototype is a category's central element. We all have artifacts' prototypical information, however, designers are not aware and do not use it explicitly. These concepts have seldom been applied in design. Consequently, we explored how to use prototypical shapes for the aesthetic design process. 1. We proposed vectorising and interpolating 32 hand drawn Pepper Mills, PMs, to get the prototypical shape. In 2, we found the most innovative, original and typical PMs (n=74, 20 PMs). 3. We then used rules to explore aesthetic design possibilities and to transfer attributes to the prototypical PM shape. PMs' aesthetics, usability, and design pedagogy issues are discussed. We suggest a structured simple way to design the product's aesthetic for non-expert designers and applicable to other aesthetic cognitive variables.

**THURSDAY, AUG 24**

## D8.7

**3:15 pm – 4:15 pm**
**2504**

CHAIR
*Petra Badke-Schaub*

# Effective Design in Industry

THURSDAY, AUG 24

D8.8

3:15 pm – 4:15 pm
2506

CHAIR
*Albert Albers*

## A decade trend of utilization of design tools and methods in Japanese product industries

**Yutaka Nomaguchi, Masashi Takami, Anna Sakaguchi, Kikuo Fujita**
Osaka University, Japan

Researchers in the design engineering domain have devoted to develop various tools and methods which support new product development activities. However, there are less research works surveying their utilization in industries, and few works focusing on its trend during a certain period. This research aims at clarifying how much design tools and methods have been utilized in Japanese industries in the last decade, and what factors promote or disturb their effective utilization. First, this paper reports a questionnaire survey performed in 2014 on utilization of various tools and methods in product development process of Japanese manufacturing industries. Its results are compared with those of Japanese survey carried out in 2002. Three metrics are set to evaluate the utilization: awareness, usage and effectiveness. The analysis of the questionnaire survey can roughly reveal some trends of the utilization. In addition, this research carries out the interview to analyze the detailed situations. Analysis of the changes of the three metrics during the decade and the interviews reveal factors behind those trends.

## Holistic approach for design and re-design of production units

**Markus Stäbler[1], Jakob Weber[1], Kristin Paetzold[2], Michael Vielhaber[3]**
[1]Daimler AG, Germany; [2]Universität der Bundeswehr München, Germany;
[3]Saarland University, Germany

This paper presents a novel approach to enable change within the life cycle of a production unit and enhance the usability of a re-design and change process by consistent interaction between the design and evaluation method. The method, based on Axiomatic Design, is used to find a design solution for a changeable production unit in a structured way. In a later phase of the life cycle the corresponding evaluation method gives a result which results in the need for parts of the previously designed production unit to be adjusted in order to improve the changeability of the entire system. The paper demonstrates a significant improvement in usability by combining design and evaluation process. In addition, the holistic approach is validated and explained by an use case of the automotive industry.

### A concept and prototype for a new app to support collaborative and multi- criteria decision making in product development

**Thomas Luft, Simon Rupprecht, Sandro Wartzack**
Friedrich-Alexander-University Erlangen-Nuremberg, Germany

As products become increasingly complex, product developers have to make decisions effectively and efficiently. Therefore, the long term goal of the authors is the development of a new app to support collaborative and multi-criteria decision making in product development. For this, the basic requirements of such a new app are presented. Based on this, the methodological concept and procedure are briefly explained. Afterwards, a first prototype of the app with the core functionalities and the user interface is presented. Finally, this prototype is applied and evaluated by an example. In the future, the authors aim to improve the concept and to integrate further functionalities by implementing the presented concept as a real smartphone app.

### Pattern recognition for the integration of mechanical simulations in product development workflows

**Sebastian Schweigert, Martin Schöner, Udo Lindemann**
Technical University of Munich, Germany

The emergence of computer-aided systems and especially numerical methods has revolutionized the product development process. Several types of simulations and calculations during the process are nowadays state of the art. In order to manage the mass of resulting data, simulation data management systems have evolved and spread across specific branches dealing with the interaction of design and simulation departments. In this paper, together with workflows from the development process of an industry partner in SIPOC and BPMN, development tasks are separated according to their department — design or simulation — in order to show the interaction along a process. As a result, three different patterns are recognized within the generated depictions: capsuled patterns, integrated patterns, and outside patterns. Specific behaviour towards simulation data management issues and particularly simulation requests can be stated for each of them. Consequently, this approach can support the implementation process of a simulation data management system by selecting suitable forms of simulation requests according to the workflow.

**THURSDAY, AUG 24**

## D8.8

**3:15 pm – 4:15 pm**
**2506**

CHAIR
*Albert Albers*

# Dr. M.G.(Ron) Britton

## P.Eng., FCAE, FEC, 3M Teaching Fellow

**Biography:** Born in Regina and raised in Lang, Saskatchewan Ron obtained his B. Sc. in Civil Engineering from the University of Saskatchewan, M.Sc. in Agricultural Engineering from University of Manitoba and Ph.D. in Agricultural Engineering from Texas A&M University. Ron spent five years working in industry between his B.Sc. and his M.Sc. His work took him from Winnipeg to London, England and Toronto. During that time he concentrated on the design of buildings, with an emphasis on wood, and ultimately focusing on agricultural buildings. Ron has held academic appointments at both Texas A&M and the University of Manitoba. In 2001 he was awarded a Natural Sciences and Engineering Research Council Chair in Design Engineering, a position he held for 10 years. During that time he was instrumental in the establishment of the Internationally Educated Engineer Qualification program, and the creation of a faculty-wide emphasis on design education.

Professionally, he is a member and past President of Engineers Geoscientists Manitoba, and served on the Board of Directors of the Canadian Council of Professional Engineers. He is a Fellow and past President of the Canadian Society of Bioengineering, an honorary lifetime member of the Society for Teaching and Learning in Higher Education, and a member of numerous other technical and education related societies. Ron is a 3M Teaching Fellow and has received a number of other awards including the CCPE Medal of Distinction in Engineering Education, the CSBE Maple Leaf Award, the APEGM Merit Award and Outstanding Service Award and the University of Manitoba Dr. & Mrs. H.H. Saunderson Award for Excellence in Teaching, the Dr. & Mrs. D.R. Campbell Outreach Award and the Champion of Engineering Education award.

At home, Ron is a proud father and grandfather, and a sometimes obsessive baseball fan.

**THURSDAY, AUG 24**

**4:30 pm – 5:15 pm**
**Great Hall & Foyer**

CHAIR
*Michael Kokkolaras*

# Sitting in a Design Chair – Reflections on the NSERC Chairs in Design Engineering Program

At the beginning of the 21st century, the Natural Sciences and Engineering Research Council of Canada announced an innovative new funding program entitled Chairs in Design Engineering. The purpose of the program was, and still is, “to improve the level and quality of design engineering activity within Canadian universities.”

Dr. Tom Brzustowski, then President of NSERC, and the creative force behind the program, saw this as a means of countering the research focus that had come to dominate most Engineering programs in Canada.

In the NSERC literature Design Engineering is defined as "an enabler of innovation". "It is the activity that creates the concepts and designs, and develops the new and improved products, processes and technologies…" It "integrates mathematics, basic sciences, engineering sciences and complementary studies in developing elements, systems and processes to meet specific needs. It is a creative, iterative and often open-ended process subject to constraints which may be governed by standards or legislation to varying degrees depending upon the discipline." The goal of the CDE program is to educate engineering students in a manner that enables them to feel comfortable in this sort of work environment. Ultimately NSERC intends to maintain 16 concurrent CDEs across Canada to assure a continuing, and growing, population of institutions with a focus on design engineering education.

The program is not formulaic. In general it is objective driven, much like a design problem. There are expectations that must be met, but again, these are little more than design constraints. There is a specific requirement to "increase the design engineering capacity of the university by creating additional design-engineering-related positions". This seem to be reasonable given that changes in a curriculum require people who can deliver those changes.

In 2001 the first Chairs in Design Engineering were awarded to five persons at universities across Canada. Ron Britton was one of those five persons. His Chair was renewed in 2006 for a further five years.

Ron's presentation will reflect on his experience with the CDE program in general, and the Manitoba program in particular.

**THURSDAY, AUG 24**

**4:30 pm – 5:15 pm**
**Great Hall & Foyer**

CHAIR
*Michael Kokkolaras*

THURSDAY, AUG 24

## Closing Session

**5:15 pm – 6:00 pm Great Hall & Foyer**

**Michael Kokkolaras**
Introduction of the Keynote Speaker

**Ron Britton**
Closing Keynote Speaker

**Anja Maier**
Programme Committee Chair

**Mike Van der Loos**
Conference Chair

**To be determined at the Design Society General Meeting**
Incoming Design Society President

**Introduction of the ICED19 Program and Organising Committee Chairs and Announcement of Venue and Dates**

**Close of the Conference**

## Farewell

**6:00 pm – 8:30 pm Great Hall & Foyer**

This is your last chance to visit with friends and colleagues before heading home.

# UBC Lab Tours

**09:00 CARIS Lab.** *Human-robot interaction design.*
The Collaborative Advanced Robotics and Intelligent Systems (CARIS) Lab focuses on research related to cooperative robotics in both industrial applications and assistive applications in workplace, home and healthcare environments. In this tour, we will demonstrate a Stewart platform robot used for human balance research, a humanoid robot programmed to exhibit human-like behaviours in object handling tasks, and an augmented-reality system for intuitive robot programming in industrial settings.

**10:00 SPIN/MUX Lab.** *Multi-modal and haptic design.*
The SPIN (Sensory Perception and Interaction) Lab conducts interdisciplinary research with the goal of designing and building innovative physical, touch-based user interactions to solve real problems for real people. For example, we are looking into applications such as wearables/clothing, mobile devices, and robots for assisting in domains such as touch based therapy, and dealing with sensorially overloaded environments. The MUX (multimodal user experience) Lab is involved in research such as personalizable user interfaces and technologies to support interactions for older users. Visitors will be able to see demos regarding our affective robot project (Cuddlebot).

**11:00 HATCH.** *Incubator space for start-ups.*
HATCH is UBC's on-campus incubator for UBC technology ventures that are at the stage of developing their products and launching their businesses. As UBC's tech incubator, HATCH helps promising entrepreneurs develop their research at a pace determined by the technology itself. HATCH gives entrepreneurs the realistic, comprehensive support they need to address the world's challenges and launch their ventures.

**FRIDAY, AUG 25**

**11:30 Lunch in ICICS**

# Off-site Industry Tours

**12:00 pm – 6:00 pm | A bus will be arranged.**

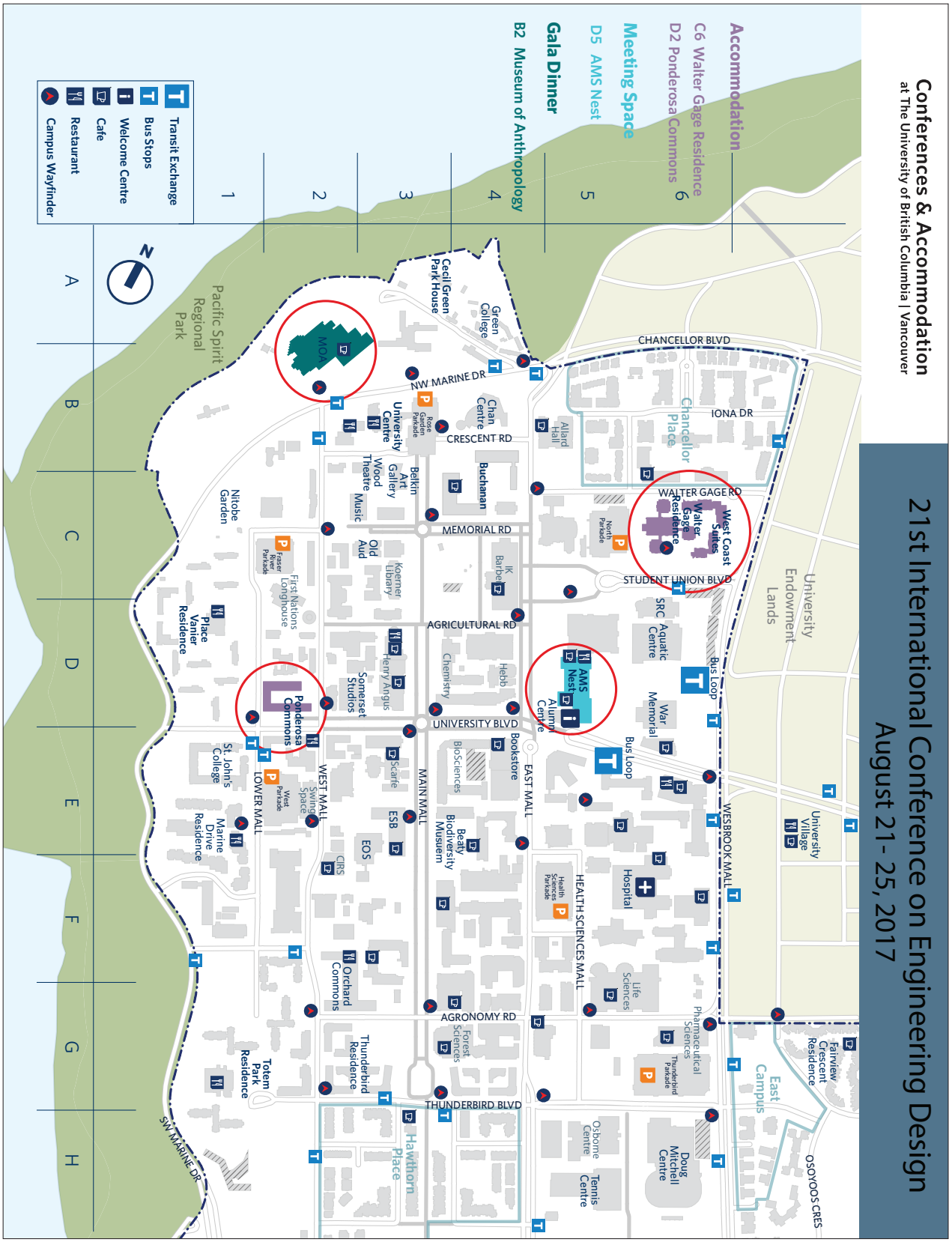
**MistyWest** – *Product design consultancy company*
MistyWest is an engineering design consultancy that blends equal parts deep technical knowledge, creative fervour, aesthetics, experience, and the tools of our craft to serve our clients. We take ideas for complex products from napkin sketch to full production. We work across verticals such as medical diagnostics, education, sustainable energy and transportation. On this tour, one of the founders, Josh Usher, and his colleagues will explain the company's design philosophy and provide examples of designs that have resulted from the application of that philosophy to solve clients' "hard problems" and have led to innovative, patented designs at scale.

MistyWest

**Stantec** – *architectural and engineering design*
From the iconic welcome at Vancouver International Airport to the brightly lit fabric of BC Place Stadium, you can see how Stantec has shaped our community. We unite approximately 22,000 employees working in over 400 locations across 6 continents. Our work—engineering, architecture, interior design, landscape architecture, surveying, environmental sciences, construction services, project management, and project economics, from initial project concept and planning through to design, construction, commissioning, maintenance, decommissioning, and remediation—begins at the intersection of community, creativity, and client relationships. Come tour our Vancouver office to hear more about our innovative people and projects.

Stantec

# CAMPUS MAP


Conferences & Accommodation
at The University of British Columbia | Vancouver
21st International Conference on Engineering Design
August 21- 25, 2017
Accommodation
C6 Walter Gage Residence
D2 Ponderosa Commons
Meeting Space
D5 AMS Nest
Gala Dinner
B2 Museum of Anthropology
Transit Exchange
Bus Stops
Welcome Centre
Cafe
Restaurant
Campus Wayfinder
Pacific Spirit Regional Park
University Endowment Lands
CHANCELLOR BLVD
NW MARINE DR
IONA DR
CRESCENT RD
WALTER GAGE RD
MEMORIAL RD
STUDENT UNION BLVD
AGRICULTURAL RD
UNIVERSITY BLVD
AGRONOMY RD
THUNDERBIRD BLVD
SW MARINE DR
WESBROOK MALL
EAST MALL
MAIN MALL
WEST MALL
LOWER MALL
HEALTH SCIENCES MALL
OSOYOOS CRES
MOA
Cecil Green Park House
Green College
Chan Centre
University Centre
Rose Garden Parkade
Allard Hall
Chancellor Place
West Coast Suites
Walter Gage Residence
North Parkade
Buchanan
Belkin Art Gallery
Wood Theatre Music
Nitobe Garden
Old Aud
Koerner Library
Fraser Parkade
First Nations Longhouse
IK Barber
Place Vanier Residence
Henry Angus
Somerset Studios
Chemistry
Hebb
AMS Nest
Alumni Centre
SRC Aquatic Centre
War Memorial
Bus Loop
Bookstore
BioSciences
Scarfe
ESB
Beaty Biodiversity Museum
Ponderosa Commons
St. John's College
West Parkade
Swing Space
Marine Drive Residence
CIRS
EOS
Forest Sciences
Orchard Commons
Thunderbird Residence
Totem Park Residence
Hawthorn Place
Health Sciences Parkade
Hospital
Life Sciences
Pharmaceutical Sciences
Thunderbird Parkade
Osborne Centre
Tennis Centre
Doug Mitchell Centre
University Village
Fairview Crescent Residence
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# CONFERENCE AREA

**Registration/Information Desk Hours**
***Sunday, August 20***
3:00 – 7:00 pm Gage Towers, Fort Camp

***Monday, August 21***
8:00 am – 8:00 pm The Nest, Level 1
***Tuesday, August 22***
8:00 am – 7:00 pm The Nest, Level 1

***Wednesday, August 23***
8:00 am – 1:00 pm The Nest, Level 1

***Thursday, August 24***
8:00 am – 1:00 pm The Nest, Level 1

**Conference Venues**
All of the ICED17 conference venues are located on the University of British Columbia campus. The Sessions, Workshops, Design Society Events, and most of the Special- and Social Events of the conference will take place in the newly constructed AMS Nest (6133 University Blvd, Vancouver, BC). The Gala Dinner will take place at the stunning Museum of Anthropology.

Please refer to pages 284–285 for maps.

**Name Badge**
Admission to all conference activities are by name badge only, please be sure to wear your badge at all times.

**Conference Catering**
Coffee breaks and lunches for conference attendees will be held in the Nest.

**Responsibility**
The Organizing Committee assumes no responsibility for accident, losses, damage, delays, or any modifications to the program arising from unforeseen circumstances. It accepts no responsibility for travel or accommodation arrangements.

The participant acknowledges that he or she has no right to lodge damage claims against the Organizing Committee should the conference proceedings be hindered or prevented by unexpected political or economic events or generally by acts of God, or should the non-appearance of speakers or other reasons necessitate program changes.

**Internet Access**
Wireless internet access is available in most buildings and outdoor spaces on campus by choosing the "ubcvisitor" network from your wireless options. Additional internet stations are available at any UBC library.

**On-Campus Accommodation**
*Walter Gage Residence & the West Coast Suites* – 5959 Student Union Boulevard

*Ponderosa Commons* – 2075 West Mall

All residences are open 24 hours per day, 7 days per week. Check-in is from 3:00pm and check-out is by 11:00am.

For more information, please contact the front desks through the Conferences and Accommodation Reservations Office at 604-822-1000 or toll free at 1-888-822-1030.

**Banking and Foreign Exchange**
There are four banks located on campus, providing banking and exchange facilities. Times listed are subject to change.

Three banks are located in the University Village:

*Bank of Montreal*
Monday – Friday: 10:00am – 5:00pm

*Canadian Imperial Bank of Commerce*
Monday – Tuesday: 9:00am – 5:00pm
Wednesday – Friday: 9:00am – 7:00pm
Saturday: 9:00am – 4:00pm

*Scotiabank*
Monday – Wednesday: 9:30am – 5:00pm
Thursday: 9:30am – 6:00pm
Friday: 9:30am – 5:00pm
Saturday: 9:00am – 4:00pm

One bank is located in Wesbrook Village:
*RBC Royal Bank*
Monday – Thursday: 9:30am – 7:00pm
Friday: 9:30am – 6:00pm
Saturday: 9:00am – 4:00pm

Automated teller machines are available in all banks, in the lobby of Walter Gage Residence, and in the Nest.

**Taxis**
Taxis are available in front of the Walter Gage Residence, or by calling 604-681-1111. Fare to the airport or downtown is about $35 – $40 CAD.

**Public Transit**
The new Translink (Vancouver's public transit system) UBC Bus Exchange, located off Wesbrook Mall at University Boulevard, will partially open for drop-offs only. This means that all transit riders will board on Wesbrook Mall when leaving campus, and arrive in the new UBC Bus Exchange.

Bus routes affected are the 99 B-Line, 25, 33, 41, 43, 49 and 480. These routes are being relocated until construction of the new UBC Bus Exchange and Gage South Student Residence is completed in Summer 2019.

Translink's Compass Card is a reloadable fare card that works everywhere on transit in Metro Vancouver. You can load fare products onto one card and tap your way across the system. If you do not have a Compass Card, you can **pay cash on a bus (exact change only)** to get a bus transfer ticket. You can use your bus transfer for 90 minutes, but you'll need a Compass Card or Compass Ticket to transfer to SkyTrain, SeaBus or West Coast Express. Buses require exact change ($2.85 for a One Zone fare within Vancouver, valid 90 minutes).

Compass cards can be purchased on campus at the UBC Bookstores, at the Shoppers Drug Mart in University Village and at Save-on-Foods in Wesbrook Village. For more information on bus fares and schedules, visit www.translink.bc.ca

**Childcare**
Osprey Child Care is located in The Nest. The hours of operation are Monday – Friday 7:30 – 18:30, and Saturday 9:30am – 16:30. Child care services are available for $20 per hour, with light snack provided in morning and afternoon. For more information on the service and how to register, please go to http://iced17.org/child-care-at-ubc/.

**Campus Safety**
Campus security can be reached at 604-822-2222 in an emergency, otherwise at 604-822-8609 for non-emergencies. There are also blue light phones located on campus, which provide a direct connection to security for emergency situations or general assistance.

**Emergency Telephone Numbers**
Emergency – fire, police, and ambulance: 911
Police (RCMP) non-emergency line: 604-224-1322

**Emergency Medical Care**
Urgent Care Centre at UBC Hospital
Open daily from 8:00am to 10:00pm
Phone: 604-822-7121 or 911
Address: 2211 Wesbrook Mall

**Insurance**
Liability insurance is the responsibility of each individual delegate. Visitors are not covered by the Canadian Medical Health Insurance Plan. Delegates should have their own medical coverage.

**Walk-In Clinic**
*University Village Medical*
Phone: 604-222-2273
Address: 228-2155 Allison Road
(upstairs from Staples)
Monday to Friday 8:00am to 6:00pm
Saturday 10:00am – 4:00 pm
Hours are subject to change based on doctor availability, please call the clinic to check their current hours

*Careville Medical Clinic & Pharmacy*
Phone: 604-259-7744
Address: 3317 Wesbrook Mall
Monday – Friday 9:00am – 5:00pm

**On Campus Pharmacies**
*University Pharmacy IDA*
Phone: 604-224-3202
Address: 5754 University Blvd.
Monday – Friday, 9:00am – 8:00pm
Saturday – Sunday, 10:00am – 6:00pm

*Shoppers Drug Mart*
Phone: 604 228-1533
Address: 5940 University Blvd.
Monday – Sunday 8:00am to 10:00pm

*Save-on-Foods Pharmacy*
Address: 5945 Berton Ave.
Monday – Friday 9:00am – 9:00pm
Saturday – Sunday 10:00am – 6:00pm

*Careville Medical Clinic & Pharmacy*
Address: 3317 Wesbrook Mall
Monday – Friday 9:00am – 6:00pm
Saturday 10:00am – 2:00pm

**Lost and Found**
All materials lost or found in academic buildings are brought to the Lost and Found Office located in the Campus Security Office. The Security Office is located at 2133 East Mall, or can be reached from 8:30am to 4:30pm, Monday through Friday at 604-822-9922. Visit security.ubc.ca/content/lost-and-found to report a lost item.

**The AMS Nest and University Village**
The Nest, which serves as the conference venue, also offers a number of food outlets, shops and services. Additionally, at the entrance to the campus on University Boulevard is a small shopping centre, within walking distance of the conference venues and accommodations. The University Village includes banks, a pharmacy, photocopying and printing services, a small grocery, restaurants, coffee shops, and fast food outlets.

**Messages**
Messages for delegates staying on-campus may be left by calling the Conferences and Accommodation Reservations Office at 604-822-1000 extension 3 or toll free at 1-888-822-1030 (calls to the toll free line cannot be transferred to a guest's room). All private suites have voicemail capabilities. Budget rooms in shared suites are not equipped with telephones, but messages can be posted on the Message Board in the residence lobby or delivered to the room.

**Parking**
Limited parking is available for those guests staying on-campus for a daily rate. Delegates staying off campus can park in the one of the parkades or budget surface lots on campus.

**Printing and Photocopying Services**
Copiesmart and Staples both offer a range of printing and copying services, and are located in the University Village.

ICED17 does not offer printing services for presenters.

**Post Office**
Canada Post is located at University Village inside University Pharmacy IDA.

Monday – Friday 9:00am – 8:00pm
Saturday 10:00am – 6:00pm
Sunday 12:00pm – 4:00pm

**Recreational Facilities**
The BirdCoop is located in the Student Recreation Centre with a comprehensive range of exercise equipment, and is open Monday to Thursday: 6:30am to 9:00pm, Friday: 6:30am to 7:00pm, Saturday: 10:00am to 5:00pm, Sunday: 12:00pm to 5:00pm. There is a reduced rate of $8/day for guests staying on-campus.

The UBC Aquatic Centre has public drop-in times for its pool, gym, sauna and whirlpool facilities. For more information, please visit www.aquatics.ubc.ca.

There is a Climbing Wall at the north end of the second floor of the Student Union Building called the "Aviary". Information is available at www.ubc-voc.com/aviary

**UBC Bookstore**
The university bookstore is located on the corner of University Boulevard and East Mall. The bookstore is open Monday to Tuesday: 9:30am to 5:30pm, Wednesday: 9:30am to 7:00pm, Thursday to Friday: 9:30am to 5:30pm and Saturday: 11:00am to 5:00pm.

Guests of Conferences & Accommodations at UBC receive a 15% discount on regular-priced clothing, giftware, general books and stationary. Please use promo code CONF17 when making a purchase online or in person. Online purchases can be made at www.bookstore.ubc.ca

**Construction on Campus**
The ICED17 Organizing Committee greatly appreciates the patience of all our conference delegates, with regards to the construction on campus. UBC is undergoing several major projects to improve the layout and sustainability of campus facilities for students and visitors.

**UBC Sustainability Initiatives**
UBC offers a comprehensive set of sustainability projects and initiatives to help facilitate the change towards a sustainable future. UBC demonstrates leading practices in both institutional and residential green building on campus.

Accommodation: Housekeeping is dedicated to using green and environmentally friendly products when servicing your room. Guests can opt out of having their towels changed daily.

# NOTES

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