Knowledge types to support product developers in different product engineering activities - a Systematic Literature Review

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Abstract: Product engineering is a highly knowledge intensive process, where knowledge is required as input for various decisions and product engineering activities and is created and gathered during engineering activities such as validation. Thereby, the efficient management of this knowledge can be a strong competitive advantage and is essential for product development in short time and high quality. Methods to gather, transfer and work with and organize the right knowledge in the right moment can increase the efficient management of knowledge. However, to enable this, it is necessary to analyze the knowledge types required in specific product engineering activities. Therefore, in a Systematic Literature Review, the respective literature was analyzed, summarize and clustered in 7 categories of knowledge relevant for product engineering. Furthermore, the allocation of the identified knowledge types to product engineering activities was explored.

1. Motivation

Product engineering is mainly driven by knowledge. With technological progress, the complexity of products and systems are also constantly increasing, forcing companies to build up expertise to deal with them. Additionally, the decreasing life cycles of products increase the requirement to bring competitive products to market in shorter time [1]. Thus, it is important, that in addition to the knowledge continuously generated in the development process, existing knowledge from previous product generations can be effectively reused, because long-term success of companies is based on knowledge from past projects and requires an overview of the existing knowledge [2]. Therefore, product developers must identify and use the right knowledge in and for the respective product engineering activity as basis for the development and engineering of new product generations. In doing so, different types of knowledge are required for different product engineering activities [3].

Many authors already dealt with structuring knowledge types relevant for product engineering and applied various metrics. This contribution aims at adding another structure of the relevant knowledge types to be able to match them with the engineering activities and enable the transfer and reuse of knowledge based on the understanding of the reference system [4].

2. State of the Art

2.1 Process models in product engineering

Various models exist to describe product engineering processes and projects. These approaches aim at structuring product engineering projects by providing frameworks, process models and activities. Thereby, product developers shall be assisted in reaching their development goals. Well established approaches such as the 3-cycle model of product creation [5], the VDI 2221]6] or the V model of the standard VDI 2206 [7] pursue these goals on different levels of formalisation and detail.

With the iPeM – integrated Product engineering Model, Albers et al. provide a holistic process model that closes the gap between engineering design and process management [8]. Thereby, the iPeM (compare figure 1) is based on the system triple of product development and describes product engineering as the continuous realisation of the system of objects according to a system of objectives through the operation system [9]. The operation system is a socio-technical system comprised of structured processes activities and processes, while the activities are divided into macro (areas of engineering) and micro (technical problem solving) activities [10].

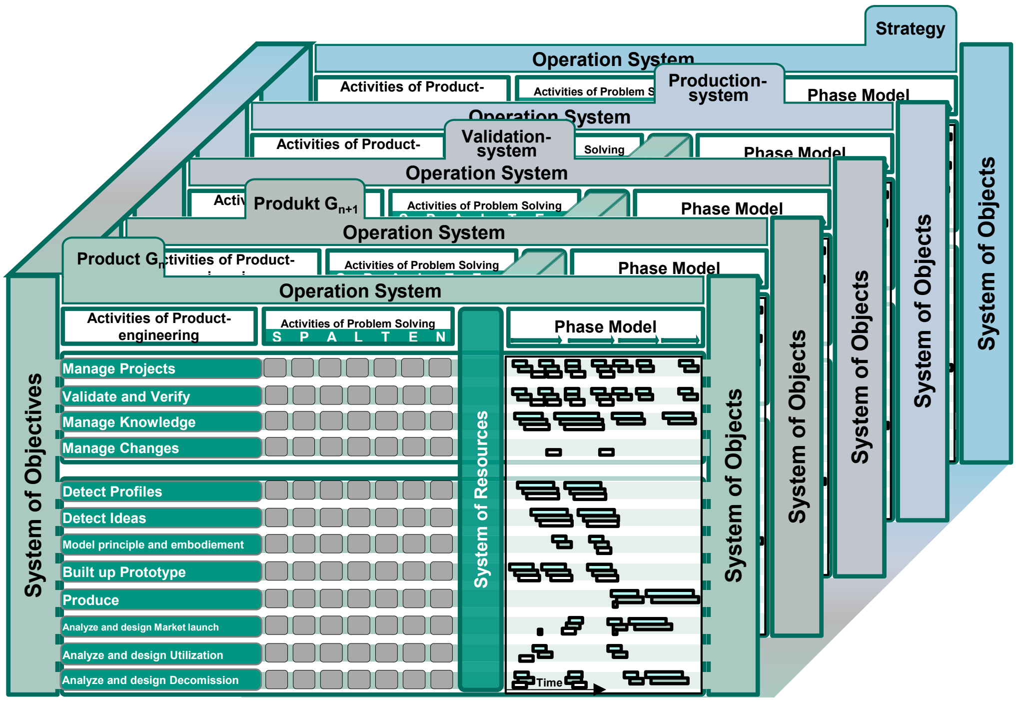

Figure 1: iPeM - integrated Product engineering Model [10]

The iPeM has various layers representing and enabling to model various areas of a company or development project [10]. This enables the consideration of knowledge transfer in between these areas as well as required and evolved knowledge for the different activities.

2.2 Reuse of existing knowledge in product development

Since technical products increase in complexity and are required to be developed in a decreasing amount of time, the reuse of existing knowledge and solutions is inevitable [11] and already subject of research for many years [12,13,14,15].

With the model of PGE – Product Generation Engineering, Albers offers a model to describe the development of any new technical systems. One basic assumption made in the model of PGE is, that “[e]very product development is based on existing subsystem solutions or concepts – referred to as “reference products”. Their structure and subsystems are either carried over in the engineering of new technical products or serve as a starting point for developing subsystems newly. The engineering of every new technical product is thus seen as the development of a new product generation, even if it is the first generation of a certain product. Reference products can be chosen from immediate predecessors of a product generation but also competitive products, products from different sectors, systems from R&D projects or university research” [4].

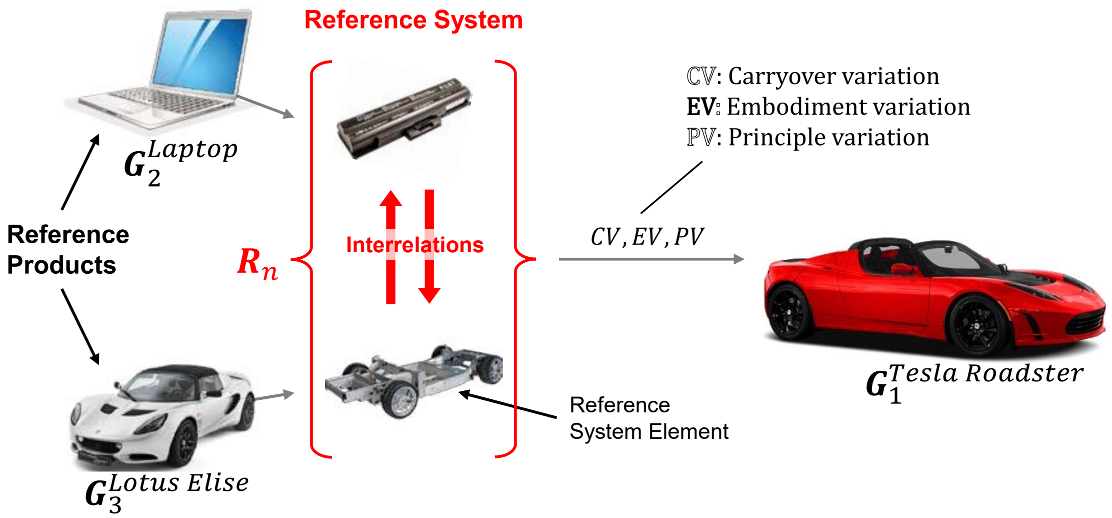

Figure 2: The reference system in the model of PGE [4]

Thereby, the reference system in the model of PGE offers a possibility to describe the transfer of existing knowledge into the current product development project.

Various authors already investigated the classification of knowledge in product development. For example, Hubka distinguishes in the classification of design knowledge between the specifications expertise, procedural knowledge, know-how and theory [16]. In another classification according to Ahmed, a distinction is made between process and product knowledge [17]. Another perspective is presented by Venselaar, where four types of knowledge are noted. These four types of knowledge are named as declarative, procedural, situational and strategic knowledge. In addition, a further distinction is made between these knowledge types as domain-specific and general [18].

With the aim of structuring the knowledge types in the field of product development, a model is designed by Roth by defining 14 knowledge types that are of importance with regard to the product development process [19].

3. Research Questions, Methodology

The current state of research reveals a research gap regarding the classification of knowledge types in the field of product engineering. Different, individual classification approaches and definitions prevail, so that there is no uniform structuring of knowledge types in product development. Therefore, this paper aims to answer the following research questions:

1) Which types of knowledge are described in the literature in the context of product engineering?
2) How can the identified knowledge types be structured in the context of product engineering?
3) How can these types of knowledge be assigned to the activities of product engineering?

To identify contradictory or similar findings on this topic the approach of a systematic literature review (SLR) is used. The process of the SLR consists of several steps, beginning with the definition of research questions, which are stated above [20]. In a second step relevant types of literature, a suitable search string and a search engine are defined. This SLR was limited to journals and conference proceedings as source types.

The identification of relevant literature is done by choosing a suitable search string that allows to find a large number of definitions and understandings of knowledge types in product development. Therefore, the search string should meet the following criteria:

- Finding types of knowledge, knowledge characteristics as well as fields of knowledge
- Finding possible knowledge designations, knowledge structuring and classification approaches
- Limitation of the search to the field of product development and related areas

Meeting the above criteria, the following string is used for the systematic literature search:

("knowledge type" OR "type* of knowledge" OR "knowledge characteristic*" OR "characteri* of knowledge" OR "knowledge domain*" OR "domain* of knowledge" OR "knowledge field*" OR "field* of knowledge" OR "knowledge area*" OR "area* of knowledge" OR "knowledge generaliz*" OR "generaliz* of knowledge" OR "knowledge classify*" OR "classification* of knowledge" OR "knowledge generali" OR "knowledge evaluation" OR "evaluation of knowledge" OR "knowledge naming" OR "naming of knowledge" OR "knowledge identification" OR "identification of knowledge") AND ("product develop*" OR "product design" OR "product engineering" OR "innovation management" OR "knowledge engineering" OR "innovation engineering")*

Screening the digital library "Scopus", 1047 documents could be identified (February, 28th 2021). Limiting these results to English and German language and to conference proceedings and journals, 991 documents remain. Subsequently, afterwards abstracts are analyzed to remove non-relevant contributions resulting in 153 documents. Therefore, inclusion and exclusion criteria were defined. Documents, which are too specific to an individual context or do not focus on knowledge types in product development are excluded. After reading the full-text, in total 29 literature sources could be identified, which are then analyzed completely to answer the first research question.

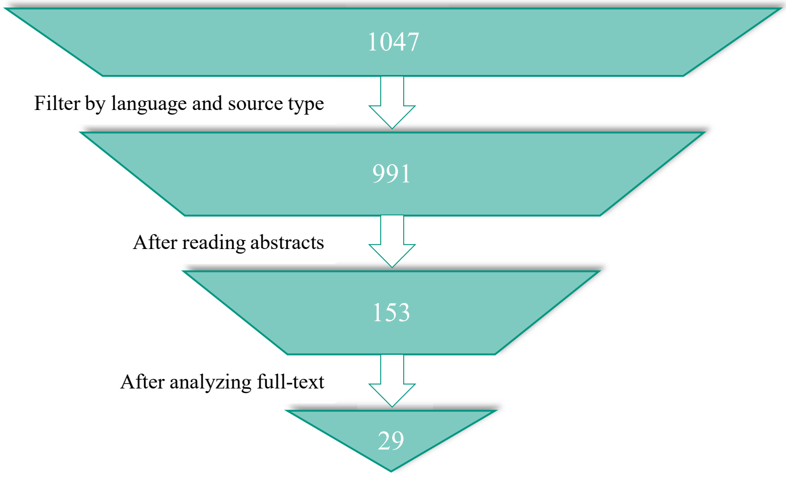

Figure 3 : Filtering process of literature

From these literature results, knowledge types are structured to answer the first and second research questions. These findings are evaluated and further supplemented in an online workshop. Industry persons from different companies as well as scientific researchers from Karlsruhe Institute of Technology (KIT), which all work in the field of product development, participated in this workshop.

First, the objective of the literature research and the workshop procedure were explained to the participants. An online collaboration platform was used for the interactive design of the workshop. This allows the participants to work simultaneously on different, previously defined tasks. The identified types of knowledge, which have been structured beforehand, served as a basis for the participants so that they can evaluate and add further types of knowledge in product engineering. To answer research question three, the participants were asked to assign these knowledge types to the activities of product engineering.

4. Results

4.1 Results of the systematic literature review

The systematic literature review provides various perspectives of knowledge types from different authors which are listed in the following table. From this, the inconsistent nomenclature within the subject matter becomes evident.

Table 1 Types of knowledge in product engineering – results of the SLR

Source	Knowledge Types
Ganesan et al., 2015 [21]	Product knowledge, process knowledge
Frishammar et al., 2012 [22]	Domain-specific knowledge, procedural knowledge, general knowledge

Fu et al., 2006 [23]	Market knowledge, human knowledge, technology knowledge, procedural knowledge
Rundquist, 2012 [24]	Domain-specific knowledge, procedural knowledge, general knowledge
Ahmed, 2007 [25]	Process knowledge, product knowledge, declarative knowledge, Procedural knowledge, situational knowledge, strategic knowledge
Xu et al.,2013 [26]	Descriptive knowledge, procedural knowledge, reasoning knowledge
Corallo, 2012 [27]	Business Knowledge, Technical Knowledge Business knowledge: costs of production, business strategy etc. Technical knowledge: product functionality, product technology etc.
Marvel and Droege, 2010 [28]	Knowledge of ways to serve markets, knowledge of customer problems, knowledge of markets, knowledge of technology
Gao and Nee, 2018 [29]	Declarative knowledge (know-what), procedural knowledge (know-how), causal knowledge (know-why
Roth et al., 2010 [19]	Various classifications: 1) Design knowledge specifications: Expertise, procedural knowledge, know-how, theory 2) Process and product knowledge 3) Declarative, procedural, situational and strategic knowledge Own classification: 14 knowledge types: Expert, normative, specialized and factual, experience, episodical, practical, general methodical, special methodical, operational, conditional, management, product, market-/customer and business strategy knowledge
Cross and Sivaloganathan, 2007 [30]	Specialist knowledge with 10 knowledge components: Country- or market specific requirements Experience, best-practice, tips and tricks Product-specific parameters Interactions, trade-offs and design rules Knowledge contacts Legislation Manufacturing process capability and available materials Preferred parts and installation requirements Stakeholder behavior Stakeholder requirements and feedback
Wölfel, 2008 [32]	Design Knowledge: divided into object knowledge, realization knowledge and process knowledge
Ahmed et al., 2020 [33]	Knowledge related to product design, its manufacturing and knowledge related to quality procedures
Jauregui-Becker and Wits, 2012 [34]	Declarative and procedural knowledge in design process
Tama and Reidsema, 2010 [35]	Product design: market, human, technology and procedural knowledge
Zhenyong et al., 2020 [36]	know-what, know-why, know-how, know-who; knowledge management including customer information, product development, production files, and product delivery and service; knowledge in product design and development stage: design method, design rule, factual knowledge, design principle, product model, design process knowledge, domain expert knowledge, and product design cases
Wang et al., 2018 [37]	Concept development of product design: Process knowledge: design methods, techniques, principles, criteria, strategies Product knowledge: requirements, appearances, functionalities, techniques to achieve functionalities, structures, relations between parts and assemblies, various constraints, design rationale
Vroom and Olieman, 2011[38]	Industrial design engineering knowledge: design theories, methods and techniques; design aspects; product domains
Morkvenas et al., 2009 [39]	Explicit and tacit knowledge
Ahmed et al., 2020 [40]	Required features of the product, available materials, manufacturing processes, assembly, and measurements of parts; material selection: strength, stiffness, cost and aesthetics product geometric features generation product design: knowledge to generate ideas, knowledge to evaluate ideas, make decisions, and to structure the design process
Duda, 2018 [41]	Production knowledge
Luft and Wartzack, 2012 [42]	Product Knowledge: product requirements, construction technology, metrology, product

	configuration and structure Process Knowledge: process requirements, process description Document knowledge: Internal, external knowledge Empirical knowledge: Internal, external knowledge
Yuping et al., 2008 [43]	Product Design Knowledge divided into: Requirement Design: Enterprise Requirement, Use Requirement, Technical Requirement Conceptual Design: Principle Analysis, Functional Analysis, Structural Analysis, Case Base Detailed Design: Standard Specification, Technical Manual, Standard Part, Manufacturing Assembly Information
Goto et al., 2008 [44]	Design Knowledge: five types product structure, product hierarchy, product function, product constraint, design process
Donnellan and Fitzgerald, 2004 [45]	Seven different classifications: 1) Prescriptive (know-how), descriptive (know-that) 2) Shared work producers, shared work practitioners, expertise seeking novices, knowledge producers 3) Explicit, tacit 4) Conceptual framework, system architecture, system design, system prototype, system evaluation 5) Knowing the organization, the players in the game, how to coordinate across time and space, how to develop capabilities, how to innovate 6) Tacit, explicit, operative, substantive, heuristic, algorithmic, deep, shallow 7) Pre-project, product and process design, manufacturing Own classification: Shallow: market opportunities, meeting potential customer needs Fundamental Principles: fundamental engineering principles and challenges, theoretical concepts, practical implications Operative: knowledge how to execute the nitty-gritty aspects of design and resolve engineering problems Procedural: developing of a process for the development process Causal: explore causative aspects of product performance in the market place
Schmidt et al., 2015 [46]	Product-depended (product characteristics) and product-independent knowledge (basic and specific knowledge)
Ma et al., 2013 [47]	Function, structure and process knowledge
Van der Elst and Van Tooren, 2009 [48]	Domain-specific vs. problem-specific and conceptual vs. procedural
Deng et al., 2009 [49]	Knowledge about product (divided in knowledge about product description and product state), processes, methods, tools, specific application domains and other resources

4.2 Structuring approach of knowledge types in product engineering

Based on the results from the literature review, the knowledge types are structured to summarize required knowledge in product engineering. By clustering the knowledge types, seven categories of knowledge were identified according to the content:

1) Common knowledge
2) Management knowledge
3) Market knowledge
4) Product knowledge
5) Production knowledge
6) Process knowledge
7) Technology knowledge

The knowledge types from literature are assigned to these categories and are then presented in a workshop with experts in the field of product engineering from research and practice. The participants are invited to brainstorm further knowledge types to the presented structured knowledge types collected from literature.

It was intended to structure all knowledge types identified from literature and in the workshop to the seven categories in a hierarchical way. However, it was not always possible to distinguish whether the results of both, literature review and workshop are knowledge types or rather information. That is why, it was not possible to assign the results to different levels of abstraction. Further studies are therefore needed.

4.3 Linkage model of the knowledge types to the activities of product engineering

During the second part of the workshop the participants were asked to assign the knowledge types from literature and workshop as required input knowledge for the activities of product engineering of the iPeM. An excerpt of this allocation from the digital whiteboard of the workshop is shown for category 3 "Market knowledge" in *Figure **4***. The shown excerpt of the whiteboard is in German language since the workshop was conducted in German. On the left-hand side knowledge types from literature (yellow notes) and additional knowledge types from workshop participants (orange and green notes) are illustrated. On the right-hand side the workshop participants assigned those knowledge types to the product engineering activities. It needs to be emphasized, that due to the limited time of the workshop, it was not possible to assign all knowledge types to the activities. A conclusive matching of knowledge types to the activities should be done in a follow-up study.

Nevertheless, the results of the workshop confirm, that knowledge types are necessary in several engineering activities and that not all knowledge types are relevant in each activity.

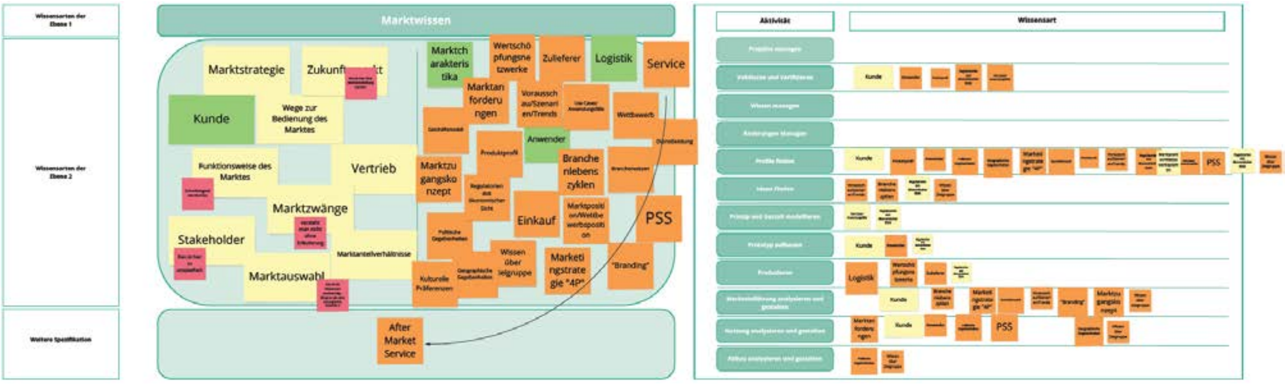

Figure 4 : Excerpt of the results of the workshop

5. Discussion and Outlook

This research paper provides an overview of different types of knowledge in the context of product engineering. This summary already illustrates that a variety of also inconsistent classifications and structuring's exist. These vary not only in the classification of knowledge, but also in the level of abstraction.

Since there is no universal understanding of knowledge types in the field of product engineering, different types of knowledge are also often not clearly distinguishable from each other. Therefore, it was necessary to make a specific classification that meets the requirements of an engineering process. For the assignment of knowledge types to product engineering activities, the iPeM served as an appropriate basis.

The assignment of the knowledge types to the activities of the product engineering was done by experts in a workshop and, thus represents a subjective perception. Due to the workshop design (mostly the limitation of time), no conclusive result could be reached and the illustrated result in Figure 4 can only represent an intermediate result and has to be investigated further (e.g. there are activities with no knowledge types assigned at all). Therefore, the performed assignment does not provide valid results to make statements about knowledge types as relevant input for the respective activities. It must also be analyzed whether the chosen degree of abstraction of the knowledge types is suitable to enable a linkage with the activities of product engineering.

In a holistic evaluation of this research it can be stated that the presented structuring of knowledge types of product engineering is not yet a suitable basis for product developers to identify necessary knowledge for their engineering task. Therefore, it must be noted that this work is not exhaustive and further specification and validation steps are required for an activity-based assignment of knowledge types in the context of product engineering.

In consecutive research, the allocation of knowledge types to engineering activities can be the input for an approach based on the understanding of the reference system for knowledge transfer in engineering projects and processes. Hereby, the activity specific allocation offers the potential to establish approaches based on the understanding of the reference system that are adaptable to the activities.

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