NordDesign 2014
August 27 – 29, 2014
Espoo, Finland / Melbourne, Australia

Impacts of making design decision sequence explicit on NPD project in forest machinery company

Halonen Nillo[1], Lehtonen Timo[2], Juuti Tero[3]

[1]*Department of Mechanical Engineering and Industrial Systems, Tampere University of Technology*
nillo.halonen@tut.fi
[2] *Department of Mechanical Engineering and Industrial Systems, Tampere University of Technology*
timo.lehtonen@tut.fi
[3] *Department of Mechanical Engineering and Industrial Systems, Tampere University of Technology*
tero.juuti@tut.fi

Abstract
The front-end of an NPD project is a challenging area due to lack of adequate information, limited time, multidisciplinary teams and concurrent engineering. In this kind of environment communication and knowledge sharing becomes critical. This paper introduces a method of mapping design decision sequence as used in an NPD project, which specifically addresses the challenges of front end product development. The objective of the paper is to present the empirical results of a case study conducted at a Finnish forest machinery company, analysing the impact of making design decision sequence explicit by using a method of Product Structure-based Information Flow Modelling (PSIFM). The goal of PSIFM is to improve the management of NPD projects by supporting the shared understanding between different disciplines and reusing the existing design process knowledge.

Keywords: design decision sequence, design process knowledge, project management

1 Introduction

The early phase of product development is often described as 'fuzzy'; though there is great opportunity to influence the product's success, there is only limited amount of information available. Furthermore, developing complex products with a limited time frame requires multidisciplinary teams and concurrent engineering, which causes significant challenges for information and knowledge sharing. Often when talking about New Product Development (NPD) projects, the discussions focus on examples which do not base their design on the solutions of a previous design. In general, this kind of NPD is rarely the case in industry [1]. In many occasions, previous design knowledge exists and could be reused, however the challenge of the early phase of product development remains. Could the efficient application of the existing design process knowledge be used to overcome some of the challenges companies are facing in the early phase?

In our previous studies we have considered flow models to identify process knowledge in the NPD projects [2]. These flow models have rigorous modelling rules to capture the information transformation process of an NPD. The modelling rules are based on the Transformation-Flow-Value production theory by Koskela and Monozukuri – reflections on Japanese manufacturing paradigm by Fujimoto [3-4]. The studies have indicated that the method is a promising concept for modelling reasoning within product development process as it enables to create a mind-set of characteristics and properties and outline their dispositional relationships in a process model. This study is a continuation of this research direction and addresses especially the modelling of design reasoning in a multidisciplinary project environment. Ultimately, the aim is to represent the shared understanding of different disciplines of the process knowledge.

This paper presents the results of an empirical study testing the method of mapping design decision sequence, which addresses more deeply how the multidisciplinary design decision sequence can be made explicit. For this purpose a research question is formulated:
How a product structure based information flow modelling effect executing integrated product and production development projects?

Based on the research group's experience it was hypothesised that that mapping design decision sequence improves the execution of integrated product and production development projects by supporting the design process from different perspectives. The hypothesis is formulated into the following proposition as illustrated in figure 1.

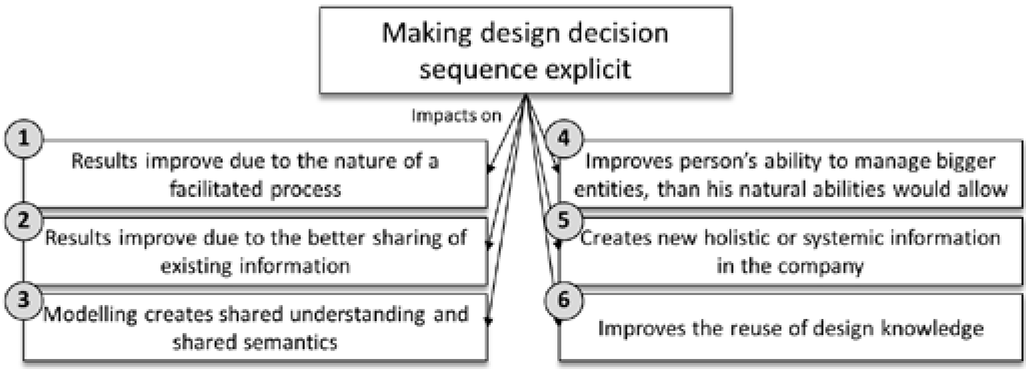

Figure 1 Proposition for the impact of making design decision sequence explicit

The proposition is that mapping design decision sequence has advantages functioning as a facilitation tool and improves sharing of existing information. On a team level this is done by enabling members to develop a shared language and an understanding of the NPD project. On an individual level, it enables a project team member to understand and memorise complex NPD project information flow and its behaviour i.e. project decisions as deliverables and their interrelationships and sequence. Also, on both levels, the proposition is that using this methodology enables the creation of totally new systemic information and improves the reuse of design knowledge.

2 Method

The study utilises a qualitative Case Study Research methodology as the research process, which includes the sequence of planning, designing, preparation, collecting, analysing and sharing phases [5]. During the planning phase the research questions are identified and research method is chosen. In the design phase unit of analysis, theoretical background, propositions, logical linking the data to the propositions, case study design, and procedures for maintaining case study quality are chosen. During the preparation phase case study protocol is defined. The collecting phase includes following the case study protocol by collecting evidence, creating a case study data base and maintaining a chain of evidence. The analysis phase consists of using different analytical techniques, answering research questions, reflecting the research hypotheses and exploring rival explanations. During the sharing phase textual and visual material are composed and published for the appropriate audience.

3 State-of-the-art

3.1 Facilitated processes and creative problem solving (CPS) techniques

Product development projects always require innovation, whether ongoing, incremental or radical. In most cases, existing business units focus on incremental development [6]. Creating new knowledge can sometimes require great efforts and design teams can run into challenges and constraints with how to achieve these creative solutions. A facilitated process uses a set of creative problem solving (CPS) techniques to overcome these challenges. With the help of a facilitator, who guides and structures the process, a group is enabled to work more smoothly, become motivated and productive. The role of the facilitator is critical in many situations as he or she has to find the right CPS techniques for the unique dynamic of the group [7].

CPS techniques used in a facilitated process are designed for different kind of problem solving situations. These techniques can be classified into two categories; analytical and intuitive. Analytical techniques use structure to generate a logical pattern of thought, whereas intuitive techniques allow the participants to take "giant leaps". The success of using a CPS depends greatly on group's cohesiveness and experience of using different CPS techniques. [8]

3.2 Support for information sharing

In this study information sharing is supported by providing mean s to enhance communication within multidisciplinary project. The literature offers two major approaches for communication in design process. One approach deals with product structure, division of labour, and organisational interfaces, and aims to develop ideal information flow patterns focusing on how information should be moving within an organisation. The other approach looks at different factors affecting communication on an individual and team level. These factors consists elements such as availability of information about product specifications, transparency of decision-making, information representations and overview of sequence of tasks. [9]

3.3 Support for shared understanding

Shared understanding in design communication is defined as a "*similarity of the (individual) perceptions of actors about how the design content is conceptualized or an effective transactive memory*" [10]. Shared understanding contributes to more efficient knowledge transfer, finding of shared goals and supports collaboration between different disciplines [11].

One way to foster shared understanding is to use boundary objects, which have the ability to steer the perspectives of different disciplines. Boundary objects have typically a standardized structure, such as maps or forms [12]. Boundary objects can be structured repositories of information such as libraries, ideal abstractions of real world such as diagrams, coincident boundaries such as the interrelationships between different disciplines and standardised forms serving a method of common communication [13].

3.4 Support for cognitive abilities

Humans have a bounded rationality, which directly affects their problem solving abilities, such as a limited capacity to handle and store information. Visual displays, such as cognitive mapping- techniques exist, which overcome some of these limited abilities. Some of the main advantages these approaches are said to achieve are that they provide external storage of information, enable to organise information spatially, supports offloading of cognitive processes onto explicit ones and provides means to externalise the needs for human's internal computation [14]. A number of cognitive skills have been identified as central concepts for this research, which include divergent thinking, visual thinking, spatial reasoning, qualitative reasoning and problem formulation. [15]

3.5 Support for acquiring systemic knowledge

This study utilises Systems thinking, more specifically Soft Systems Methodology to support the acquiring of systemic knowledge and through this, enabling the identification of new systemic information. Soft Systems Methodology is a way to model multidisciplinary knowledge processes, where the goal is to find a balance between disciplinary arguments or world views of the process. The process includes requirements (goals), responsibilities, information elements, sequence flow, and constraints. [16]

3.6 Support for capturing existing design process knowledge

In this study design process knowledge is considered as knowledge of design reasoning patterns. For this purpose, this study utilises an approach for modelling design reasoning, a way of making sense of things in product development. The study considers the abductive approach of design reasoning, in which the working principles are known in the beginning of an NPD, but the requirements and 'players' have yet to be defined [17]. In this study the term design decision sequence is used, which is consistent with the term design reasoning.

4 Product Structure Based Information Flow Modelling (PSIFM)

The methodology examined in this study is PSIFM, which is targeted to support design management methodology to realise and execute product and production development projects. The PSIFM has been developed in Tampere University of Technology. It carries over from from Koskela's Transformation-Flow-Value production theory [3]. Fujimoto's ideas on the Japanese manufacturing paradigm, Monozukuri has been an inspiration for the methodology, providing rules to model information transformation in a process [4].

The PSIFM methodology is constructed of different phases and offers a set of tools to be used by different stakeholders involved in an integrated product and production development project. The different phases are represented in table 1.

Table 1 Phases of the PSIFM process

	Name	Description
1	Identifying design elements	Identify domains that are designed together as a single design element. A design element can include several components that are designed together, in a cluster.
2a	Mapping generic engineering bill of materials (GEBOM) [2].	GEBOM includes the design elements captured during the first phase. As an outcome is a list of design elements that construct the whole product.

2b	Mapping network of sub-deliverables	Each design element in GEBOM consists of a network of sub-deliverables from customer requirements to a physical product. The network of sub-deliverables is mapped separately for each of the design elements.
2c	Mapping design decision sequence	This includes design principles i.e. product life cycle requirements, rules, design routines and means in a technical system.
3	Uniting maps together	During this phase the networks of sub-deliverables and the design decision sequence are combined into a same model. The result is design process knowledge.
4	Adding maturity information [2]	The maturity of information is a combination of three factors: 1. How complete is the design of the particular element. 2. How complete are predecessors of the particular element. 3. How well are properties of design proposal within the desired properties.
5	Ready for use and to be updated	Design process knowledge should be reusable in new product development projects, which rely on incremental innovations and the use of existing design solutions

PSIFM utilises flow thinking and Flow Modelling in the mapping phase [2],[18-19]. However, it should be noticed that in this study the scope is to examine the impacts of phase 2c, i.e. mapping design decision sequence.

5 Mapping design decision sequence

During the mapping of a design decision sequence, the goal is to make the design principles explicit. These include the different product life cycle requirements such as customer requirements and organisational requirements, rules, design routines, and means in a technical system onto same model. In comparison to a design rationale, the aim is to find reasons behind design decisions on a more general level in a product family, which involves incremental development projects, rather than capturing the rationale from a specific project. In a sense, design handwriting could be a good term used to represent the design decision sequence as designs vary between different organisations quite like handwriting varies between different people.

A typical starting point in the mapping is the map creator, who interviews people, constructs the initial versions of the map and later on facilitates the discussion for developing the map further. The interviewees are the persons, whose decision sequence are made explicit and who will develop a shared understanding of the design decision sequence. The following table 2 represents the three main steps in mapping design decision sequence.

Table 2 Steps of mapping design decision sequence

	Name of the step	Description	Outcome
1	**Understanding business and technical system**	Understanding a company's Strategic Landscape (CSL) [20]. Finding out information on product characteristics and product properties of a technical system.	Readiness for capturing the design decision sequence through open-ended interviews, communication and discourse.
2	**Map creation**	Forming a map of design decision sequence collecting information through open-ended interviews with	First visible drafts of the design decision sequence. These first versions are still

		product developers and project managers, from different disciplines on their design principles	invalidated and might represent only few disciplines worldview.
3	**Map validation and further development**	Workshops, facilitated sessions on validating and further developing map of design decision sequence including several developers from different disciplines aiming towards an accommodation between different worldviews.	Design decision sequence representing the shared understanding of the PDP-organisation.

The main outcome of the interviewing phase is strongly dependent on the skills of an interviewer and his or her knowledge on the technical systems. In practice, the interviewer needs the ability to see the systemic interactions and dependencies directly from the discussions that are conducted through phone, video conference or a face-to-face meeting. For this reason, interviews and actual map creation in small group sessions require initial preparatory tasks. These include learning and understanding the Company Strategic Landscape (CSL), which is a structuring method to identify the technical systems, value chains, strategic plans and goals, operational processes and organisational structures [20]. The most important outcome of this method is identifying the interdependencies and interactions between the different elements. A CSL model is typically captured through workshops involving people from the different levels of the organisation including the management level. It is also beneficial for the interviewee to study product characteristics and product properties.

While implementing map creation, which is the second phase, the interviewer prepares new, more specific questions for open-ended interviews and discussion sessions. Due to rapidly changing nature of these sessions, the structure of the process as well as the key question to be discussed has to be relatively open and flexible, as the interview process is highly dependent on the nature and activeness of people participating the session. The questions to be asked and discussed during the session may for example cover the following topics:

- How do you design?
- Where do you start the development process?
- How do you make a great product?
- What kind of information or deliverables do you require to decide on…?
- Who has the information on… if not you?

As a result, the interviewer combines the information captured into a model applying flow thinking [2]. This means that all the elements captured are to be modelled as part of a flow. The logic comes from the idea that, one design element requires certain information before it can be decided. All elements should eventually lead to the final outcome and all the elements should be able to be tracked to the opening elements of the decision sequence. Also the level of detail should be the same, avoiding headlines as elements. Obviously, these are very challenging rules to be followed as the information can be anything and everything. It is very natural for developers to structure their thoughts first in a more abstract level such as conceptual design and then split it into more detail ending up in the more concrete parameter, variable or quality information elements. Thus, flow thinking is more of a guideline to be followed when aiming towards more of a standardised structure.

The model can be documented in a timeline order starting from the left and ending to the right. Typically starting from the life cycle requirements such as customer requirements and companies strategic or resource based requirements, ending up with different information elements or design elements, which are functions turned into quantities and in variable quality. Often, the product in focus is actually a component or a module part of a bigger system. In this kind of situation connective elements, information from other components, are also separate information elements.

The third step involves multidisciplinary group sessions, where the initial models are validated and developed further. These sessions aim to create a shared understanding and actively forces people to discuss what are the primary objectives of the product, which should be determined first and in which order different disciplines arise and become significant. The result is a model, which represents all the worldviews of the participants. It is not a compromise, or a consensus, but as Soft Systems Methodology defines it, it is an accommodation which has all the participants' momentary approval [16].

6 Case study

6.1 An overview of the case study

The case study is conducted in a Finnish forest machinery company in autumn 2013 during their NPD project. In the case study Product Structure-based Information Flow Modelling - methodology (PSIFM) was used in the early stage of the NPD project to make existing design process knowledge more explicit and therefore, more systematically reusable for future projects. This paper focuses only on the impact of mapping the design decision sequence, which is one of the main phases of PSIFM.

6.2 Field procedures

The researcher took part in the project by carrying out trials in which the target was the integration of the PSIFM-methodology as part of the NPD process and facilitating several workshops within the case company. The results are derived from the analysis of different project outcome documents, open-ended interviews, participant observations during the site visits, as well as, the physical artefact that is the concept modelling tool Cmap, which was used during the course of the study.

The case study started with a preparatory phase, studying the company's business and products and preparing outlines for interviews and workshops. An open-ended interview with two mechanical engineers and the project leader was conducted through a video conference. This was followed by a mapping phase conducted by the researcher. The initial version of the design decision sequence was validated and further developed in a workshop during a site visit. In this session, there were the two mechanical designers, the project leader and a product manager. In the final session part-taking were the different disciplines and sections of the organisation involving sales, R&D, production and upper management. This included product developers and product managers from automation and software. Before and after this final session there was also preparation and minor validation on by the researcher and the project leader.

7 Results

During the case study, a map of the design decision sequence was created, which in the end consisted of 197 information elements, from which 23 were customer requirements, 6 were the company's strategic goals and 16 were interface elements. Interface elements are information elements of other components connecting the product/component to other products/components in a broader technical system. The rest of 152 were design information elements, i.e. product characteristics such as parameters, solution principles and qualitative variables. The design decision sequence can be seen in figure 2.

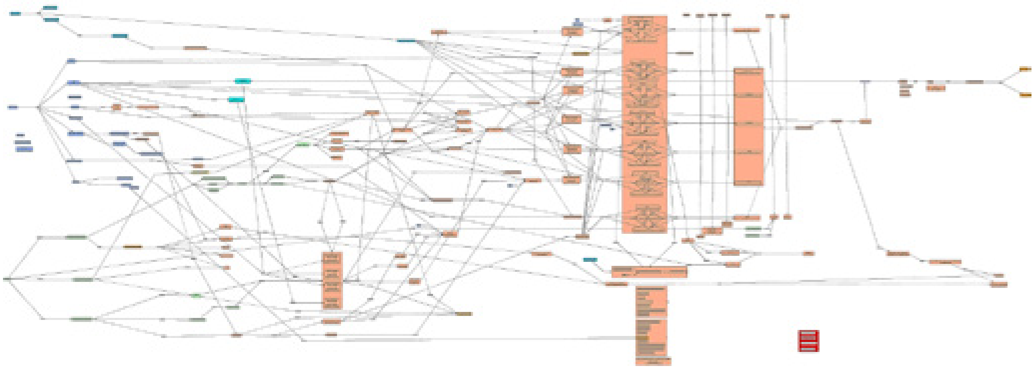

Figure 2 Map of design decision sequence

The observations during the group workshops indicated that the results were positive towards the formulated hypothesis. The method worked as a facilitation process. The researcher worked as the facilitator and the method itself worked as a creative problem solving technique and a boundary object. However, the more significant findings were the result of combining these different means used in the method.

The significant findings of the study indicate that the method:

- Supports the project leader to gain more comprehensive systemic knowledge of the NPD and enables a more effective project management.
- Enables the multidisciplinary team to identify critical interdisciplinary information elements of the NPD in the very early state of the project.
- Improves the teams and individuals capability to learn quickly the design process knowledge.
- Enables the creation of new systemic information and supports incremental innovations.

The method was seen as a promising tool for supporting the project leader. The resulting model of design decision sequence represented a holistic view of which information elements are decided and in which order they are adopted. For the project leader this provides essential information on what kind of division of labour aligns with the model, which elements are the most critical from the requirements point of view and what elements are in the projects critical path. In addition, it provides means and language for the project leader to communicate more effectively on project matters. This finding was realised especially in the final session, where some of the participants already familiar with the model could easily introduce the model to new participants seeing the model for the first time.

The method supported the identification of critical interdisciplinary information elements in the very early state of the NPD. The nature of the visual tool proved to be fruitful in facilitating the communication and steering the process of knowledge sharing to cover design elements more comprehensively. A comment from one of the mechanical designers supports this finding: "*The tool documents and brings specific elements to the table at the right time, which would not have necessarily happened in normal circumstances. Also in the very early* *state of NPD project different disciplines are discussing on the interdependencies between the disciplines, which has not happened before*."

The facilitation of learning was supported with the following comment: "*The design decision sequence illustrates the big picture of the NPD project and this improves perceiving the project as a whole.*" As a visual thinking tool, the design decision sequence allows people to remember the behaviours of the design decision sequence extending the capabilities to memorise the sequence with the help of several mnemonics such as spatial and colour mnemonics. The final session was the most productive environment for identifying and building on the shared understanding as it was full of new discoveries and understandings. One comment from a designer stated that: "*The method facilitates the understanding especially in the early state of an NPD project.*"

The method provided new systemic information during the sessions. A comment from one of the designers supporting this finding states that: "*The method brings different requirements to the picture, for example company's strategic targets. These kind of elements have not been considered this way in NPD projects until now.*" From participant observation point of view, this benefit was seen as the most significant advantage of the method as the participants were able to systematically discuss what design information elements are the most important in the specific project and discuss the possible directions for incremental innovations.

The limitation of the study is the very complexity of the phenomenon what the study is trying to describe and distil. There are numerous and dynamic variables involved in both, the case study context and the method of modelling design decision sequence, which make the analysis of what causal relationships exist between the specific elements challenging.

8 Conclusions

This paper introduces a method of making design decision sequence explicit, as used at a Finnish forest machinery company. The design decision sequence is part of a broader method of Product Structure Based Information Flow Modelling (PSIFM), aiming towards improved management of an NPD project. The significant findings indicate that the method's approach of design reasoning has the potential to contribute to support project management in the very early state of an NPD. In the future studies the methodology of PSIFM should be applied in a broader scale. The results of the future studies are expected to provide effective means to integrate design decision sequence as part of everyday project management.

A further area of interest that arises from this study is to focus on the concept of capability building on individual, project and organisational level. There are indications that the method of design decision sequence makes these different levels of capability or know-how explicit and manageable.

References

[1] Lehtonen, T., Juuti, T., Oja, H., Suistoranta, S., Pulkkinen, A. & Riitahuhta, A., "A framework for developing viable design methodologies for industry", *International Conference on Engineering Design ICED11,* Technical University of Denmark, 2011.

[2] Lehtonen, T., Pakkanen, J., Juuti, T., Vanhatalo, M. & Becker, I., "Achieving integrated Product and Production Development with Knowledge Creation and Flow Model", *In Proceedings of Conference on Flexible Automation and Intelligent Manufacturing, FAIM,* Tampere University of Technology, 2012.

[3] Koskela, L., "*An exploration towards a production theory and its application to construction. Doctoral Dissertation*", VTT Publications, Technical Research Centre of Finland, 2000.
[4] Fujimoto, T., "*Competing to Be Really, Really Good. The Behind-the-Scenes Drama of Capability Building Competition in the Automobile Industry*", International House of Japan, 2007.
[5] Yin, R.K., "*Case Study Research – Desing and Methods. Fourth edition*", SAGE publications, California, USA, 2009.
[6] Berends, H., Vanhaverbeke, W., & Kirschbaum, R., "Knowledge management challenges in new business development: Case study observations", *Journal of Engineering Technology Management*, Vol.24, pp 314-328, 2007.
[7] McFadzean, E., "The Creativity Continuum: Towards a Classification of Creative Problem Solving Techniques", *Creativity and Innovation Management,* Vol.7, No.3, pp 131-139, 1998.
[8] Couger, J.D., "*Creative Problem Solving and Opportunity Finding*", Boyd & Fraser Publishing Co., Danvers, Massachusetts, 1995.
[9] Maier, A., Dönmez, D., Hepperle, C., Kreimeyer, M., Lindemann, U., & Clarkson, P., "Improving communication in design: recommendations from the literature", *International Conference on Engineering Design ICED11,* Technical University of Denmark, 2011.
[10] Kleinsmann M., & Valkenburg R., "Barriers and enablers for creating shared understanding in co-design projects", *Design Studies*, Vol.29, No.4, pp 369-386, 2008.
[11] Lee, C.P., "Between Chaos and Routine: Boundary Negotiating Artifacts in Collaboration", *Proceedings of the Ninth European Conference on Computer-Supported Cooperative Work*, September 18-22, Paris, France, 2005.
[12] Wenger, E., *Communities of Practice: Learning, Meaning and Identity.* New York, Cambridge University Press, 1998.
[13] Star, S.L., "The Structure of Ill-Structured Solutions: Boundary Objects and Heterogeneous Distributed Problem Solving", *Distributed Artificial Intelligence*. Gasser, L., Huhns, M.N., Eds., San Mateo, CA, Morgan Kaufmann, Vol. 2, pp 37-54, 1987-1989.
[14] Hegarty, M., "The Cognitive Science of Visual-Spatial Displays: Implications for Design", *Topics in Cognitive Science*, Vol.3, pp 446-474, 2011.
[15] Shah, J., Woodward, J., & Smith, S.M., "Applied tests of engineering design skills: Visual thinking characterization, test development and validation", *Proceedings of International Conference on Engineering Design ICED11*, Technical University of Denmark, 2011.
[16] Checkland, P., & Poulter, J., "Soft Systems Methodology", *Systems Approaches to Managing change: A Practical Guide*, Reynolds, M., Holwell , S., Eds., pp 191-242, 2010.
[17] Dorst, K., "The Nature of Design Thinking", In Dorst, K., Stewart, S., Staudinger, I., Paton, B. and Dong, A., eds. *Design Thinking Research Symposium 8*, pp 131-139, Sydney, 2010.
[18] Halonen, N., Lehtonen, T., Pakkanen, J., Juuti, T., Ellman, A. & Riitahuhta, A., "Product Life Cycle Disposition Model" *Proceedings of International Design Conference, Dubrovnik*, May 19-22, University of Zagreb, 2014.
[19] Pakkanen, J., Becker, I., Lehtonen, T., & Juuti, T., "Capturing the flows of the product process o", *Proceedings f Design Conference*, 2012.
[20] Juuti, T. & Lehtonen, T. "Using Multiple Modular Structures in Delivering Complex Products", *Proceedings of NordDesign*, Reykjavik, 2006.