New combination of methods for supporting a simplified set-based design approach

Citation for the original published paper (version of record):
Ström, M., Gustafsson, G., Johannesson, H. (2024). New combination of methods for supporting a simplified set-based design approach. Proceedings of the Design Society, 4: 135-144.
http://dx.doi.org/10.1017/pds.2024.16

INTERNATIONAL DESIGN CONFERENCE – DESIGN 2024
https://doi.org/10.1017/pds.2024.16

New combination of methods for supporting a simplified set-based design approach

Mikael Ström [1,✉], Göran Gustafsson [2] and Hans Johannesson [2]

[1] RISE, Sweden, [2] Chalmers University of Technology, Sweden

✉ mikael.strom@ri.se

Abstract

This work presents a Set-Based Design inspired approach for generation, evaluation and reduction of a solution space of alternative product concepts. Also, the aspect of how to implement the process in an industrial environment was investigated. The hypothesis, confirmed by case studies, is that it can be done using existing methods like Enhanced functional modelling, brainwriting, the Gallery method, Axiomatic Design, causal diagrams and Pugh matrices. The method can be successfully introduced in a timeframe of a few working days and support development engineers in the concept design phase.

Keywords: set-based design, axiomatic design, causal diagrams, conceptual design, systematic approach

1. Introduction

There is a need for creative and systematic methods for generation and evaluation of design alternatives in the concept design phase of a set-based design (SBD) process (Sobek et al., 1999). Information about the alternatives can be obtained by testing or simulation, but this is often both time consuming and costly. A quicker and cheaper way can be to extract information from the concepts using reliable well-known methods that can be introduced to a product development team in a short time, as exemplified in Ström et al. (2016B). Substantial work has been done to develop SBD, as described, e.g., in Shallcross et al. (2020), Specking et al. (2018A), and Toche et al. (2020). Many of these studies show promising results from using SBD. Previous studies have however revealed a need for efficient ways to introduce such methodology in a quick way (Ström et al. 2016A; 2016B) to establish a hands-on experience and understanding of the advantage of SBD from applying it on industrial problems. Concept design consists of phases of investigation of customer needs, creation of requirement specifications, generation and evaluation of concepts, and elimination of inferior alternatives followed by testing of prototypes (Ulrich and Eppinger, 2012). In this work, we suggest a set-based inspired approach which models functional requirements, supports generation and evaluation of solutions, and visualizes causalities. Similar approaches have been made by Conrad et al. (2008) and Luedeke et al. (2018), based on iterations. This work instead suggests a process aimed at convergence by elimination of inferior solutions (Sobek et al., 1999). Salustri and Parmar (2004) have an interesting approach but without connection to SBD. Almefelt and Claesson (2015) have used creative and systematic methods for innovative concept generation but do not concentrate on analysis of dependencies and intrinsic features of the product. The focus in the presented work is on how to compose, quickly introduce and implement an efficient combination of methods for collaborative evaluation of design alternatives by using intrinsic features of the concepts in combination with the developers´ knowledge.

Based on the observations mentioned above, the following research questions have been formulated:

- How can existing Product Development (PD) methods be combined to facilitate an efficient process for evaluation and reduction of a solution space of design alternatives by using intrinsic features of the concept?
- How can such methods be quickly introduced, implemented, and tested in a collaborative environment?
- Why does the suggested combination of methods work?

2. Frame of reference

Below follow descriptions of existing theory used in this work.

2.1. Set-Based Design

In industrial PD, important decisions are often made early in the design process. Even if neither the problem itself nor the customer needs and why previous solutions failed or succeeded are well understood, and feasibility is still not proven, a solution candidate might well be selected and iteratively improved. This procedure is known as Point-Based Design (PBD) (Sobek et al., 1999). It can however cause time-consuming and costly loopbacks if the selected solution fails.

In Set-Based Design (SBD) (Sobek et al., 1999), contrary to PBD, a set of different design alternatives is studied. Options are successively eliminated when proven or perceived to be inferior compared to others with respect to the stated criteria. Figure 1 shows a common type of solution space with two dimensions. One dimension is principally different alternative designs, and the other is parameterised variants of these.

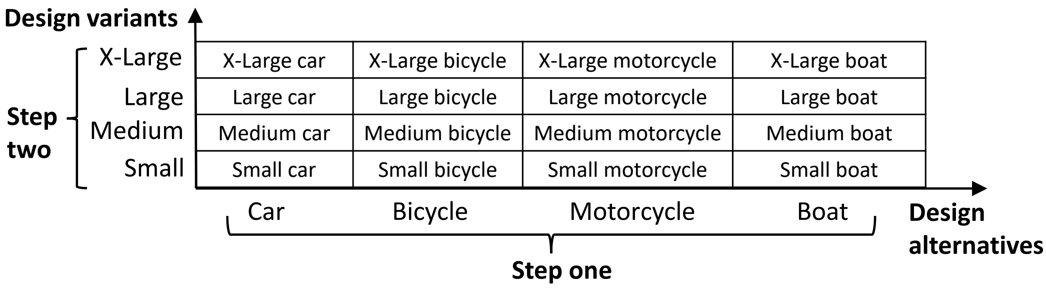

Figure 1. The two-dimensional solution space (Ström, 2022)

Tasks to be performed in Step one of a two-step PD process (see Figure 1) are specification of design criteria, creative and systematic synthesis of design alternatives, quantitative and qualitative evaluation, comparison of design alternatives and elimination of inferior ones. The remaining design alternative in SBD is by default the best one that exists at the time. The principles are described in Sobek et al. (1999).

2.2. Axiomatic Design

Axiomatic Design (AD) is a way to utilize intrinsic features of a solution candidate based on the following two axioms that predict the goodness of a design solution:

1. The independence axiom: Maintain the independence of functional requirements (FRs)
2. The information axiom: Minimise the information content (where information is a measure of system complexity) (Suh, 1990)

Based on these axioms and other fundamental knowledge, Suh (1990) has formulated theorems and corollaries which can be used by development engineers to find design solution (DS) alternatives to the functional requirements. In AD, DSs are denoted design parameters (DPs). The aim is to fulfil the two axioms as well as possible. In the design equation of AD, FRs are linked via the Axiomatic Design Matrix (Suh, 1990) to their respective design parameters (DPs). In this way a system´s internal functional dependencies can be detected. The equation and the matrix are the basis for the evaluation.

https://doi.org/10.1017/pds.2024.16 Published online by Cambridge University Press

A relative estimate of a system´s information content (or complexity) is its number of FRs, as each FR must be fulfilled by a DP, which adds to the total system complexity.

2.3. Common methods for synthesis and analysis

In the 6-3-5 method (Pahl et al., 2007), keywords characterising different solutions are generated by a group of ideally six participants. Brainwriting, described by Linsey et al. (2011), is a closely related method in which handwritten sketches are used instead of keywords. The Gallery method (Pahl et al., 2007) is another technique to promote creativity, in which sketches are posted on a wall to inspire new ideas. Other creative and intuitive methods can be found both in Pahl et al. (2007) and in Ulrich and Eppinger (2012).

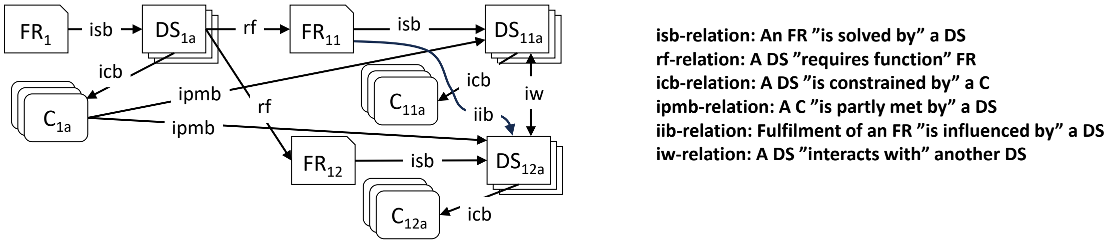

Figure 2. The EF-M model (Johannesson and Claesson, 2005)

Enhanced Function-Means (EF-M) modelling (Johannesson and Claesson, 2005) is an illustration of the axiomatic design equation, but it contains more information and images of relations, see Figure 2. These influences and interactions can be used for analyses of the structure model based on the axioms of AD. EF-M structures can thus be modelled and used for functional coupling analysis and to explore alternatives in their design space. This is also demonstrated by Müller et al. (2019).

Typical systematic methods are the Morphological Matrix (MM) (Pahl et al., 2007), analysis of natural systems (biomimicry), comparison with existing products and interviews with lead users. Pugh (1991) describes the matrix which bears his name, which is used to cross-fertilize solutions, compare them and eliminate inferior ones, thereby promoting design convergence.

2.4. Complexity

Pugh (1991) defines the complexity of a design as $CN = K \cdot (N_p \cdot N_{op} \cdot N_c)^{1/3}$, where

Table 1. The complexity number of Pugh (1991)

CN	Complexity Number
K	Nondimensional constant, which can be set to 1 for similar designs
N_p	Number of parts
N_{op}	Number of different parts
N_c	Number of contact surfaces

In this work, the number of parts (N_p) is equal to the number of DSs at a certain level in the EF-M model of a concept (see section 2.3), and the number of contact surfaces (N_c) equals the number of "interacts with" relations in the EF-M model.

2.5. Instant Set-Based Design

The Instant Set-Based Design (ISBD) methodology (Ström et al., 2016A; 2016B) is a collection of methods aiming at introducing and applying SBD in a one-day workshop. ISBD aligns with SBD by first exploring the conceptual design space and then eliminating weak solutions (Sobek et al., 1999). Since ISBD is a workshop event with a time limit of a day, it only uses knowledge that is available within that time frame. For this reason, intrinsic knowledge about the product possible to extract on spot is of importance. The methodology is based on the following steps:

1. A brief introduction to ISBD, including the methods used.

https://doi.org/10.1017/pds.2024.16 Published online by Cambridge University Press

2. Presentation of the design problem and required functionality.
3. Generation of solutions by the brainwriting method.
4. Posting of the solutions on a wall.
5. Collaborative analysis of how each function is realised in each concept.
6. Elimination of inferior solutions by identifying weaknesses in them. Issues are written on self-adhesive notes and weak solutions are removed and stored in a design repository.
7. Application of the Gallery method to the remaining solutions.
8. Use of a MM to generate more solutions by systematic combination of sub-solutions.
9. Posting of improved solutions on the wall and comparison of them using a Pugh matrix.
10. Identification of knowledge gaps and ways to bridge them to fulfil the required functionality.
11. Elimination of the least feasible solutions based on the results from the Pugh matrix.

The methodology can be introduced in only one day in an industrial developer of mechanical or electro-mechanical products.

2.6. Causality and trade-offs

Relationships between entities can be visualised in extended causal diagrams to increase the understanding of mutual dependencies of product criteria (Gustafsson et al., 2016). The impact of one entity on another is shown by an arrow and a plus or a minus sign to indicate how a change in the first entity numerically influences the other.

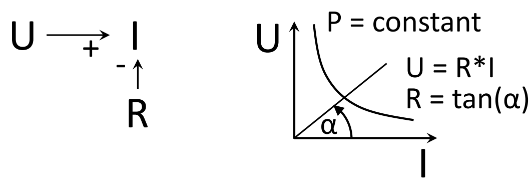

Figure 3. Ohm's law, U = R*I, illustrated in two different ways; The graph to the right also contains a trade-off curve for power; I = current, P = power, R = resistance and U = voltage

Figure 3 shows how causal diagrams, functional dependencies, and trade-off curves can be used to visualise knowledge and thereby make it accessible in an alternative way to mathematical expressions. This type of information is easy to understand. The tool can be quickly introduced in an industrial context, and then used without need for external support (Gustafsson et al., 2016).

3. Research approach

As argued by Gericke et al. (2020), available engineering methods can to a greater extent than heretofore be used in concert to improve products. This was already hinted at by Pahl et al. (2007), who describe a thorough combination of creative and systematic methods for concept generation and evaluation.
The constituents of the approach proposed in the present work are well-known methods described in the literature and above. The authors have previously tested these methods in industrial settings, some individually and others in combination. In this work we will combine all of them.
Notes and photos were taken to document the research, and at least two researchers were present in workshops conducted together with industrial partners. The latter have confirmed the feasibility of the results gained, as is described in Gustafsson et al. (2016), in Raudberget et al. (2018), and in Ström et al. (2016A; 2016B; 2023). The results have made it possible to further improve the application of the tested methods in the work presented here.

4. Results

4.1. Applied workflow

A workflow like ISBD was applied in two industrial case studies. It is described in Figure 4 and involves EF-M modelling, brainwriting, the Gallery method, MM, axiomatic coupling, complexity analysis,

https://doi.org/10.1017/pds.2024.16 Published online by Cambridge University Press

extended causal diagrams (as in Figures 5 and 6), and Pugh matrices. The workflow is an extension of ISBD through the addition of EF-M modelling, theory from axiomatic design, and extended causal diagrams.

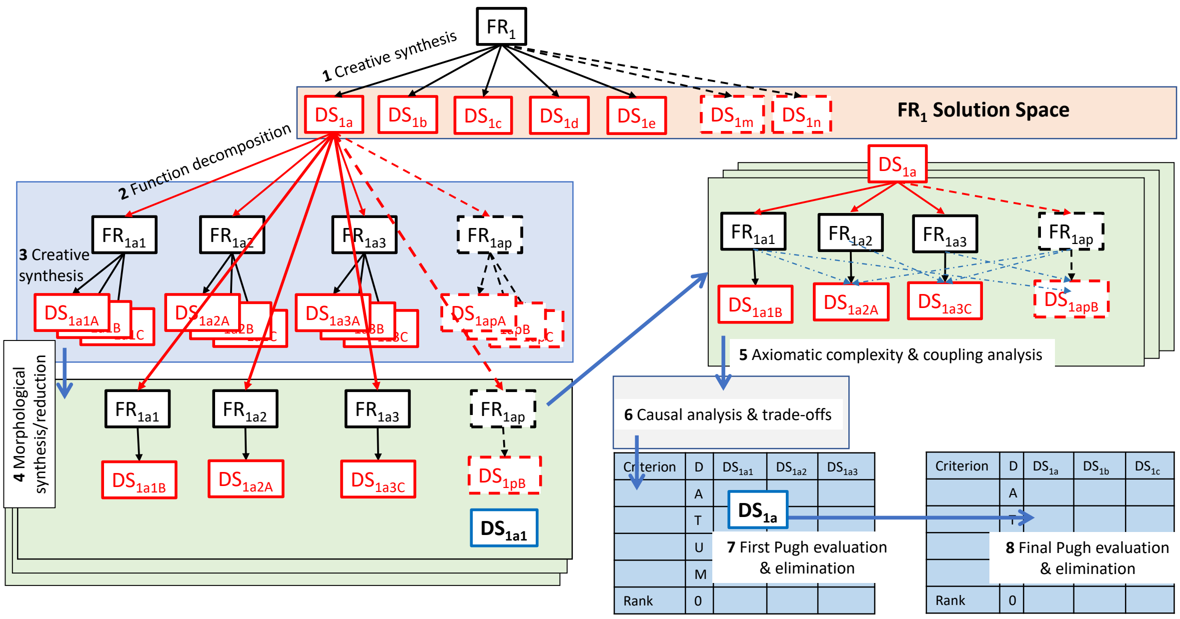

Figure 4. The principal workflow and application of the new combination of methods

The workflow contains the following steps:

1. **Creative synthesis:** Brainwriting and the Gallery method are used to generate Design Solutions (DS) to fulfil the top functional requirements (FRs).
2. **Function decomposition:** Created DSs are decomposed using EF-M modelling, resulting in FRs of each DS.
3. **Creative synthesis:** Brainwriting and the Gallery method are used to generate a second level of DSs with the FRs from step 2 as a starting point.
4. **Morphological synthesis/reduction:** MMs are used to generate more concepts by utilizing all new realistic combinations of sub DSs.
5. **Axiomatic complexity & coupling analysis:** Remaining DSs are analysed using coupling analysis in the EF-M model of each concept. Also, the complexity of each concept is calculated using the definition in section 2.4.
6. **Causal analysis & trade-offs:** Each concept is analysed using extended causal diagrams and trade-off curves. See Figure 4 and Figure 5.
7. **First Pugh evaluation & elimination:** For the sub-DSs of each DS_{1x} in the FR_1 solution space, the criteria on each sub-DS are together with the number of couplings and the complexity number used in a Pugh matrix to compare and eliminate inferior solutions at sub-DS level. This step is repeated for each DS_{1x} in the FR_1 solution space.
8. **Final Pugh evaluation & elimination:** The different DSs at the top level are compared in a Pugh matrix using FR_1, constraints (C_{1x}), number of couplings and complexity number as criteria. This step is not needed if there is only one solution in the FR_1 solution space.

In the industrial cases, steps 1-3 were carried out by the companies which provided the cases. The research team made a more accurate EF-M model, and then performed the subsequent steps 4-7 and compared them with the results from the companies. By adding EF-M modelling to the process, the concepts produced with creative methods were analysed and described in relation to the initial requirements. Relations internal to the concepts were also unveiled and classified, and of particular interest were the types "is influenced by" and "interacts with" (see Figure 2).

https://doi.org/10.1017/pds.2024.16 Published online by Cambridge University Press

The relation "is influenced by" indicates the existence of a functional coupling and thereby a conflict with axiom 1 in AD. A relation of the type "interacts with" signals mutual dependence between design solutions contributing to increased complexity and will also add to the information content in a concept which conflicts with axiom 2 in AD.

The extended causal diagram together with the EF-M models increased the understanding of the concepts and supported group discussions among development engineers. Since ISBD was created to quickly introduce a simplified variant of SBD in a time frame of a day, the knowledge used to evaluate and eliminate DSs is furnished by the workshop participants. The addition of axiomatic coupling and complexity analysis, and extended causal diagrams brought about better insights into the generated concepts, which were used in the comparison and elimination of design solutions in a Pugh matrix. The number of functional couplings and the complexity number belonged to the matrix criteria.

4.2. Industrial cases

The methodology described in Section 4.1 was applied to two industrial design cases: An oil conduit in the engine compartment of an automobile, provided by Akwel Sweden AB, and a sliding door mechanism, provided by ASSA ABLOY Entrance Systems AB.

4.2.1. The case of the oil conduit

The top FR of the oil conduit is to convey oil from one point to another in an engine compartment of an automobile. Top design solution alternatives were a pipe system (DS_1) and a hose system (DS_2). The functional requirements (FRs) for the pipe system are FR_{11}: allow flow of oil, FR_{12}: allow flexibility, FR_{13}: avoid resonance, and FR_{14}: allow the drain of oil. For the hose system, FR_{12} is replaced by FR_{21}: carry load, and FR_{23}: fix position replaces FR_{13}.

There are six constraints (Cs) on the oil conduit: C_1: Minimum natural frequency (to avoid resonance), C_2: maximum stress, C_3: possible to produce with existing manufacturing equipment, C_4: fits into the engine compartment, C_5: resists corrosion, and C_6: withstands high temperatures.

FRs are assumed to be solved by the following alternative designs:

- FR_{11}: single pipe (DS_1), two pipes (DS_2) (divided by bellows/joints), or reinforced hose (DS_3).
- FR_{12}: bellows (DS_4) or pivot joints (DS_5).
- FR_{13}: clamps (DS_6), ring damper (DS_7), or material stiffness (DS_8).
- FR_{14}: drain position and line geometry (DS_9).
- FR_{21}: cover reinforcement (DS_{10}).
- FR_{23}: clamp (DS_6).

A MM in step 4 (see Figure 4) generated 18 different solutions. Evaluation and elimination with respect to incompatibility between DSs resulted in six remaining solutions, listed in Table 2.

Table 2. The remaining solution alternatives after the first elimination

DS	Solution type	No. of functional couplings	CN
Pipe 1	DS_2, DS_4, DS_6, DS_9	2	6,69
Pipe 2	DS_2, DS_5, DS_6, DS_9	5	8,82
Pipe 3	DS_1, DS_5, DS_6, DS_9	3	5,85
Pipe 4	DS_2, DS_4, DS_7, DS_9	2	6,3
Pipe 5	DS_2, DS_5, DS_7, DS_9	2	7,56
Hose 1	DS_3, DS_6, DS_9, DS_{10}	0	7,56

Further considerations resulted in the following eliminations: Pipe 2 had too many couplings and high complexity. Pipe 4 and pipe 5, with a ring damper, did not fulfil condition C_6. Hose 1 was too complicated to manufacture and did not meet condition C_3.

The remaining alternatives, pipe 1 and pipe 3, were compared with respect to natural frequency (C_1) and stress (C_2) using extended causal diagrams (see Figure 5 and Figure 6). A pivot joint does not decrease the stress independently of the bend angle in the same way as can be done with bellows, so pipe 3 was

https://doi.org/10.1017/pds.2024.16 Published online by Cambridge University Press

also eliminated as inferior to pipe 1. If the constraint C_4 requires small bend angles, the result will be a tube with a small “pivot joint orientation angle”. It is clear from Figure 6 that the stress will increase due to small angles on an almost straight tube.

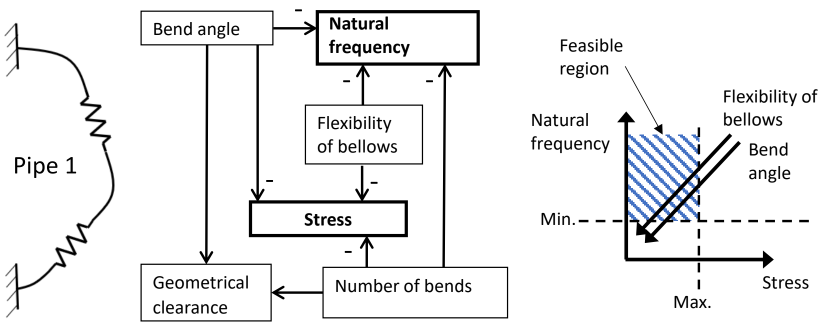

Figure 5. Impact of properties on natural frequency and stress in pipe 1, with bellows (DS4), which do not allow torsion

In Figure 5, the case with small bend angles, the stress in the tube can be reduced by increasing the flexibility of the bellows, which is independent of the bend angle. An arrow without plus or minus sign in Figure 5 and Figure 6 indicates an impact, but not whether it is positive or negative.

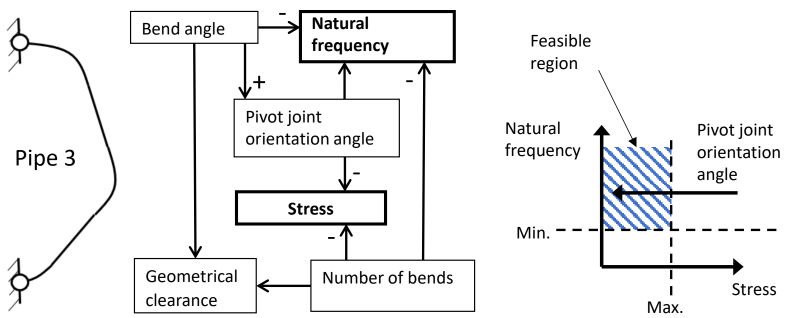

Figure 6. Impact of properties on natural frequency and stress in pipe 3, with pivot joints (DS5), which do not transfer torque or allow longitudinal displacement

4.2.2. The case of the sliding door

The case of the sliding door has three design alternatives in step 4 of the workflow: A belt drive (Figure 7a), a cog wheel drive (Figure 7b), and a motor hub drive (Figure 7c).

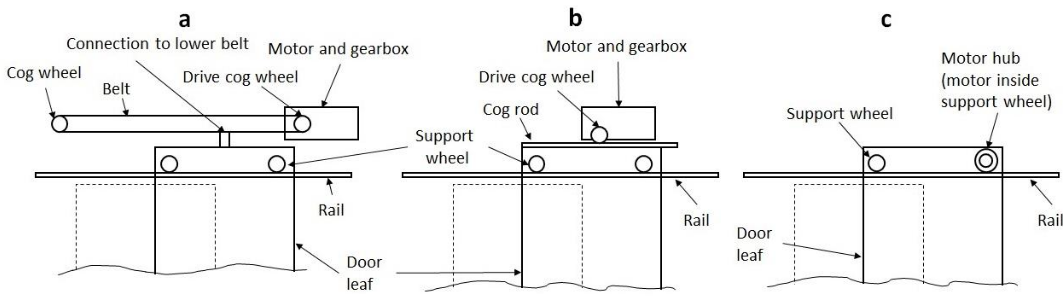

Figure 7. Three alternative designs of the sliding door; Door openings are in dashed lines

Coupling and complexity analysis, and extended casual diagrams were applied with good results. This case is more complicated than the oil conduit. The proposed method is nevertheless applicable. This strengthens the generality and validity of the method as well as the presented results. In step 7 of the process described in section 4.1, the DSs in Figures 7a, 7b and 7c are evaluated using a Pugh matrix. Criteria are Sub-FRs, functional couplings, complexity, and constraints. This resulted in the elimination

https://doi.org/10.1017/pds.2024.16 Published online by Cambridge University Press

of DSs 7a and 7b, and DS 7c remains as the most suitable solution. More information about this case can be found in Ström (2022).

5. Discussion

The proposed development process and its methods are applied to two industrial cases. The approach is found easy to use and has a clear value in both design problems. The effort to introduce the methodology in an industrial context is in line with previous experience from applications of ISBD, EF-M models, AD, and extended causal diagrams. Based on the results from previous industrial case studies (Gustafsson et al., 2016; Raudberget et al., 2018; Ström et al., 2016A; Ström et al., 2016B;), involving some of the applied methods and the two case studies in this research, the time for introduction of the proposed process in an industrial context is expected to be two to three working days.
Development engineers that took part in the introduction of the methods used in the approach were able to compare, in a qualitative manner, the new way of working with their previous. With Pedersen's (2000) way of validating results, the method suggested in this work was judged superior. Examples of improvements were larger and more promising solution spaces, improved understanding of generated concepts, fewer iterations needed, and shared knowledge.

5.1. Research questions, and answers

Q1: How can existing PD methods be combined to facilitate an efficient process for evaluation and reduction of a solution space of design alternatives by using intrinsic features of the concept?
Answer: The presented research shows that part of the concept development process, including synthesis, evaluation, and reduction of a solution space, can be efficiently supported by a combination of established single methods with ISBD as a framework. Creative and systematic methods for synthesis can be used together with EF-M models, AD coupling, and complexity analysis. Extended causal diagrams can provide support for a deep internal dependency analysis and criteria balancing, and Pugh matrices can finally be used for relative evaluation and elimination.
Q2: How can such methods be quickly introduced, applied, and tested in a collaborative environment?
Answer: The approach described in this article has the potential to produce valuable results already during the introduction phase and pave the way for further use. This is achieved by:

- Using well-established methods that are at least already partly known to the receiving organisation.
- Applying the proposed methods to real industrial design problems.
- Limiting the design problem to a system with maximum 50 components.
- Introducing it at team-level in the organisation.
- Applying the methodology in a workshop session with assistance from an outside expert.
- Supporting the introduction with highly visual methods.

Q3: Why does the suggested combination of methods work?
Answer: The usefulness of each method, the consistency of the combination and the ease of introduction contributed to the positive result.
Reliability of the results is assured by using well-established methods and tools in the composition of the proposed design process as well as in the research approach. The different involved methods are well known and have been individually and widely used in different studies, e.g., Al-Ashaab et al. (2013), Almefelt and Claesson (2015), Araci et al. (2021), Feyzioglu and Kar (2017), Kamala et al. (2018), and Wu et al. (2012). Functional decomposition as well as creative and systematic methods to generate and evaluate design solutions are described by Pahl (2007). Enhanced F-M models are described and validated by Müller et al. (2019). The treated design problems are in both cases analysed using AD. Similar approaches were taken by Feyzioglu and Kar (2017), and by Wu et al. (2012). The advantage of causal diagrams is also pointed out by Esnal-Angulo and Hernandis-Ortuño (2019).
In this work, all observations were made by two or more researchers, with agreement on the results. During workshops, data was collected from multiple sources, and notes were taken.
Generality of the results concerns their applicability in other settings than those in the study. In the presented work, the generality is limited by the fact that both cases concern mechanical and electro-

https://doi.org/10.1017/pds.2024.16 Published online by Cambridge University Press

mechanical design problems. The developed method has however been proven feasible when applied to this wide problem category. The combination of involved methods has been validated in cases originating from industrial practice in similar ways as described by Pedersen (2000).

5.2. Transferability of the methods

The approach has been tested on two different mechanical and electromechanical products. Nothing indicates poor applicability to problems of these types. How it works on problems relating to other technologies must be left to experts in those fields to decide. It is however not well suited to problems in which causal effects and relationships cannot be objectively assessed and treated (Ström et al., 2023).

6. Conclusion

From the results of this work, it can be concluded that:

- Methods from systematic design and axiomatic design can be successfully combined with a Set-Based approach to synthesise, evaluate, and reduce a solution space of design alternatives.
- Introduction of new working methods is facilitated if the methods are returning positive results already during the introduction, and consensus about this is achieved.
- Methods such as axiomatic design, EF-M modelling and extended causal diagrams can take advantage of intrinsic knowledge from design solutions when evaluating them.

7. Future work

In line with this work and the work of Gericke et al. (2020), it is likely that there are several more fruitful combinations of methods from the area of engineering design to be made. Also, other work sequences than the one presented here can be subjects of future investigations.

Acknowledgments

We are grateful for having been allowed insight into industrial projects at Akwel Sweden AB and ASSA ABLOY Entrance Systems AB. This research was partially sponsored by XPRES (Centre of Excellence in Production Research) – a strategic research area in Sweden.

References

Al-Ashaab, A., Golob, M., Attia, U.M., Khan, M., Parsons J. et al. (2013), “The transformation of product development process into lean environment using set-based concurrent engineering: A case study from an aerospace industry”, Concurrent Engineering Research and Applications, Vol. 21, No 4, pp. 268-285. https://doi.org/10.1177/1063293X13495220

Almefelt L. and Claesson A. (2015), “Design methodology applied for product innovation in a multi-disciplinary project – a case study”, Proceedings of the International Conference on Engineering Design, ICED, Vol. 8, No. DS 80-08, pp. 101-110. Politecnico di Milano, Italy.

Araci, Z.C., Al-Ashaab, A. and Garcia Almeida, C. (2021), “Physics-based trade-off curves to develop a control access product in set-based concurrent engineering environment”, International Journal of Lean Six Sigma, Volume 13, Issue 4, pp. 824 - 846. https://doi.org/10.1108/IJLSS-10-2016-0061

Conrad, J., Köhler, C., Wanke S. and Weber C. (2008), “What is design knowledge from the viewpoint of CPM/PDD?”, DESIGN 2008, Dubrovnik - Croatia, pp. 745-751.

Esnal-Angulo, I. and Hernandis-Ortuño, B. (2019), “Behaviour study of an eccentric pulley transmission system using systemic methods”, DYNA, Vol. 86, No. 210, pp. 204-210. https://doi.org/10.15446/dyna.v86n210.76073

Feyzioglu, A., and Kar, A.K. (2017), “Axiomatic Design Approach for Nonlinear Multiple Objective Optimization Problem and Robustness”, Cybernetics and Information Technologies, Vol. 17, No. 1, pp. 63-71. https://doi.org/10.1515/cait-2017-0005

Gericke, K., Eckert, C., Campean, F., Clarkson, P.J., Flening, E., Isaksson, O., Kipouros, T., Kokkolaras, M., Köhler, C., Panarotto, M. and Wilmsen, M. (2020), “Supporting designers: moving from method menagerie to method ecosystem”, Design Science, Vol. 6, No. E21. https://doi.org/10.1017/dsj.2020.21

Gustafsson, G., Raudberget, D., and Ström, M. (2016), “Unveiling Fundamental Relationships in Industrial Product Development”. Procedia CIRP, Vol. 50, pp. 204-209. https://doi.org/10.1016/j.procir.2016.05.092

Johannesson, H. and Claesson, A. (2005) “Systematic Product Platform Design: A Combined Function-Means and Parametric Modelling Approach”, Journal of Engineering Design, Vol. 16, No. 1, pp. 25-43. https://doi.org/10.1080/09544820512331325247

Kamala, S., Chauhan, P.J., Panda, S.K., Wilson, G., Liu, X. and Gupta, A.K. (2018), “Methodology to qualify marine electrical propulsion system architectures for platform supply vessels”, IET Electrical Systems in Transportation, Vol. 8, No. 2, pp. 152–165. https://doi.org/10.1049/iet-est.2017.0080

Linsey, J.S., Clauss, E.F., Kurtoglu, T., Murphy, J.T., Wood, K.L. and Markman, A.B. (2011) “An Experimental Study of Group Idea Generation Techniques: Understanding the Roles of Idea Representation and Viewing Methods”, Journal of Mechanical Design, Vol. 133, No. 3. https://doi.org/10.1115/1.4003498

Luedeke, T. F., Köhler, C., Conrad, J., Grashiller, M., Ruf, T., et al. (2018), “CPM/PDD as an integrated product and process model for a design-thinking based, agile product development process”, DESIGN 2018, Cavtat, Dubrovnik, pp. 2063-2073. https://doi.org/10.21278/idc.2018.0311

Müller, J.R., Isaksson, O., Landahl, J., Raja, V., Panarotto, M., Levandowski, C. and Raudberget, D. (2019) “Enhanced function-means modelling supporting design space exploration”, Artificial Intelligence for Engineering Design Analysis and Manufacturing, Volume 33, Special Issue 4, pp. 502-516. https://doi.org/10.1017/S0890060419000271

Pahl, G., Beitz, W., Feldhusen, J., and Grote, K.-H. (2007), “Engineering Design - A Systematic Approach. 3rd ed.”, Springer London. https://doi.org/10.1007/978-1-84628-319-2

Pedersen, K., Bailey, R., Allen, J.K., and Mistree, F. (2000), “Validating design methods & research: the validation square”, ASME Design Engineering Technical Conferences, Baltimore, Maryland, USA, pp. 1-12.

Pugh, S., (1991), “Total design”, Addison-Wesley, New York, USA.

Raudberget, D., Ström, M., and Elgh, F. (2018), “Supporting Innovation and Knowledge Transfer from Individual to Corporate Level”, Advances in Transdisciplinary Engineering, Volume 7, pp. 576-585. https://doi.org/10.3233/978-1-61499-898-3-576

Salustri, F.A., and Parmar, J. (2004), “Diagrammatic visualisation of early product development information”, Proceedings of DTM04: Design Theory and Methodology, 2004, Salt Lake City, pp. 1-10. https://doi.org/10.1115/DETC2004-57013

Shallcross, N., Parnell, G.S., Pohl E., Specking E., (2020), “Set-based design: The state-of-practice and research opportunities, Systems Engineering”, Vol. 23, No. 5. pp. 557-578. https://doi.org/10.1002/sys.21549

Sobek, D., Ward, C.A. and Liker, J.K. (1999) “Toyota’s Principles of Set-Based Concurrent Engineering”, MIT Sloan Management Review, Winter.

Specking, E., Whitcomb, C., Parnell, G.S., Goerger, S.R., Pohl, E., and Kundeti, N.S.A. (2018), “Literature Review: Exploring the Role of Set-Based Design in Trade-off Analytics”, Naval Engineers Journal, American Society of Naval Engineers, Vol. 130, No. 2, pp. 51-62.

Ström, M., (2022), *Applying lean principles and set-based approaches in product development*, *[PhD Thesis]*, Chalmers University of Technology. ISBN 978-91-7905-699-5.

Ström, M., Raudberget, D., and Gustafsson, G. (2016) “Development of a methodology to implement set-based design in a day”. Proceedings of International Design Conference, DESIGN 2016, Cavtat, Dubrovnik, pp. 523-532.

Ström, M., Wolf, K., Jean-Jean, J., Gustafsson, G., and Johannesson, J. (2023) “A set-based-inspired design process supported by axiomatic design and interactive evolutionary algorithms” Int. J of Prod. Dev., Vol. 27, No. 3, pp. 186-212. https://doi.org/10.1504/IJPD.2023.133054

Ström, M., Raudberget, D., and Gustafsson, G. (2016) “Instant Set-based Design, an Easy Path to Set-based Design”. Procedia CIRP Design Conference 2016.

Suh, N. (1990), “The Principles of Design”, New York, NY, USA, Oxford University Press.

Toche, B., Pellerin, R., and Fortin, C. (2020), “Set-based design: a review and new directions”, Design Science, Cambridge University Press, Vol. 6, No. 18. https://doi.org/10.1017/dsj.2020.16

Ulrich, K.T. and Eppinger, S.D. (2012), “Product Design and Development, 5th ed.”, Boston, Massachusetts, USA, McGraw-Hill.

Wu, Z., Cheng, X. and Yuan, J. (2012) “Applying Axiomatic Design Theory to the Multi-objective Optimization of Disk Brake”, 5th International Conference on Computer and Computing Technologies in Agriculture, CCTA 2011, IFIP Advances in Information and Communication Technology, Springer, Berlin, Germany Vol. 370, No. 3, pp. 62-73. https://doi.org/10.1007/978-3-642-27275-2_7