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Supporting Innovation and Knowledge Transfer from Individual to Corporate Level

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Abstract. In most development processes, there is an early phase dedicated to creative concept development aiming at finding solutions to the problem at hand. To arrive at a high-quality solution, several ideas may be conceived and evaluated. However, emerging information and knowledge about product concepts is often not shared on a corporate level since only the final result is documented. This can lead to a significant waste, especially in Set-based design. This paper presents a pragmatic way to structure emerging design information, transferring individual design knowledge to a corporate level. It introduces the Concept Dashboard to track the progress of the concept development and uses an industry standard project workflow system to store and retrieve emerging concept knowledge.

Keywords. Set-based design, innovation management, conceptual design, design evaluation

Introduction

Industrial product development often follows structured, repeatable processes based on distinct activities and phases. Several versions of phased development processes are proposed by Ulrich and Eppinger [1], Pugh [2], Pahl and Beitz [3] , Cooper [4] among others. In most processes, there is an early phase dedicated to creative work. Often, the goal is to create concepts and ideas that solve the problem at hand and most processes prescribe that several ideas must to be conceived and evaluated. However, emerging information and knowledge about product concepts is often not shared on a corporate level since only the final result of the design process is documented in the PDM system through drawings, programs, schemes etc. Several companies are acting on markets where short lead time in development of unique solutions and an ability to master changes in requirements are of vital importance. Building knowledge and means for swift development, easy adaptation of concepts and designs as well problem solving is essential. The exploration of a phenomenon and rejected concepts or solutions in the early phases can be valuable resources when changes occurs in current project as well in future projects. There is therefore a need of better support for formalizing and

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structuring emerging design information in the early phases so that quicker and better design decision can be made in present and future projects.

This also implies to manage the unused alternatives in a way that they can be retrieved and reused at a later point in time, thus making the development process more effective. There are several ways to address this issue in specialized software and processes, but the focus of this paper is to develop a methodology based on common software widely used in companies, such as Excel, PDM systems etc., which makes the implementation less cumbersome. The purpose is to improve the product development process by developing a way to manage the designs and ideas that are eliminated during development, i.e. storing and retrieving both the designs and other information as well as the reasons for not using them. The methodology will support practitioners in the effort to incorporate support for documentation of information and knowledge during the early phases of product development. The methodology is illustrated by an industrial case study where the need for managing intermediate design information is investigated and a way to manage them by the methodology is presented.

1. Related theories and theoretical framework

The quest for managing corporate design knowledge is challenging and several approaches are presented in literature. In Lean product development this knowledge is managed in a “Knowledge value stream” [5]. Here, design knowledge is codified and stored in graphs and text format as Knowledge Briefs. Another approach is to use ontologies to formally describe the objects as well as the relations between the objects in a design. This type of description is rich in information and defines concepts, relations, instances and axioms that is a generalization of knowledge which can be operated on [6] to provide new insights.

The presented research is an application of Instant Set-based Design (ISBD) and the state of the is limited to this as well as the applied creative and systematic methods that are suitable for industrial settings, i.e. possible to perform within a limited period of time. ISBD [7] is a simplified variant of Set-Based Design [8]. ISBD is a way to make the development process more effective and has been scientifically studied in 10 industrial cases. The purpose is to make the introduction of Set-Based Design easier compared to the full version, thus making it possible to introduce it in one day. ISBD consists of several elements: Set-based Design, the 6-3-5 method, the gallery method, the morphological matrix and the inverse Pugh matrix [7]. Other scholars have combined the 6-3-5 method and the Gallery method with positive effects [9], however, not combined with Set-based design. In the development of the ISBD methodology [10] it was found that the generic methods as presented in textbooks are not suited to an industrial context in their original form. The methods must therefore be adapted to the new situation.

The implementation of ISBD starts with the workshop leader gives a brief introduction to the elements of the methodology. Initial concepts are generated by the 6-3-5 method and the results are evaluated by the gallery method. The concepts are posted on a wall and clustered in functional families, followed by a first round of elimination: Concepts having several issues are removed. The remaining concepts are further developed by one individual participant having received feedback from the discussions in the Gallery method. The improved solutions are described in the inverse Pugh matrix. The purpose of the matrix is not to select a best concept but rather the contrary, to eliminate inferior alternatives. Hence the name *inverse Pugh matrix*. The elimination principle is a cornerstone in Set-based design as described in [11] for the reason that tangible motives for elimination are easier to find compared to picking the best alternative, particularly at a stage when the maturity of the different solution concepts is low. To leverage on this idea, the weak points for each concept is clearly stated in the matrix as well as the knowledge gaps that needs to be bridged by information or tests to safely eliminate an alternative. The tests are left as “homework" for the participants and the purpose is that the companies can continue ISBD without the support from the researchers.

2. Case description

The case study focuses on the design process of an OEM company that designs and produces consumer products. The company is on an international market and has factories in different parts of the world. The context is mechanical design and the firm has started using Instant Set-based Design (ISBD) [7]. This method creates several of variants as well as other design information and the objective is to leverage these intermediate results created in the process and prepare them for future use. The unit of study is a case of new product development using an active research strategy with workshops at the company. The data was collected for 18 months including a Master thesis, meetings with company representatives, two workshops and one questionnaire.

2.1. Company needs and challenges

The project focused on the flow of design knowledge and how this can be managed to improve the innovation in the organization. The background is that the number of employees at the product development department had been significantly reduced with a corresponding loss of knowledge. The company therefore wanted to improve this situation by making the knowledge capture and reuse more efficient. The first step was to investigate the state of practice at the company [12]. This provided a starting point for further research and development activities by meetings and workshops with company representatives. The following challenges regarding innovation and knowledge management were identified [12]:

- The company has not a structured approach to create new ideas or solve problems and it is up to the individual to choose working method.
- The company has no standardized method for choosing between alternative solutions in concept development or problem solving, etc. In later phases they use the House of quality to evaluate ideas or solutions or prototypes to ensure the functionality of a concept
- The company has not a standardized way of documenting decisions, solution alternatives or choices in design or in daily problem-solving. It is therefore hard to motivate why a solution was chosen and what the alternatives were. Information is used at Gate reviews to make decisions, but not seen as asset for future projects. Even though information exists in the project documentation it is not organized and hard to reuse and only the chosen solution is enough documented.

3. Supporting innovation and knowledge transfer from individual to corporate

Given the challenges in section 2, two prioritized areas of improvement were identified in cooperation with the company: The need for a structured innovation mechanism and a support to management design knowledge so that it can be reused as a part of the innovation process. The company wanted a pragmatic, light weight methodology to improve both areas. For the innovation aspects, they were encouraged by the researchers to implement Instant Set-based Design (ISBD).

There are several methods and tools available to manage knowledge, but to introduce new software was not an option in the initial stage, the objective was to develop a solution based on existing processes and tools. The solution should support documentation and management of concept information and knowledge during the early phase of product development. It should also support documentation of design decisions and knowledge gaps. Moreover, it should assist the designer to plan and prioritize information seeking and test of concepts and working principles. Both incomplete design information and the reasons for eliminating ideas and concepts should be included.

3.1. Manage design alternatives in a Concept Dashboard

The presented support provides two essential functions that i) manages design alternatives and ii) organizes this information. These are combined into the Concept Dashboard. This is a further development of the inverse Pugh matrix that has been extended to accommodate information to specifically enable tracking of the elimination process. To distinguish this from the Pugh matrix, we name the new matrix the Concept Dashboard (CD).

The CD aims to visualize high- level information in the different concepts and is supported by common IT tools to manage information during concept creation, selection and storing and retrieval. The CD is a template divided into three areas and can be created in Excel, Word etc. It is used throughout the development and the relation between the inverse Pugh matrix and CD can be seen in Figure 1. Here, area 1 holds information to specifically enable tracking of the elimination process which is a key feature of Set-based design for managing multiple concepts. Area 2 is the inverse Pugh matrix and area 3 area is flexible and extends to track the development of the new design iterations. New criteria, solutions and evaluations can easily be added by creation a new spreadsheet tab or by inserting new columns which makes it easy to track the progress.

3.2. Organization of design information

The information gained by doing tests and investigations needed to eliminate potential solutions in the Concept Dashboard is wasted if it cannot be stored, retrieved and understood. The company has several thousands of test documents in the database that are not useful since the context of the tests are unknown. To improve this, the proposed solution was to use an existing workflow system. These systems are common in product developing and manufacturing companies and are used for storing project data as well as for managing the flow of information and activities.

Concept Dashboard							
Concept	Internal Gears	Variant of Internal Gears	Gas spring w. blocking function	Electro Magnet		...	Future Concept
Responsible	-	Designer 1	Designer 2	Designer 3		...	
Current Knowledge Gap	1	General forces and torque on shaft	Space claim	Assess magnetic normal force and current consumption		...	3
Test	-	Hand calculations	Quick CAD	Hand calculations		...	
Result	-	Not OK	Not OK	OK		...	
Criteria						...	
Lock position	R	?	+	+		...	
Prevent lock in reverse position	E	0	+	?		...	
Number of positions	F	-	+	?		...	
Prevent unintended depolyment	E	?	0	?		...	
Fail Safe	R	0	0	+		...	
-						...	
-	2					...	
-						...	
-	E					...	
More criteria						...	

Figure 1. The relationship between the Pugh matrix and the Concept Dashboard: Area 1 is the process tracking part, area 2 is the inverse Pugh matrix and area 3 is created to track the development of a new design iteration

In the presented case, the existing workflow system was used to manage the CD and the accompanying documentation, test results etc. created which supports working in a way that is familiar for the employees. In Figure 2, a schematic view of the process is illustrated.

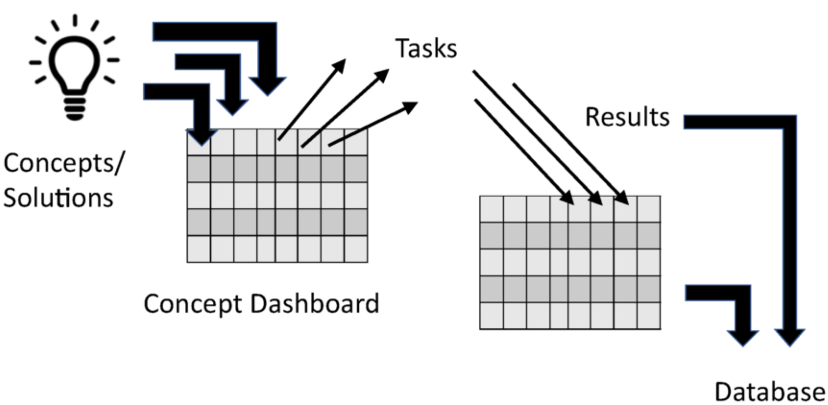

Figure 2. Using the Concept Dashboard and a Workflow system to control Set-based innovation.

Several ideas and concepts can be generated and organized (Section 4). The knowledge gaps are identified for each idea and concept, tasks to resolve the gaps are defined and assigned to specific individuals. For a small task, it may be sufficient just to update the CD and for larger tasks the functions in the workflow system can be used. The tasks are executed, supporting documents collected and the results are summarized in the CD. With the new information available, concepts can be eliminated and new knowledge gaps for the remaining solutions are identified and new tasks defined and distributed. The CD and supporting documents are stored in the workflow system.

4. Illustrative example

The example is a redesign of a mechanical staple gun and since the information comes from a future product, some details are changed due to confidentiality agreement. The company aims at upgrading the ability of the staple gun to use more types of staples without investing heavily in new tooling so the scope is restricted to redesigning only internal part in the gun. The current design has a plunger that is pulled by a handle. The plunger is connected to a leaf spring that stores the energy for shooting the staples.

4.1. Supporting Innovation

Set-based Innovation is a collaborative design methodology and the participants must be well informed of the problem at hand to be able to contribute to its solution. In the first workshop there were five engineers and one researcher. The workshop started according to the way for implementing ISBD as described in [7]: First, a presentation of the design challenge followed by a brief presentations of the methods used: Set-based design, the 6-3-5 method, the inverse Pugh matrix, the gallery method and the Concept Dashboard. The morphological method can also be included if more concepts are needed, but it was not used in the presented case since the purpose was to introduce the Concept Dashboard.

To facilitate the work, previous products, drawings, physical staple gun parts, were provided as sources of knowledge and inspiration. The process follows the principles of Set-based Design [8], with a gradual narrowing of the set of active solutions. The solutions were generated by the 6-3-5 method and the initial results were evaluated by the gallery method. In this version of the gallery method, the concepts are posted on a wall and clustered in functional families, followed by a first round of elimination: potential issues with each solution family is individually identified by each participant. The issues are written on Post-it notes and placed on the corresponding solution descriptions on the wall. Concepts having several problems are removed, photographed and archived in the workflow system.

The remaining concepts were assigned to individual participants for another round of improvement but with the additional benefit that they now can incorporate feedback received from the discussions in the Gallery method. These improved solutions form the new baseline and each one is described in the Concept Dashboard.

The purpose of the DC is not to select a best concept but rather the contrary, to eliminate inferior alternatives. The elimination principle is a cornerstone in Set-based design as described in [11]. Therefore, the weak spots for each concept are clearly stated in the DC as well as the information or tests needed to resolve these.

After the first workshop, the CD had the information given in Table 1. Three basic concepts were found and for each of them, the knowledge gaps were discussed.

Identification of knowledge gaps and ways to resolve them, is used as evaluation criteria. For each concept, knowledge gaps are identified and tentative measures to bridge them or to falsify the concept are described. This can be testing, building prototypes, searching for information, consulting experts etc.

In the presented study, several gaps were identified for each concept with corresponding ways of evaluation. The strategy is to eliminate the least feasible alternatives instead of selecting the best alternative as described in [13]. To progress quickly and with low cost, the elimination starts with knowledge gaps that are straightforward and relatively easy to investigate. Since the evaluations require practical engineering work, tasks are assigned different designers and done between meetings, which is another difference compared to Pugh's method.

4.2. Transfer individual concept knowledge into a corporate level

The produced documents are stored together with the CD in the workflow system collecting all information at the same place such as sketches, tests, lo-fidelity CAD-models, excel sheets, data sheets etc. All data is then stored in this specific concept development case, which is assigned an identification number and is therefore searchable and linked to product information such as drawings. In this way the results will be retrievable as opposed to the way concept development is usually done in the company.

As soon as new information is available, the results are denoted in the CD. New criteria, solutions and evaluations can easily be added by creating a new spreadsheet tab or by inserting new rows and columns which makes it easy to control the progress. In Table 1, the right-hand column is added after the initial knowledge gap *"How to separate the plunger?"* is resolved. A quick CAD model showed that the suggested solution would fit inside, thereby closing the gap. The next gap to resolve is *"Manufacturability and pricing"* that is closed by checking the pricing with suppliers and to present the concept to a manufacturing engineer. The new design uses a tougher material that may be harder to manufacture and more expensive, which is important information early in a project and used for eliminating a concept.

A means to add a knowledge management process into the existing project workflow system that support Instant Set-based design was created, including a new class of projects called Innovation where concept information (e.g. idea sketches, tests, concept evaluation preliminary CAD models, calculations and documents) can be stored in one place (Figure 3). This will provide a standardized way of working and supports access to information on various levels of granularity by its search mechanisms.

Table 1. The Concept Dashboard for the new plunger mechanism. New criteria and evaluations can be added by creating a new spreadsheet tab or by inserting new rows and columns to track the progress.

Concept Dashboard					
Concept	Current Model	Movable plunger	Centered plunger	2-part plunger	2-part plunger New durable material
Responsible	-	Designer 1	Designer 2	Designer 3	Designer 3
Knowledge Gap	-	Friction problem? Can the front be moved?	Feeder and magazine design? Is there enough space?	How to separate the plunger?	Manufacturability and pricing
Evaluation	-	Hand calculations	Prototype of front and plunger	Rough CAD model	Contact suppliers
Result	-	*Not OK*	*Not OK*	*OK*	
Enough feeder force	R	?	+	+	
Well distributed staple force	E	0	+	?	
Straight shooting	F	-	+	?	
Allow staple type 7	E	?	0	?	
Allow staple type 9	E	0	+	?	
Low part count	N	-	+	?	
Easy reloading	C	?	0	?	
Lock position	E	0	1	1	
Prevent unintended deployment		0	0	0	

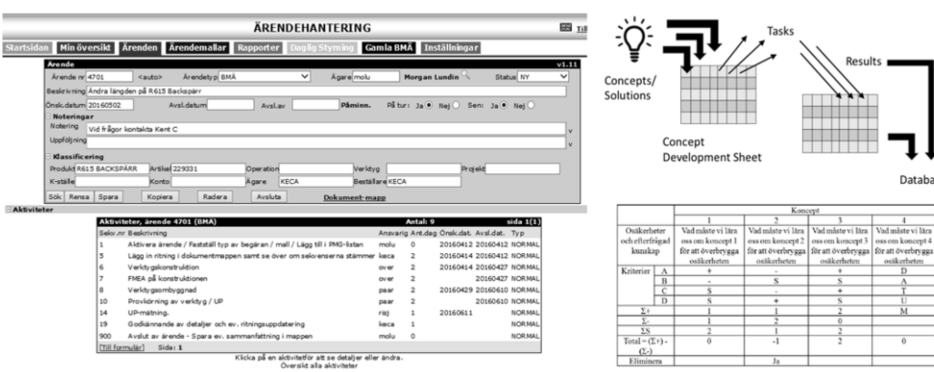

Figure 3. Updated project management system for capturing concepts, decision etc. in early phases with supporting documentation e.g. concept development and concept evaluation sheets (partly in Swedish).

5. Conclusions

In most product development processes, there is an early phase dedicated to innovative and creative work. The goal is to create concepts and ideas that solve the problem at hand and most processes prescribe that several ideas must to be conceived and evaluated. However, emerging information and knowledge about product concepts is often not shared on a corporate level for future changes and projects. This work has focused on how to support both the innovation capability and the knowledge transfer from individual to corporate level.

The presented methodology is an extension of Instant Set-based Design and adds a Concept Dashboard that visualizes knowledge gaps and organizes the concept elimination process. Moreover, it uses a workflow system to manage the information, providing search functionality in different ways and keeps track of the tasks needed to eliminate inferior concepts. The methodology was developed in close cooperation with engineers and the design manager of a firm which makes the process relevant to their needs. The company has initiated the work with a customized workflow that supports Instant Set-based design and has now a possibility to add a knowledge management process into the existing workflow management system. The proposed workflow is structured in functional groups for different subsystems such as handle system, plunger system, frame system etc. This fosters a standardized way of organizing concepts rather than just storing information in a project folder.

In most development processes, only the final result is documented which implies that intermediate design knowledge and information is wasted and cannot be incorporated in the innovation process. All this information can now be organized in a way that the whole organization can access it in a structured way using familiar tools. It thereby becomes available for the organization and thus a part of the innovation resources. Moreover, a workflow system also requests action, creating a pulse in also in the concept work. Besides a better organization of design information, another benefit for the company is the improvement of the idea generation process by introducing the formal methodology Instant Set-based Design as well as getting a tool for idea evaluation and elimination.

To evaluate the effects of the methodology, a full implementation in the workflow system is needed. Also a more structured use of design guidelines such as presented in [14] could be beneficial. For the question of generality, the ISBD method has be tested at ten other firms with consistent results and the formalization of the Concept Dashboard should not be considered problematic. Using a workflow system to manage the flow of design information may be less general and more studies are needed to see if the methodology is relevant to other firms.

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References

[1] K. T. Ulrich and S. D. Eppinger, *Product Design and Development*, 5rd ed. McGraw-Hill, Boston, 2012.

[2] S. Pugh, *Total design*. Addison-Wesley, New York, 1991.

[3] G. Pahl, W. Beitz, J. Feldhusen and K.H. Grote, *Engineering Design – A Systematic Approach*. Springer, Berlin, 2007.

[4] R. G. Cooper, Selecting winning new product projects: Using the NewProd system, *Journal of Product Innovation Management,* Vol. 2, 1985, No. 1, pp. 34-44.

[5] M. Kennedy, K. Harmon and E. Minnock, *Ready, Set, Dominate: Implement Toyota's Set-Based Learning for Developing Products and Nobody Can Catch You*. Oaklea Press, Richmond, 2008.

[6] R. P. Fernandes, I. R. Grosse, S. Krishnamurty, P. Witherell and J. C. Wileden, Semantic methods supporting engineering design innovation, *Advanced Engineering Informatics,* Vol. 25, 2011, No. 2, pp. 185-192.

[7] M. Ström, D. Raudberget and G. Gustafsson, Instant Set-Based Design, an Easy Path to Set-Based Design, *Procedia CIRP,* Vol. 50, 2016, pp. 234-239.

[8] D. K. Sobek, A. Ward and J. Liker, Toyota's Principles of Set-Based Concurrent Engineering, *Sloan Management Review,* Vol. 40, 1999, No. 2, pp. 67-83.

[9] E. C. Julie S Linsey, Tolga Kurtoglu, J.T. Murphy, K.L. Wood and A.B. Markman, An experimental study of group idea generation techniques: understanding the roles of idea representation and viewing methods, *Journal of Mechanical Design,* Vol. 133, 2011, No. 3, Article number 031008.

[10] M. K. Ström, D. Raudberget and G. Gustafsson, Development of a methodology to implement set-based design in a day, in *Proceedings of 14th International Design Conference, DESIGN 2016, Volume DS 84*, 2016, pp. 523-532.

[11] D. Raudberget, The decision process in Set-based Concurrent Engineering-An industrial case study, in *Proceedings of 11th International Design Conference, DESIGN 2010*, 2010, pp. 937-946.

[12] K. Ganesh and P. Pravin Kumar, *Mapping of development process for Tacit knowledge transfer in Product development organization: Knowledge management in change managent*, Master's Thesis, Tekniska Högskolan i Jönköping , 2017.

[13] D. Raudberget, Practical Applications of Set-Based Concurrent Engineering in Industry, *Journal of Mechanical Engineering- Strojniški vestnik,* Vol. 56, 2010, No. 11, pp. 685-695.

[14] D. Raudberget and C. Bjursell, A3 reports for knowledge codification, transfer and creation in research and development organisations, *International Journal of Product Development,* Vol. 19, 2014, No. 5-6, pp. 413-431.