Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 142 (2026) 292–297

www.elsevier.com/locate/procedia

36th CIRP Design Conference (CIRP Design 2026)

From Implicit to Quantified: Understanding and Assessing Knowledge in System Generation Engineering

Lars Gesmann*, Maximilian Fischer, Philipp Kreith, Jonas Bayh,
Alex Martin, Tobias Düser, Albert Albers

Karlsruhe Institute of Technology (KIT), Kaiserstr. 12, D-76131 Karlsruhe

* Corresponding author. Tel.: +49 721 608 48245. E-mail address: lars.gesmann@kit.edu

Abstract

The development of complex systems, such as cyber-physical systems, heavily relies on an efficient management of available knowledge. Within the model of SGE - System Generation Engineering, which conceptualizes product development as a cross-generational process based on reference systems and their reference system elements (RSEs), knowledge provides the foundation for well-informed development decisions. However, the lack of a clear, shared understanding of "knowledge" within the model of SGE limits systematic planning and consistent application of its mechanisms, hindering the operationalization of model-based development across system generations. This contribution addresses this gap by developing a unified, model-aligned understanding of knowledge within the model of SGE. Building on a systematic analysis of key SGE literature complemented by expert workshops, recurring assumptions about knowledge were identified and structured. The findings reveal four central dimensions of knowledge: knowledge depth, knowledge context, knowledge origin, and knowledge management. These dimensions capture the multifaceted, contextualized, evolutionary, and dynamic character of knowledge in SGE and provide a consistent framework for its integration into model-based development. Based on this conceptual foundation, ongoing work will focus on operationalizing the framework through a catalog of guiding questions that enables the systematic assessment of knowledge related to reference system elements. This will facilitate informed planning, support the consistent application of variation operators within the model of SGE, and advance the operationalization of knowledge in cross-generational product development. By enabling traceable, knowledge-based development decisions, this contribution supports systematic, model-based design of the next generation of complex systems and positions knowledge as one of three pillars – alongside amount of change and complexity – for assessing consistency risks across system generations.

Keywords: System Generation Engineering; Reference System; Knowledge Management; Knowledge Conceptualization; Product Development Processes

1. Motivation

Knowledge is a central element of product development and has a significant influence on innovation capacity, quality, and the management of development risks [1, 2]. In the development of complex systems such as cyber-physical systems (CPS), the effective use of knowledge is particularly critical due to the high degree of interdisciplinarity, system complexity, and the long-term perspective across multiple generations of systems [3]. In the context of the model of SGE – System Generation Engineering, knowledge regarding the underlying reference system elements (RSEs) holds a central role. It serves as the basis for decisions regarding carryover, attribute, or principle variation in subsequent generations [4]. Consequently, the availability, quality, and transparency of knowledge have a direct influence on the success of cross-generational development [5].

10.1016/j.procir.2026.05.263

However, observations in research and business contexts demonstrate significant variations in the underlying understanding of knowledge within the model of SGE. Both academic staff and practitioners rely on divergent, often implicit, notions of knowledge. This heterogeneous picture not only hinders the systematic handling and targeted use of knowledge but also the development of robust methods for identifying and managing knowledge-related risks within SGE. In the absence of a coherent and widely accepted conceptual understanding, significant opportunities remain unexplored, and risk assessment becomes challenging.

Therefore, a uniform and operationalizable understanding of knowledge in the context of the model of SGE is essential for deriving empirically sound recommendations for action, systematically designing knowledge transfer and accumulation, and creating a solid foundation for sustainable development and innovation processes in the course of SGE. This paper aims to address the aforementioned gap by offering a structured understanding of knowledge in the context of the model of SGE across four dimensions. It also takes initial steps toward operationalization via an assessment perspective on RSEs, thereby laying the foundation for a guideline for its systematic and quantitative assessment [6]. This contribution facilitates a more consistent application of variation operators and ultimately promotes the operationalization of knowledge in cross-generational product development.

2. State of research

2.1. The model of SGE

In order to better understand the role of knowledge in cross-generational product development, it is necessary to first consider the model of SGE – System Generation Engineering.

The model of SGE conceptualizes the development of technical systems as an evolutionary, cross-generational process and serves as both a descriptive and prescriptive model for planning and supporting product development [6]. This model is founded on two hypotheses derived from practical observations.

Firstly, each new system generation is developed on the basis of references from existing or already planned socio-technical systems and their documentation. These references are captured in the reference system and described as reference system elements (RSEs). Collectively, these RSEs form the structural and functional foundation of a system generation [7].

Secondly, the subsystems of a new generation are derived through three types of variation applied to the RSEs: carryover variation (CV), attribute variation (AV), and principle variation (PV) [3, 8] (see Fig. 1). CV describes the reuse of an RSE with only necessary adjustments at interfaces; AV maintains the solution principle but alters function-determining attributes; and PV replaces the solution principle with a new one. These variation mechanisms can be applied across different system levels, such as function, property, or embodiment.

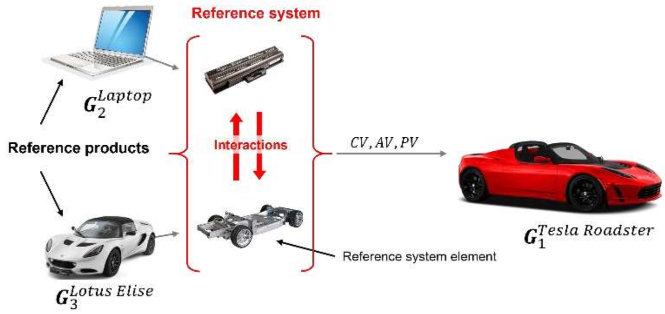

Fig. 1: The reference system in the model of SGE illustrated using the Tesla Roadster [7].

The model of SGE emphasizes the pivotal role of knowledge by structuring development around reference systems and systematic variation. The determination of carryover, attribute, or principle variation is contingent upon the availability, quality, and applicability of knowledge concerning RSEs [6]. While the model implicitly assumes this knowledge as a foundation, a coherent and operational understanding of knowledge within SGE has yet to be established. Addressing this gap is imperative for facilitating systematic transfer, supporting consistent decision-making, and assessing risks across system generations. From a broader standpoint, knowledge stands as one of three pillars for assessing consistency risks in cross-generational development, alongside the amount of change and complexity [9].

2.2. Knowledge in the Context of SGE

In engineering research, knowledge is generally regarded as more than information; rather, it represents a synthesis of skills, understanding, and experience, thereby serving as a guide for actions [10, 11]. Information only becomes knowledge through contextualization, i.e., by embedding it into meaningful structures that allow for purposeful application [12]. In the context of problem-solving and development processes, knowledge assumes a critical role. It facilitates functions such as evaluating solutions, troubleshooting, and concept development [10].

A fundamental distinction is made between explicit and implicit (or tacit) knowledge. Explicit knowledge can be documented, stored, and communicated, while implicit knowledge remains rooted in individual experience, intuition, and personal cognitive models, making it difficult to formalize or transfer [13, 14]. This duality is particularly relevant in engineering projects, where technical documentation provides explicit knowledge but successful design often relies heavily on tacit expertise accumulated through years of experience.

Knowledge is further characterized by its domain-specificity and situationality, as each discipline contributes its own ontologies, methods, and tools [3]. Additionally, knowledge is always highly situation- and application-oriented, constantly relating to tangible problems or particular contexts [15, 16]. To illustrate, the interpretation of a property model in systems engineering necessitates a range of disciplinary perspectives, including mechanical, electrical, and software engineering, each of which is characterized by its own set of implicit assumptions. This situational embeddedness underscores the notion that knowledge cannot be regarded as a universally valid construct; rather, it must be contextualized to achieve operationalization.

Another salient property is the dynamic nature of knowledge [17]. The accumulation of knowledge is an ongoing process that is subject to change over time [18]. This change can be attributed to various factors, including technological advancements, organizational transformations, and the departure of individuals from specific projects. It can become outdated, lose relevance, or require adaptation to new conditions [14, 19]. This dynamism underscores the need for systematic knowledge management, which includes the identification, documentation, externalization of tacit knowledge, and ongoing maintenance [20–22]. The externalization process is increasingly supported by models, methods, and AI-based approaches. These tools facilitate the reusability of implicit knowledge in development practice [23].

In the context of SGE, knowledge is closely linked to RSEs. Knowledge about RSEs can stem from a variety of sources, such as product documentation, prototypes, validation activities, or the implicit expertise of developers [7]. The origin of knowledge exerts a significant influence on its accessibility and reliability, and ultimately on the (technical) development risk. While internal knowledge is often meticulously documented and more accessible, external knowledge tends to be more difficult to access and subject to greater uncertainty. Conversely, knowledge derived from research is frequently not yet market-proven, and knowledge from society or nature is often abstract and lacks formalization [4, 24]. This uncertainty translates directly into higher development risk, as missing knowledge must be generated through validation activities, the acquisition of new competencies, or even adjustments to production systems, underscoring the need for systematic identification, transfer, and management of knowledge across system generations [25, 26].

Furthermore, the type of variation operator (carryover, attribute, or principle) interacts with the origin of knowledge. Carryover of internal RSEs usually implies low risk, whereas attribute or, especially, principle variations based on external or poorly formalized knowledge entail higher levels of uncertainty. However, over successive generations, such knowledge may mature and become more readily reusable, thereby reducing its associated risk [5]. Concepts such as the knowledge space model provide a framework for understanding the origins of knowledge according to accessibility and source. The model distinguishes between twelve types of knowledge spaces [27].

Knowledge related to the RSE also encompasses various levels of abstraction, such as consideration at the element level or at the system level, and always requires a context-specific interpretation within the specific project context [19]. Beyond the scope of individual development projects, knowledge evolves across system generations in an evolutionary manner, manifesting through patterns, type knowledge, and innovation principles. Consequently, it not only facilitates the reuse of established solutions but also serves as a basis for the development of subsequent system generations [28].

Given that knowledge is embedded in RSEs, they become indispensable for ensuring the comparability and consistency of different development stages or generations [29]. A comprehensive understanding of the interrelationships between RSEs, variation types, and target variables is therefore crucial for effective decision-making [9].

In order to conceptualize the role of knowledge in engineering, several explanatory models have been developed. The C-K theory differentiates between the C-space of concepts, which encompasses ideas that have not yet been validated, and the K-space of established knowledge. Design is described as a co-evolution between these spaces: concepts drive the expansion of knowledge, while new knowledge enables the creation of novel concepts [30].

Complementing this, the System Triple of Product Engineering summarizes product development as the interaction between the System of Objectives (goals and constraints), the Operation System (activities, methods, resources), and the System of Objects (artifacts, models, prototypes, products) [31]. The extended ZHO triple emphasizes the developer's central role within the operation system, framing product development as an iterative cycle of analysis and synthesis [32]. Through analysis, new knowledge is derived from artifacts in the system of objects and integrated into the developer's knowledge base. This enriched knowledge base enables the synthesis of new objectives and corresponding solutions, which are then realized in the system of objects. From this perspective, knowledge is not a static resource, but rather, it is generated through interaction with systems, particularly through utilization, assessment, and refinement [32]. This underscores the significance of experience-based knowledge, emphasizing the role of practical learning and application in the development of understanding and expertise. To ensure effective transfer and reuse, knowledge must be structured and contextualized [28].

In summary, the prevailing research acknowledges knowledge as a pivotal and multifaceted resource in engineering and deliberates on its explicit and implicit dimensions, its contextual and domain-specific nature. However, within the context of SGE itself, knowledge has not yet been treated as an explicit research focus. The extant contributions addressing this subject only address individual aspects, such as its relationship to RSE, transfer processes, or its evolutionary development across generations. Consequently, a systematic and comprehensive understanding of knowledge in the context of SGE remains to be developed. This deficiency not only hinders consistent theoretical application but also prevents the complete operationalization of the model in practice. This assertion is especially valid in the context of objectively evaluating types of variation, ensuring knowledge transfer, and managing knowledge-related risks across system generations.

3. Research design

3.1. Research Objective and Research Question

The objective of this paper is to develop a robust conceptual understanding of knowledge within the model of SGE. Rather than establishing a rigid definition, the objective is to derive a comprehensive, operationalizable understanding that serves as a foundation for systematically assessing knowledge in development projects and managing consistency risks across generations. Accordingly, this research is guided by the following central question:

RQ: *How can knowledge be conceptualized and operationalized within the model of SGE to support its systematic assessment in cross-generational development?*

This question addresses the theoretical challenge of developing SGE-compliant terminology and the practical necessity of establishing evaluation criteria within the context of the model of SGE.

3.2. Research Approach

To answer this research question, two different approaches were combined. Firstly, a qualitative content analysis of SGE-related literature was conducted, which resulted in the identification of explicit and implicit assumptions concerning knowledge. The analysis identified recurring patterns, including the distinction between explicit and implicit knowledge, its role in relation to RSEs, and its function in cross-generational development. These patterns were then clustered into preliminary categories.

Secondly, the literature review results were supplemented with exploratory considerations. To this end, a semi-structured workshop with eleven experts in the field of the model of SGE was conducted. Participants were asked to evaluate the preliminary categories and their elements for completeness and discuss their relevance to real-world development contexts. Participants were also asked to suggest any relevant elements not yet mentioned. The workshop was supported by a virtual whiteboard, which allowed participants to directly annotate categories and elements. Moreover, the workshop was recorded and was analyzed ex-post. Next, the workshop results were then synthesized with the findings from the literature and the categories were revised accordingly. The categorization aims to systematically organize knowledge related to SGE while enabling context-specific interpretations. To assess the robustness of the revised categorization, a second expert workshop with eight researchers was conducted, focusing on applicability, clarity, and comprehensibility.

This combined approach ensures that the resulting conceptualization of knowledge is both grounded in literature and aligned with expert practice. Furthermore, it captures implicit assumptions that have not yet been explicitly addressed in extant research, thereby establishing the foundation for systematic and quantitative knowledge assessment in the model of SGE.

4. Results

The qualitative evaluation of the data enabled the structured categorization of knowledge along four dimensions: *knowledge depth*, *knowledge context*, *knowledge origin*, and *knowledge management* (see Fig. 2). Together, these dimensions capture the heterogeneity of knowledge forms, their contextual embeddedness, and their evolutionary development across system generations.

Fig. 2: The four core dimensions of knowledge in SGE.

Knowledge Depth. In SGE, knowledge spans explicit and implicit forms, ranging from codified documents and formal models to tacit expertise embedded in practice. It is distributed across abstraction levels (e.g., component-level facts vs. system-integration understanding) and must be understood as an integrated unit of skills, comprehension, and experience. The degree of formalization strongly influences the reliability of knowledge transfer across system generations. The systematic externalization and validation of knowledge fosters the utilization of RSEs, thereby mitigating potential risks. Therefore, documented evidence, validated test results, and established references are crucial prerequisites for cross-generational reuse of knowledge.

Knowledge Context. The process of acquiring knowledge is predicated on the contextualization of information. Within the scope of SGE, this contextualization is domain-specific, situation-dependent, and closely tied to particular application scenarios. Knowledge is always bound to a specific RSE, and this knowledge only becomes actionable when its relevance for a particular stage of development or discipline is explicated. Consequently, the structuring and contextual embedding of knowledge are prerequisites for its usability. Without contextual anchoring, knowledge remains abstract and risks becoming detached from concrete decision-making.

Knowledge Origin. Knowledge in SGE evolves across generations and stems from diverse sources such as product documentation, prototypes, validation activities, operational feedback, and implicit developer know-how. The origin determines the accessibility, reliability, and effort required for the integration into a new generation. Internal knowledge is generally associated with lower risk and effort, while external or research-based knowledge often requires additional validation before it can be used for transfers or variations. Direct interaction with system artifacts (e.g., testing, prototyping, observation in the system) is a key source of experiential knowledge that often enables successful transfer across generational boundaries.

Knowledge Management. Due to its dynamic nature, knowledge may become outdated or obsolete. Without systematic management, once-valid knowledge can lead to incorrect decisions that affect entire generations. Formalization, context-related labeling, versioning, and continuous updates are therefore essential to ensure reuse.

Effective knowledge management reduces uncertainty, supports objective assessment of the risk of knowledge transfer, and provides information for the selection and design of variation. Conversely, fragmented or undocumented knowledge increases validation effort and development risk.

Taken together, these four dimensions highlight that knowledge in SGE is not static but a dynamic construct comprising explicit and tacit elements, grounded in skills and experience, contextualized through application, and shaped by ongoing management. Furthermore, the dimensions of knowledge are interdependent; the depth of knowledge influences its contextualization, the origin determines its usability, and management practices ensure its persistence across system generations. This conceptualization establishes a consistent analytical basis for identifying knowledge-related risks and opportunities and supports sustainable, generation-spanning engineering practices.

A comparison with established knowledge frameworks shows that the four dimensions align with core mechanisms of the SECI model [13], the co-evolution of concept and knowledge spaces in C-K theory [30], and the dynamic interaction of artifacts and activities described in the System Triple [31]. At the same time, the cross-generational and RSE-based nature of knowledge in SGE introduces requirements not addressed in these models, particularly regarding maturity, validation, and variation decisions. Consequently, an SGE-specific conceptualization is necessary to assess knowledge-related risks and support consistent cross-generational development.

5. Operationalization

The conceptual understanding of knowledge developed in this work represents a first step toward making knowledge empirically assessable within the model of SGE. Given its critical role in enabling consistency across generations, the identified dimensions must be operationalized to support systematic evaluation in development contexts. The objective of this study is to quantify knowledge in relation to RSEs and thereby establish a basis for evaluating consistency risks in cross-generational development.

At the present stage of research, this operationalization is undergoing development. The initial exploratory approaches have been formulated to translate the conceptual categories into assessment questions, with the four identified knowledge dimensions (depth, context, origin, and management) serving as the foundation for this endeavor. These questions are intended to support the structured assessment of knowledge practices in development projects, thereby identifying both strengths and potential risks in terms of consistency.

To illustrate the approach, the following exemplary guiding questions can be formulated:

- Knowledge depth: How does the company ensure that both explicit and implicit knowledge from previous system generations is preserved, documented, and made available for future generations?
- Knowledge context: To what extent is the available knowledge tied to specific contexts, applications, or system generations, and how is it adapted for new contexts?
- Knowledge origin: How are different sources and origins of knowledge (e.g., expert knowledge, application experience, data from previous generations) systematically identified and integrated into the development of new system generations?
- Knowledge management: What mechanisms are in place to recognize and take into account the dynamics of knowledge (change, obsolescence, further development) and ensure its continued relevance?

These questions are not intended to be a comprehensive catalog; rather, they serve as an orientation to illustrate how conceptual understanding can be practically implemented. The objective of the present research is to refine, expand, and validate the inquiries outlined above into a validated assessment catalog. This catalog is to be piloted in industrial settings to enable consistency-oriented decisions across generations.

6. Conclusion and Outlook

This contribution has developed a conceptual understanding of knowledge within the context of the model of SGE. Based on a qualitative analysis, knowledge was described along four interrelated dimensions: depth, context, origin, and management. Combined, these dimensions capture the multifaceted, context-bound, evolutionary, and dynamic character of knowledge and highlight its critical role for the generation-spanning development of complex systems. The proposed understanding integrates explicit and implicit knowledge, skills, and experience into a structured and contextualized framework, thereby providing a consistent analytical foundation for both research and practice.

Utilizing this conceptual foundation, the work delineates initial steps towards the operationalization of knowledge in the model of SGE. Exemplary guiding questions were presented, demonstrating the translation of the four dimensions into practical assessment criteria for evaluating knowledge in development contexts. The purpose of these inquiries is to serve as an introductory guide for the systematic identification of strengths, gaps, and risks in knowledge practices across system generations. Within this broader research program, knowledge is established as one of three pillars for assessing risks to consistency in the cross-generational development of cyber-physical systems. Alongside knowledge, the amount of change and the complexity form complementary pillars, together providing a comprehensive framework for the evaluation of consistency risks.

Subsequent research endeavors will concentrate on refining and validating the proposed operationalization in collaboration with industry partners. This includes the development of a comprehensive and empirically grounded catalog of assessment questions, the integration of quantitative evaluation approaches, and the application of the framework in real-world development projects. Accordingly, the objective of future research is twofold: to provide methodological contributions and to deliver practical applications. The former aims to enable companies to systematically capture, manage, and reuse knowledge across generations.

Acknowledgements

This paper is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – SFB 1608 – 501798263.

References

[1] P. Hong, W. J. Doll, A. Y. Nahm, and X. Li, "Knowledge sharing in integrated product development," European Journal of Innovation Management, vol. 7, no. 2, pp. 102–112, 2004.
[2] B. K. Brockman and R. M. Morgan, "The Role of Existing Knowledge in New Product Innovativeness and Performance," Decision Sciences, vol. 34, no. 2, pp. 385–419, 2003.
[3] A. Albers et al., "PROPOSING A GENERALIZED DESCRIPTION OF VARIATIONS IN DIFFERENT TYPES OF SYSTEMS BY THE MODEL OF PGE – PRODUCT GENERATION ENGINEERING," Proc. Des. Soc.: Des. Conf., vol. 1, pp. 2235–2244, 2020.
[4] A. Albers et al., "The reference system in product generation engineering: structuring reference system elements for advanced systems engineering based on the system triple," Des. Sci., vol. 10, 2024.
[5] A. Albers, S. Rapp, C. Birk, and N. Bursac, Die Frühe Phase der PGE – Produktgenerationsentwicklung, 2017.
[6] A. Albers and S. Rapp, "Model of SGE: System Generation Engineering as Basis for Structured Planning and Management of Development," in Design Methodology for Future Products, Springer, 2022, pp. 27–46.
[7] A. Albers et al., "The Reference System in the Model of PGE: Proposing a Generalized Description of Reference Products and their Interrelations," Proc. Int. Conf. Eng. Des., vol. 1, no. 1, pp. 1693–1702, 2019.
[8] A. Albers, N. Bursac, and E. Wintergerst, "Product generation development–importance and challenges from a design research perspective," New developments in mechanics and mechanical engineering, vol. 13, pp. 16–21, 2015.
[9] L. Gesmann, M. Fischer, A. Martin, T. Düser, and A. Albers, "Towards a Standardized Evaluation Framework for Engineering Changes in the Model of SGE - System Generation Engineering (in press)," Procedia CIRP, 2025.
[10] K. North, Wissensorientierte Unternehmensführung: Wissensmanagement gestalten, 6th ed.. Wiesbaden: Springer Gabler, 2016.
[11] A. Albers, M. Klippert, M. von Klitzing, and S. Rapp, "A METHOD TO SUPPORT THE IMPROVEMENT OF KNOWLEDGE TRANSFERS IN PRODUCT AND PRODUCTION ENGINEERING," Proc. Des. Soc., vol. 3, pp. 283–292, 2023.
[12] M. Broadbent, "The Phenomenon of Knowledge Management: What Does it Mean to the Information Profession?," Information outlook, vol. 2, no. 5, pp. 23–36, 1998.
[13] I. Nonaka, H. Takeuchi, and F. Mader, Die Organisation des Wissens: Wie japanische Unternehmen eine brachliegende Ressource nutzbar machen, 2nd ed. Frankfurt am Main, New York: Campus Verlag, 2012.
[14] Verein Deutscher Ingenieure, "VDI Richtlinie 5610 Wissensmanagement im Engineering - Grundlagen, Konzepte, Vorgehen," Verein Deutscher Ingenieure, 2009.
[15] A. Albers, T. Hirschter, J. Fahl, and S. Rapp, "Analysis of the variation of the element types of properties and functions of technical systems in product development practice," Procedia CIRP, vol. 100, pp. 876–881, 2021.
[16] C. Rolland and N. Prakash, "A Proposal For Context-Specific Method Engineering," in Method Engineering: Principles of method construction and tool support, S. Brinkkemper, K. Lyytinen, and R. J. Welke, Eds., Boston, MA: Springer US, 1996, pp. 191–208.
[17] C. McInerney, "Knowledge management and the dynamic nature of knowledge," J. Am. Soc. Inf. Sci., vol. 53, no. 12, pp. 1009–1018, 2002.
[18] T. A. Stewart, The Wealth of Knowledge: Intellectual Capital and the Twenty-first Century Organization. Crown, 2007.
[19] A. Albers, S. Rapp, N. Heitger, F. Wattenberg, and N. Bursac, "Reference Products in PGE – Product Generation Engineering: Analyzing Challenges Based on the System Hierarchy," Procedia CIRP, vol. 70, pp. 469–474, 2018.
[20] M. Klippert, A. Preißner, H. Rust, and A. Albers, "Analysis of Factors Influencing Knowledge Transfer between the Product and Production System Development as well as Production," Procedia CIRP, vol. 109, pp. 340–348, 2022.
[21] A. Albers, S. Rapp, and M. Grum, "Knowledge Transfer Velocity Model Implementation – An Empirical Study In Product Development Contexts," in Knowledge Transfer Speed Optimizations in Product Development Contexts, N. Gronau and M. Grum, Eds., Gito, 2019, pp. 93–105.
[22] G. Probst, S. Raub, and K. Romhardt, Wissen managen. Wiesbaden: Gabler Verlag, 2012.
[23] A. Albers et al., "Product-Production-CoDesign: An Approach on Integrated Product and Production Engineering Across Generations and Life Cycles," Procedia CIRP, vol. 109, pp. 167–172, 2022.
[24] C. Kempf et al., "Recommendations to improve the usability of research results as reference system elements addressing corporate engineers, researchers, and policymakers," Journal of Thermoplastic Composite Materials, 2025, Art. no. 08927057251318722.
[25] H. McManus and D. Hastings, "A framework for understanding uncertainty and its mitigation and exploitation in complex systems," IEEE Eng. Manag. Rev., vol. 34, no. 3, p. 81, 2006.
[26] A. Albers, V. Zimmermann, F. Marthaler, N. Bursac, K. Duehr, and M. Spadinger, "SELECTION OF REFERENCE SYSTEM ELEMENTS IN THE MODEL OF PGE - PRODUCT GENERATION ENGINEERING: METHOD FOR THE INTEGRATION OF CUSTOMER AND USER SATISFACTION IN PRODUCT PLANNING," Proc. Des. Soc., vol. 1, pp. 2611–2620, 2021.
[27] C. Kempf, S. Rapp, K. Behdinan, and A. Albers, "Reference System Element Identification Atlas – methods and tools to identify references system elements in product engineering," World Patent Information, vol. 75, p. 102239, 2023.
[28] A. Albers et al., "Influencing factors and methods for knowledge transfer situations in Product Generation Engineering based on the SECI model," in DS 91: Proceedings of NordDesign 2018, Linköping, Sweden, 2018.
[29] A. Albers et al., "Consistency in Cross-Generational Engineering of Cyber-Physical Systems," in DS 133: Proceedings of the 35th Symposium Design for X (DFX2024), 2024, pp. 85–94.
[30] A. Hatchuel and B. Weil, "A NEW APPROACH OF INNOVATIVE DESIGN : AN INTRODUCTION TO C-K THEORY," in DS 31: Proceedings of ICED 03, the 14th International Conference on Engineering Design (DS / Design Society 31), A. Folkeson, K. Gralen, M. Norell, and U. Sellgren, Eds., Design Society, 2003.
[31] G. Ropohl, Allgemeine Technologie: Eine Systemtheorie der Technik. Universitätsverlag Karlsruhe, 2009.
[32] Albers, Albert, Lohmeyer, Quentin, Ebel, and Bjoern, "Dimensions of Objectives in Interdisciplinary Product Development Projects," DS 68-2: Proceedings of the 18th International Conference on Engineering Design (ICED 11), vol. 68, no. 2, pp. 256–265, 2011.