INTERNATIONAL DESIGN CONFERENCE – DESIGN 2024
https://doi.org/10.1017/pds.2024.272

Using product profiles for retrospective case studies in SGE - system generation engineering

Felix Pfaff ✉, Michael Schlegel, Thomas Alexander Völk, Karl Thomas Reinheckel and Albert Albers

IPEK - Institute of Product Engineering, Karlsruhe Institute of Technology, Germany

✉ felix.pfaff@kit.edu

Abstract

Supporting product developers in innovating is an important task of design research. An invention and a valid need situation described through a product profile are necessary elements of innovation. But how can we derive recommendations on how to develop "innovative" products if the success of a product can only be measured retrospectively? Retrospective case studies are one approach to investigate relationships between context factors, variations in systems and product profiles, and innovation success. To investigate these, we use product profiles in case studies across system generations.

Keywords: design research, innovation, case study, product development

1. Introduction

One of the core tasks of design research is to support product developers in developing more successful products or "innovations" (Blessing and Chakrabarti, 2009, p. 6). How can we as design researchers derive rigour recommendations on how to develop "innovative" products if the success of a product can only be measured retrospectively? One approach is retrospective case studies where success or failure can already be determined (Bauer, 2006).

According to Albers et al. (2018), the necessary elements of innovation are invention, market launch, and a valid need situation described with a product profile. These should be targeted with design support. Using references as a basis for product development is a core hypothesis of SGE - System Generation Engineering. The model of SGE describes product development as the mapping of references to the subsystems of the system in development by carryover-, attribute-, and principle variation. References are structured as elements of the reference system and come from predecessors, competitors, and even industry-external products or concepts from research. (Albers and Rapp, 2022).

To enable progress and survive against competitors, product developers have to design products in the constantly changing context of markets, society, law, politics, and the environment (Arthur, 2009). Pfaff et al. (2022) introduced a descriptive model based on the model of SGE combined with a factor-based description of the product context, that allows the collection of data in retrospective case studies to analyze relationships between context factors, variations in systems, and innovation success.

What is currently lacking is the application of the model of SGE to the product profile as one of the three necessary elements for the innovation process. The product profile models the intended customer, user, and supplier benefits of the product and takes other success factors for innovation into account at an early stage of the development process. With this contribution, we aim to provide a descriptive model to enable the collection of formalized data for the development of product profiles in retrospective case studies in the context of SGE. We applied the descriptive model to a retrospective case study of historical tower clocks and derived implications on retrospective case studies which reconstruct product profiles.

2. State of the art

2.1. The model of SGE and the generic variation operator

Design methods often focus on "green-field" new product development, even though genuine new developments are less than 10% (Kirchner and Neudörfer, 2021, p. 8). Achieving innovation success requires using existing solutions from predecessors, competitors, and industry-external sources as references - especially for products without a direct predecessor. The model of SGE - System Generation Engineering describes these relationships and is founded on two hypotheses. (Albers and Rapp, 2022) First, each new system generation is developed based on references from existing or already planned sociotechnical systems and the associated documentation (Figure 1). These references are modelled in the reference system and described as reference system elements (RSE). Second, three types of variation are used to develop the subsystems of the new system Generation G_n (Albers et al., 2020):

- *"**Carryover Variation (CV)**: an RSE is carried over into the new system generation, whereby the interior of this element is regarded as a "black box" and adjustments are made according to the requirements of system integration and boundary conditions at the interfaces."*
- *"**Attribute Variation (AV)**: the link of RSE is maintained in the new system generation. The solution principle remains unchanged compared to the reference system. However, the attribute(s) of the RSE are varied."*
- *"**Principle Variation (PV)**: RSE and their linkage are varied such that elements and links are removed or added. Thus, a new solution principle is realised, which is new in comparison to the reference system."*

Technical systems can be described on different levels, e.g. function, physics, embodiment, and production (Ehrlenspiel and Meerkamm, 2017). Therefore, variations should be described on different levels (Albers et al., 2020). The generic variation operator is the starting point for the concretization of variations for different model elements: Functions (Albers et al., 2021), properties (Albers et al., 2021), requirements (Wäschle et al., 2021), test-cases (Wäschle et al., 2021), stakeholder needs (Kubin et al., 2023). No variation types have yet been defined for the product profile.

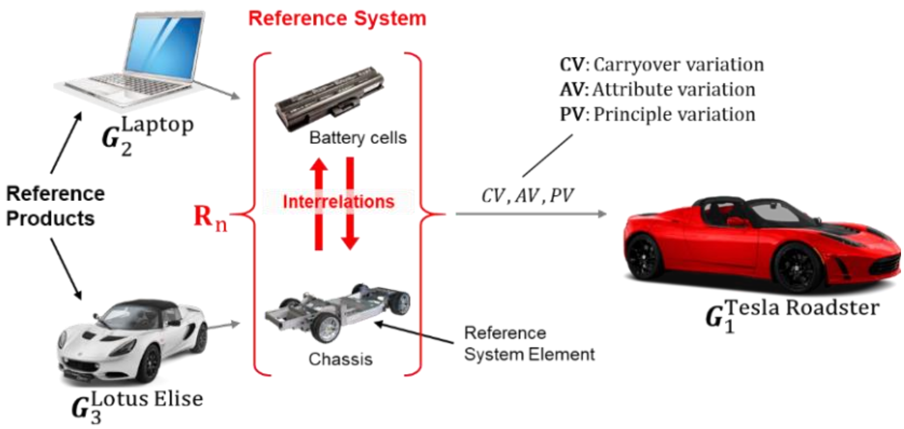

Figure 1. The reference system in the model of SGE (Albers et al., 2019). Tesla roadster: the chassis of the Lotus Elise was carried over (CV). The battery cells from the reference product laptop were integrated with a new configuration (AV)

SGE enables formalized data collection in product development processes and data-driven approaches for developing design support. Examples of design support for synthesis in early phases use lifecycle data for product optimization (Lachmayer and Mozgova, 2022). In the early stages, data-driven approaches support the identification of customer needs (c.f. Product Profile), but also increasingly product creation based on references like previously generated concepts (Bertoni, 2020).

2.2. The product profile as a part of the initial system of objectives

The system tripel of product development according to Ropohl (2009) describes product development as a continuous interaction of the system of objectives, the operation system, and the system of objects. product development as a whole can be described as the selection of RSE in the reference system and the selection of variation types (Figure 2) (Albers et al., 2020).

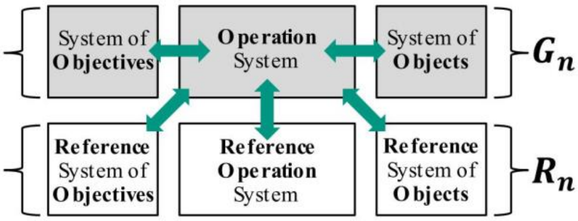

Figure 2. Interrelations of product generation G_n and reference system R_n (Albers *et al.*, 2020)

The system of objectives contains elements of various partial models and their interdependencies which describe the target state of the system generation under development. Important partial models are objectives, requirements and boundary conditions. (Ebel, 2015)

A distinguishing feature of partial models is whether they are solution-open or solution-specific. Objectives, for example, are formulated in a solution-open manner, while requirements derived from objectives are formulated in a solution-specific manner. The product profile as part of the system of objectives contains mainly solution-open modules but links them in the sense of SGE to solution-specific references. The product profile is defined as follows: *"A product profile is a model of a number of benefits that makes the intended provider, customer and user benefits accessible for validation and explicitly specifies the solution space for the design of a product generation. The number of benefits will be understood as a set of products and services, which are offered with the purpose of being sold to a customer and to provide benefits for them directly or indirectly. (Albers et al., 2018, p. 255)"*

Differentiation from competitors, product quality, and identifying target markets, early and ongoing attention to customer needs is crucial for future product success (Cooper and Kleinschmidt, 1987; Chong and Chen, 2010). The product profile is structured in modules and sub-elements, which cover these and more success factors. Through a bottom-up project analysis, 12 modules were identified: *Product profile claim, picture, initial product description, use cases, reference system, provider-, customer-, and user benefit, competitive context, demand, reference system, validation of ... (validation object) through ... (validation activity), and boundary conditions/ framework*. Modules represent analytical perspectives and contain several sub-elements. The sub-elements of the modules are an assistance and may vary depending on e.g. the development task, type of relation with the customer or the company's sector. (Albers et al., 2018, p. 257)

The product profile is often represented through the product profile template (example given in sections 4.1 and 4.2). The template is a pragmatic representation of the model. Product profiles and their elements can be developed either bottom-up or top-down. The top-down approach starts with creatively invented product claims and the bottom-up approach starts analytically from the modules and their sub-elements to later conclude in a summarizing product profile claim. (Albers et al., 2018)

2.3. Data modelling with Entity-Relationship Models

Data models form the basis for constructing information systems (Gadatsch, 2019, p. 4). Abstract data models are advantageous for theoretical design research. They are independent from specific database systems or programming languages. The well-established Entity-Relationship Model (ERM) proposed by Chen (1976) utilizes three fundamental elements to structure data:

- **Entities** are the objects of interest and model real-world aspects on an abstract level.
- **Relationships** describe the relationship between entities. Relationships can be of any kind (physical, structural, causal, temporal etc.)

https://doi.org/10.1017/pds.2024.272 Published online by Cambridge University Press

- **Attributes** can be assigned to both entities and relationships and add details to the description. Attributes can describe properties of entities or give relationships attribute values as their characteristic values.

In the model of SGE, the reference system and its elements (RSE) as well as the system generation and its subsystems can be modelled as entities. Variations can be modelled as relationships and the type of variation (CV, AV, PV) as attribute of the variation relation. (Pfaff et al., 2021)

2.4. Retrospective case study research for theory building

Yin (2018) defines a case study as "[..] an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not evident." Woodside and Wilson (2003) understand case study research broader as an "inquiry focusing on describing, understanding, predicting, and/or controlling the individual (i.e. process, animal, person, household, organization, group, industry, culture, or nationality)." The central feature of case study research is focusing the research issues, theory, and/or empirical inquiry on the individual (n=1) (Woodside and Wilson, 2003, p. 493).

Case studies often involve data from a real setting in practice and can include just one ore multiple cases. Methods for retrospective data collection are for example documents (case history compilation, archival analysis), product data (product family data); Questionnaires/surveys; and interviewing (Blessing and Chakrabarti, 2009).

Woodside and Wilson (2003) see case study research as suitable for theory building and testing, which they demonstrate with several example studies. According to Eisenhardt (1989), case study research should follow eight steps to build a theory: Getting started (Research question & a priori constructs), selecting cases, crafting instruments and protocols, entering the field, analyzing data, shaping hypotheses, enfolding literature, reaching closure. Corbin and Strauss (1990) propose an iterative way of data collection, coding and analysis to come to a grounded theory. When using grounded theory as a research method in case study research, George Allan (2003) emphasizes that a systematic and rigorous manner is needed which requires a high investment of time and resources. For theory-driven design research, Cash (2018) proposes the theory building/testing cycle with five steps that are carried out repeatedly in a 'spiral' to build up scientific knowledge: 1) discovery and description, 2) definition of variables and limitation of the domain, 3) relationship building, 4) prediction, testing and validation, 5) extension and refinement. Cash's spiral falls into variable-based theory syntheses (Yin, 2018).

3. Aim of research and research approach

The *overall aim* of the PhD project this paper belongs to is to support the developers of mechatronic products in the development of products with high innovation potential through knowledge of relationships (cf. step 3 in Cash's spiral) between the variables (cf. step 2 in Cash's spiral) context factors, variations in systems and product profiles, and innovation success. No variation types have yet been defined for the central element of the product profile.

This contribution aims to propose an understanding of variation for the product profile which can be applied to retrospective case study research. We wanted to answer the following research questions:

- RQ1: How can the variation of product profiles be described and modelled?
- RQ2: How can variation types be understood for the product profile?
- RQ3: What implications does this understanding of product profiles have for retrospective case studies?

According to Cash's five steps, RQ1 and RQ2 can be assigned to step *2) Definition of variables and limitation of domain*. RQ1 is answered by an ERM (cf. section 2.4) to describe the entities and relationships for the variation of product profiles. Derived from the ERM we selected a modelling approach that provides a sufficient level of detail and can be applied to retrospective case studies. To answer RQ2, the variation relationship was detailed with the generic SGE variation operator (cf. section 2.1) and an understanding of Carryover Variation (CV), Attribute Variation (AV) and Principle Variation (PV) for the product profile was derived. The applicability of the modelling and understanding for retrospective case studies is discussed using the J.F. Weule tower clocks case study. With RQ3 answered in the discussion section, the investigation of case studies for the following step 3) relationship building in Cash's spiral was prepared.

Case study J.F. Weule tower clocks

The case study was conducted by Thomas Völk as part of a thesis supervised by Prof. Albers and co-supervised by Felix Pfaff. Prof. em. Dr.-Ing. Hartmut Weule initiated the study and was involved as an expert on the family history and source for the archive documents used for the analysis. As part of the case study, nine tower clocks were examined technically, their product profiles were reconstructed and the product context was analyzed.

Initially a completely handcrafted one-off production, the company J.F.Weule began to expand rapidly around 1849 and was one of the world's most successful companies in the market for mechanical tower clocks at the turn of the 20th century. After the First World War, the company entered a difficult phase, which continued after the Second World War and led to the liquidation of the company in the 1950s. This publication analyzes the product profiles of the sixth and seventh product generations (Figure 3). These product generations were chosen because they mark the transition from manual winding to electric winding and the decline of the F.A. Weule.

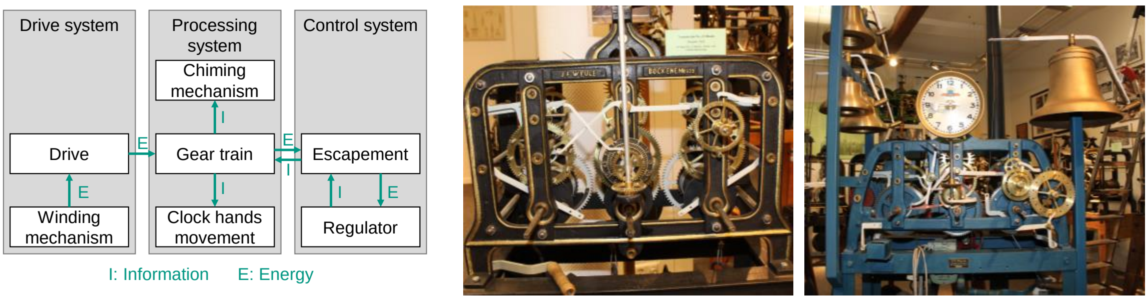

Figure 3. Left: Basic system architecture of mechanical tower clocks according to (Ramminger, 1995). Middle: Product generation six "G$_6$ (manual winding)" from 1922. Right: Product Generation seven "G$_7$ (electric winding)" from approx. 1946

The specific product profile modules were reconstructed using different methods. *Boundary conditions, demand, and competitive context* can be interpreted as context factors (c.f. section 2.1) and therefore require literature sources that objectively substantiate them. Primary sources such as technical documentation of the provider, marketing material, and sales documentation were used to reconstruct the *product claim, initial product description, use cases, and provider-/customer-/user-benefit.* Secondary sources or grey literature were additionally used to *supplement customer- and user-benefit, competitive context, and demand.*

4. Results

In section 4.1, the basic structure of the product profile and possible variation relationships are developed using an ERM. In section 4.2, RQ2 " How can variation types be understood for the product profile?" is answered and discussed using the tower clock case study.

4.1. Entities and relationships for product profile variation

The product profile is modelled hierarchically on three levels: Profile (level 0), module (level 1) and sub-element (level 2). A first possible solution for this would be to define a variation relation on all three levels between entities of the same type (Figure 4). Considering the sub-elements on level 2 would lead to several challenges: Firstly, the sub-elements across all product profile modules cannot be formalized uniformly. There are also different types of sub-elements within a module, which would make it necessary to specify the generic variation operator not only for each module on level 2 but also for different sub-elements within a module.

Secondly, the model purpose of the product profile must be considered: As part of the initial system of objectives, it is used particularly in the early phases and is not filled strictly according to wording rules, as would be the case for example in systems- and requirements engineering. Formalization at level 2 is therefore not necessarily in line with the purpose of the product profile.

https://doi.org/10.1017/pds.2024.272 Published online by Cambridge University Press

This original purpose of the model also comes into play in retrospective case studies. The reconstruction of product profiles by third parties using literature-based or empirical methods cannot claim to forensically reproduce individual sub-elements. Rather, the aim is to capture the intended purpose of the product through the interplay of the sub-elements aggregated across the individual modules and the product profile as a whole.

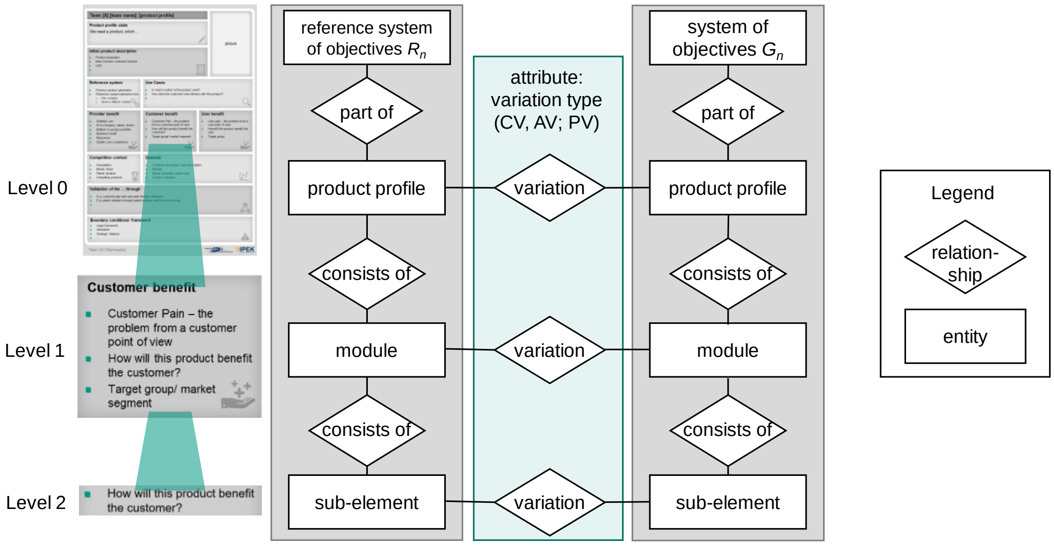

Figure 4. Entity-relationship model for product profiles and variation relationships

4.2. Understanding of variation types for product profiles

Product profile claim: "The product profile claim states the main goal in a short form and provides a brief overview of the product. “We need a product, which < solution statement>." (Albers *et al.*, 2018) Formalizing types of variation or the product profile claim can be based on its main purpose - conveying the main product goal. Therefore, the change of the main product goal can be an indicator without having to pay attention to all the wording details.

- **CV:** The main product goal is carried over from the reference system.
- **AV:** The main product goal is carried over from the reference system, but attributes are changed or added (e.g. additional targeted customer groups, additional core benefits).
- **PV:** The main product goal from the reference system is changed to a different goal (e.g. large ships: transport over the sea vs. hotel on the water).

Applying this definition to the tower clock case (Figure 5), the main product goal of "provide precise time information for centralized buildings" stays the same, but the attribute of the additional benefit regarding human interaction is changed. These are clear indicators for an AV in the product claim.

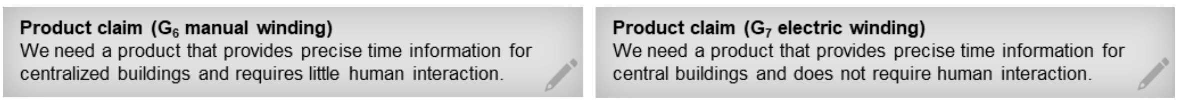

Figure 5. Comparison of the G_6 manual winding and G_7 electric winding product claims

Initial product description: "The description of the potential product provides a more detailed overview of the potential product. Usually, it contains information as e.g. the product properties, the main functions of the product or the unique selling proposition (USP)." (Albers *et al.*, 2018)
As properties and functions are the main sub-elements of the initial product description, the variation definitions for functions and properties (c.f. section 2.2) serve as a reference.

- **CV:** The main properties, functions, and USP are carried over from the reference system and adjustments are made only for integration or regarding boundary conditions.
- **AV:** The main properties, functions, and USP are carried over from the reference system, but attributes are changed (e.g. qualitatively or quantitatively better functions or properties).
- **PV:** Properties, functions, and USP are added/removed.

https://doi.org/10.1017/pds.2024.272 Published online by Cambridge University Press

In the tower clock example (Figure 6) most properties and functions remained. Another attribute was added to the acoustic signal and the winding function was changed from "manual" to "electric". This leads to an AV for the initial product description.

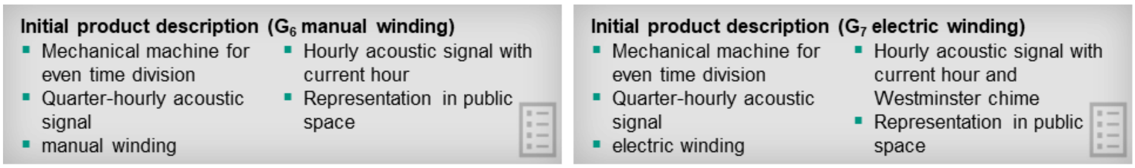

Figure 6. Comparison of the G_6 manual winding and G_7 electric winding initial product description

Use cases: Use cases describe situations where the product provides a solution and the behaviour of the system from a user's perspective. Use cases may refer to the context in which the product is used or to the specific situation in which the customer/user interacts with the product. (Albers *et al.*, 2018)
The use case description in the product profile is less comprehensive than that used in systems engineering to specify system behaviour. It is more about collecting the most important situations in which the user interacts with the system. This must also be considered in the understanding of the types of variation.

- **CV:** Use cases are carried over from the reference system and adjustments are made only for integration or regarding boundary conditions.
- **AV:** Use cases are carried over from the reference system, but attributes are changed (e.g. same situation but a different way of interaction).
- **PV:** Use cases are added/removed.

The use cases of the tower clock case (Figure 7) were carried over from G_6 **(**manual winding**)** to G_7 (electric winding) and no attributes were changed significantly (CV).

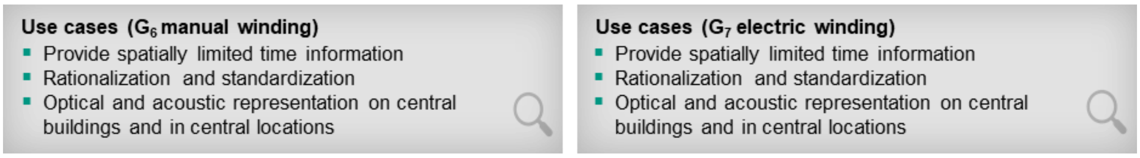

Figure 7. Comparison of the G_6 manual winding and G_7 electric winding use cases

Provider benefit, Customer and user benefit: Provider, customer and user benefits are a core part of the product profile. The provider benefit describes how the provider could profit from the development of the product not only from a financial perspective but also considering fit to the company's culture, portfolio, business models and resources, strategic benefits, or leveraged core competencies. The customer benefit describes the target group the problem to be solved and how the customer would benefit from the potential product. In the B2B sector, in particular, customers and end users often differ and are therefore considered separately. (Albers *et al.*, 2018) Even if they do not represent a different stakeholder, the distinction between buying customer and user can be helpful.
For an understanding of variation types for these benefits, the definition of variation types for stakeholder needs from (Kubin *et al.*, 2023) was used as a reference.

- **CV:** Provider/customer/user benefits are carried over from the reference system and adjustments are made only for integration or regarding boundary conditions.
- **AV:** Provider/customer/user benefits are carried over from the reference system, but attributes are changed (e.g. qualitatively or quantitatively higher benefits).
- **PV:** Provider/customer/user benefits are added/removed.

With this understanding, we analyzed the provider/customer/user benefits from the case study (Figure 8). The variation of the provider benefit can be classified as PV. While the G_6 (manual winding) generated benefits through major customer orders, the G_7 (electric winding) could not generate benefits here.
The variation of the customer benefits from G_6 (manual winding) to G_7 (electric winding) can be interpreted as a PV because a new customer benefit was added through "electricity independent operation" compared with competing concepts at that time.

https://doi.org/10.1017/pds.2024.272 Published online by Cambridge University Press

Comparing the user benefits of the two product generations, no significant change happened, which resulted in a CV.

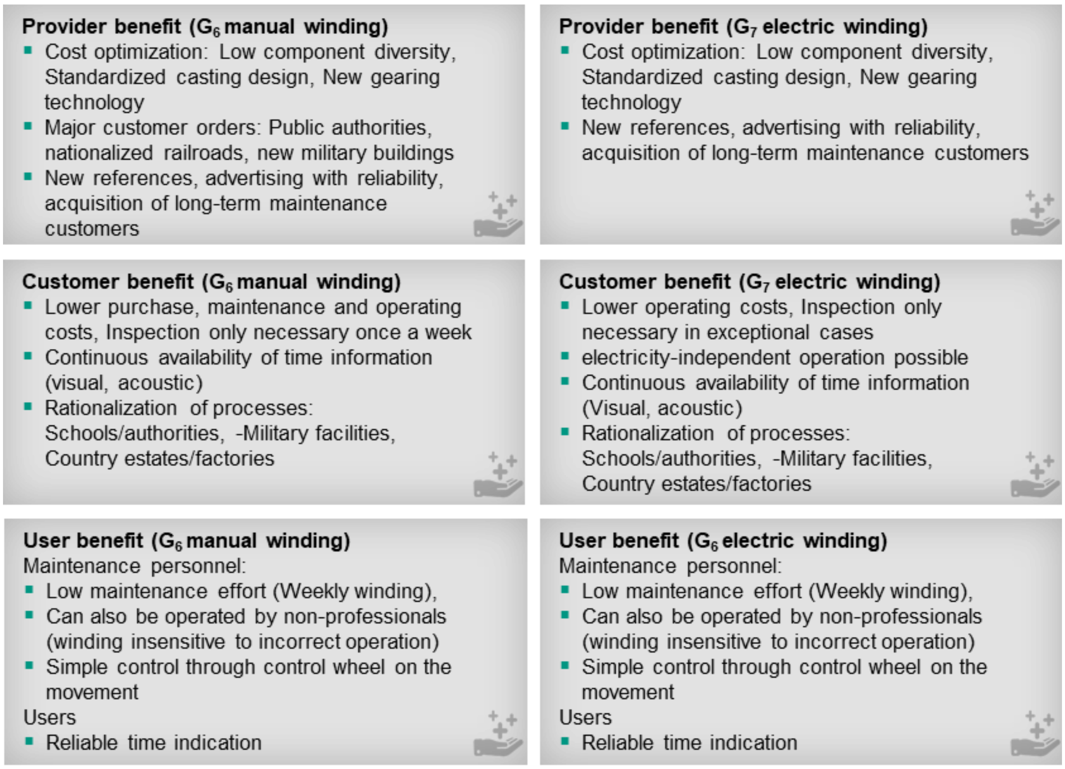

Figure 8. Comparison of the G_6 manual winding and G_7 electric winding provider/customer/user benefits

Remaining modules: For the remaining modules of the product profile - *picture, competitive context, demand, reference system, validation of … (validation object) through … (validation activity), and boundary conditions/ framework*, no variation understanding is needed for the use in retrospective case studies.

Competitive context, demand and boundary conditions/ framework cannot be influenced by the developer and therefore, according to the generic variation operator, are not entities between which a variation relationship exists. These modules can be considered as context factors in the study design for retrospective case studies. The reference system as a product profile module is already taken into account in the analysis of the system side and therefore does not need to be considered again.

4.3. Overall view

Applying the mathematical model of SGE to the product profile of the G_7 (Electric winding) with the product profile of the G_6 (Manual winding) as the only reference and considering the profile claim, initial product description, use cases, and provider/customer/user benefit, a variation share of 1/3 AV, 1/3 PV, and 1/3 CV results (Table 1).

Table 1. Types of variation for the G_7 electric winding product profile

Product claim	Initial product description	Use cases	Provider benefit	Customer benefit	User benefit
AV	AV	CV	PV	PV	CV

5. Discussion and conclusion

Product profiles model the intended customer, user, and supplier benefits of a product at an early stage of the development process and also consider other important success factors for innovation. We provided a descriptive model to enable the collection of formalized data for the development of product

https://doi.org/10.1017/pds.2024.272 Published online by Cambridge University Press

profiles in retrospective case studies in the context of SGE, which was the main goal of this contribution. The application to the F.A. Weule tower clock case study provided insights into the implications of the model for retrospective case studies. For RQ1 *"How can the variation of product profiles be described and modelled?*, an entity-relationship model analysis of the product profile leads to the module level as suitable. RQ2: *"How can variation types be understood for the product profile?"* had to be broken down to the individual modules. We defined variation types for the modules *product profile claim, initial product description, use cases, customer-, and user benefit*.
Implications of this understanding of product profiles for retrospective case studies were examined to answer RQ3. It is important to ensure that the product profile contains the intended target state, not the actual state. This target perspective was particularly challenging in the case study and is probably transferable to further retrospective analyses of elements of the system of objectives. Product profiles can be filled in top-down starting with the claim and bottom-up from the other modules to the claim. For retrospective case studies, the bottom-up option should be chosen. This approach results in product claims that are very representative of the entire product profile. The variation of product claims could be a good proxy for retrospective case studies to save analysis effort.
What was particularly noticeable in the two tower clock generations that marked the decline of F.A. Weule: As in system generations, a high proportion of PV and AV in the product profile is not an indicator of high innovation potential. The results on variations of product profiles from this contribution can help to provide insights from case studies for selecting the "right" variations and references for specific contextual situations to develop products with high innovation potential.

6. Outlook

The next step is to apply this descriptive model to further case studies to investigate relationships (cf. step 3 in Cash's spiral) between the variables (cf. step 2 in Cash's spiral) context factors, variations in systems and product profiles, and innovation success to find out in which situations certain variations and references promise potential. A case study database is currently being built up for this purpose. The insights will be made available to product developers through design support. Initial studies are being conducted with a playbook approach.
Especially for (model-based) systems engineering (MBSE), the generic variation operator needs to be specified for other model elements. This could enable the cross-generational use of (MB)SE models and the use of existing models for retrospective analysis.

Acknowledgement

Prof. em. Dr.-Ing. Hartmut Weule made the case study possible in the first place by providing the documents, his professional expertise and the personal discussions about the family history. Special thanks are due to the Bockenem Tower Clock and Local History Museum and the museum management around Mr. Drake and Mr. Haars, who were able to provide the majority of the photographic material for the clocks shown in this case study.

References

Albers, A., Fahl, J., Hirschter, T. and Rapp, S. (2021), “Application of the generic variation operator in the model of PGE – Product Generation Engineering onto the element types of properties and functions of technical systems”, *in 31st CIRP Design Conference 2021 (CIRP Design 2021), 19.-21.05.2021, Eschede, Netherlands*, Elsevier B.V., Amsterdam, Netherlands, pp. 870–875. https://doi.org/10.1016/j.procir.2021.05.029

Albers, A., Heimicke, J., Walter, B., Basedow, G., Reiss, N., Heitger, N., Ott, S. and Bursac, N. (2018), “Product Profiles: Modelling customer benefits as a foundation to bring inventions to innovations”, *Procedia CIRP*, Vol. 70, pp. 253–258. https://doi.org/10.1016/j.procir.2018.02.044

Albers, A., Hirschter, T., Fahl, J., Wöhrle, G., Reinemann, J. and Rapp, S. (2020), “Generic Reference Product Model for specifying complex Products by the Example of the Automotive Industry”, *TMCE, 11-15 May, 2020, Dublin, Ireland*.

Albers, A. and Rapp, S. (2022), “Model of SGE: System Generation Engineering as Basis for Structured Planning and Management of Development”, in Krause, D. and Heyden, E. (Eds.), *Design Methodology for Future Products: Data Driven, Agile and Flexible*, Springer International Publishing, Cham, pp. 27–46.

Albers, A., Rapp, S., Spadinger, M., Richter, T., Birk, C., Marthaler, F., Heimicke, J., Kurtz, V. and Wessels, H. (2019), “The Reference System in the Model of PGE: Proposing a Generalized Description of Reference

https://doi.org/10.1017/pds.2024.272 Published online by Cambridge University Press

Products and their Interrelations”, *International Conference on Engineering Design (ICED19), Delft, Netherlands*, August 5-8, Design Society, Glasgow, pp. 1693–1702. https://doi.org/10.1017/dsi.2019.175
Arthur, W.B. (2009), The nature of technology: What it is and how it evolves, Simon and Schuster, New York. https://doi.org/10.1016/j.futures.2010.08.015
Bauer, R. (2006), *Gescheiterte Innovationen: Fehlschläge und technologischer Wandel*, Zugl.: Hamburg, Helmut-Schmidt-Univ., Habil.-Schr., 2004, *Campus-Forschung*, Vol. 893, Campus-Verl., Frankfurt.
Blessing, L.T.M. and Chakrabarti, A. (2009), *DRM, a design research methodology*, Springer, Dordrecht.
Cash, P.J. (2018), “Developing theory-driven design research”, *Design Studies*, Vol. 56, pp. 84–119. https://doi.org/10.1016/j.destud.2018.03.002
Chong, Y.T. and Chen, C.-H. (2010), “Customer needs as moving targets of product development: a review”, *The International Journal of Advanced Manufacturing Technology*, Vol. 48 No. 1-4, pp. 395–406. https://doi.org/10.1007/s00170-009-2282-6
Cooper, R.G., Kleinschmidt E.J. (1987), "Success factors in product innovation", *Industrial Marketing Management*. Vol.16, pp. 215–223. https://doi.org/10.1016/0019-8501(87)90029-0
Corbin, J. and Strauss, A. (1990), “Grounded Theory Research: Procedures, Canons and Evaluative Criteria”, *Zeitschrift für Soziologie*, Vol. 19 No. 6, pp. 418–427. https://doi.org/10.1515/zfsoz-1990-0602
Ebel, B. (2015), “Modellierung von Zielsystemen in der interdisziplinären Produktentstehung. Dissertation”, in Albers, A. (Ed.), *Forschungsberichte des IPEK - Institut für Produktentwicklung*, ISSN: 1615-8113, Vol. 85, Karlsruhe.
Ehrlenspiel, K. and Meerkamm, H. (2017), *Integrierte Produktentwicklung: Denkabläufe, Methodeneinsatz, Zusammenarbeit*, 6th ed., Carl Hanser Verlag GmbH & Co. KG, München.
Eisenhardt, K.M. (1989), “Building Theories from Case Study Research”, *The Academy of Management Review*, Vol. 14 No. 4, pp. 532–550. https://doi.org/10.2307/258557
Gadatsch, A. (2019), *Datenmodellierung: Einführung in die Entity-Relationship-Modellierung und das Relationenmodell, essentials*, Springer Fachmedien Wiesbaden, Wiesbaden.
George Allan (2003), “A critique of using grounded theory as a research method”, *Electronic Journal of Business Research Methods*, Vol. 2 No. 1.
Kirchner, E. and Neudörfer, A. (2021), “Grundregeln der Gestaltung”, in Bender, B. and Gericke, K. (Eds.), *Pahl/Beitz Konstruktionslehre: Methoden und Anwendung erfolgreicher Produktentwicklung*, 9. Aufl., Springer Vieweg, Berlin, Deutschland, pp. 467–523.
Kubin, A., Wagenmann, S., Reichert, F., Mandel, C. and Albers, A. (2023), “Stakeholder Needs in Systems Engineering: A Proposal for a Formal Definition”, in *SYSCON 2023: the 17th Annual IEEE International Systems Conference: April 17-20, 2023, Vancouver, Canada conference proceedings, 4/17/2023 - 4/20/2023, Vancouver, BC, Canada*, IEEE, Piscataway, NJ, USA, pp. 1–8. https://doi.org/10.1109/SysCon53073.2023.10131072
Pfaff, F., Eberhardt, C., Patlakis, C., Nowak, M., Rapp, S. and Albers, A. (2022), “Descriptive model for evolutionary innovation research in Product Generation Engineering”, in *The XXXIII ISPIM Innovation Conference: Innovating in a Digital World, 5-8 June, Copenhagen, Denmark*, LUT Scientific and Expertise Publications. https://doi.org/10.5445/IR/1000153615
Pfaff, F., Rapp, S. and Albers, A. (2021), “Modelling and Visualizing Knowledge on the Reference System and Variations Based on the Model of PGE - Product Generation Engineering for Decision Support”, *Proceedings of the Design Society*. 2021. https://doi.org/10.1017/pds.2021.478
Ramminger, H. (1995), *Turmuhren der Firma Weule im Zeitraum von 1848 bis 1952*. Materialien für den Technikunterricht, Hausarbeit zur Prüfung für das Lehramt an Grund- und Hauptschulen, Universtität Hildesheim.
Ropohl, G. (2009), *Allgemeine Technologie eine Systemtheorie der Technik*, KIT Scientific Publishing, Karlsruhe.
Wäschle, M., Timucin, M., Radimersky, A., Mandel, C., Fahl, J. and Hirschter, T. (2021), “Vorgehen zur systematischen Verknüpfung von Produktanforderungen und Systemarchitektur unter Berücksichtigung der PGE”, in Binz, H.-G., Spath, D. and Roth, D. (Eds.), *Stuttgarter Symposium für Produktentwicklung SSP 2021 Stuttgart, 20. Mai 2021, Wissenschaftliche Konferenz, Stuttgarter Symposium für Produktentwicklung*, Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO, Stuttgart.
Woodside, A.G. and Wilson, E.J. (2003), “Case study research methods for theory building”, *Journal of Business & Industrial Marketing*, Vol. 18 No. 6/7, pp. 493–508. https://doi.org/10.1108/08858620310492374
Yin, R.K. (2018), *Case study research and applications: Design and methods*, Sixth edition, Sage, Los Angeles, London, New Dehli, Singapore, Washington DC, Melbourne.