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GENERIC STRUCTURE OF KNOWLEDGE WITHIN THE PRODUCT DEVELOPMENT PROCESS

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1. Introduction

"Knowledge has become the most crucial component in the struggle for competitiveness" [Richter, 1995]. This is why the resource knowledge turns out to be an increasingly important factor of success, especially in the dynamic and complex markets. Information and knowledge are consequently shifted into the focus of the value-added process. From this statement, it can be concluded that knowledge has to be instrumentalised in order to improve competitiveness.
However, the intention of this paper is not to follow up with general approaches of knowledge management systems, but to develop a basic structure for knowledge within the product development process (PDP). Literature contains a large number of procedures for analysing, classifying and naming knowledge. The authors deduce from their analyses that there is no standardised terminology that allows rectified actions dealing with the resource knowledge in the future. However, it is not the intention to define a general terminology. The multidisciplinary character of knowledge and the various criteria resulting from different points of view and goals suggest a high number of taxonomies on itself. Therefore, the issue of a preferable, general structure of knowledge within the PDP is discussed to make it available to several fields of applications. On the one hand, the focus is especially on the implementation of an agent-based design system for the PDP and, on the other hand, on modern methods for the evaluation of companies and their knowledge as a dynamic quantity – the so-called intellectual capital reports.
The secondly mentioned area offers chances to develop the knowledge base and thereby the opportunity to enhance the whole PDP (costs, time …). The following considerations apply to several basic approaches as well as to the development of a proposal for a structuring model.

2. Overview of general structuring models for knowledge

The term "*knowledge*" has been interpreted in several forms in literature. The authors naturally require that it is essential to first clarify the meaning for the paper and the following development of a structuring model within the product development process. In agreement with Ahmed [Ahmed 2005], amongst other things, knowledge can be subdivided in explicit, implicit and tacit knowledge. Explicit knowledge – from the author's view referred to as "information" (knowledge cannot be externalised without losing its necessary time-independent networking and contexts) – is knowledge that can easily be deposited, stored and managed. Implicit knowledge represents knowledge that is hard to externalise and, in extreme cases, knowledge that cannot be externalised (so-called tacit knowledge – the intuitive feeling of the designer). To consider the composition of knowledge (data/information/knowledge) helps to understand this view. Ahmed states that "in general, definitions of information distinguish

information from data through a context, implying that this context is included in information and not in data" [Ahmed, 1999].
In addition, she says that the user's role "is to determine what is data, information and knowledge. Data, information and knowledge are relative concepts that cannot be defined in absolute terms as they are dependent on the user. The distinction between data and information depends on the user's awareness of the context. The distinction between information and knowledge is dependent on the user's ability to interpret the information" [Ahmed 1999] (shown in Figure 1).

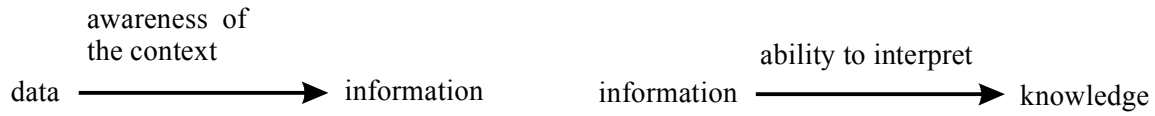

Figure 1. Composition of knowledge

2.1 General approaches of structuring models for knowledge

Published in 1982, Hubka [Hubka, 1982] dealt with a distinction of engineering design knowledge for the first time. Four specifications (Expertise, Procedural knowledge, Know-how and Theory) induce a subcategorisation of engineering design knowledge as shown in Table 1.

Table 1. Distinction of engineering design knowledge

	Expertise - propositions about technical systems	Procedural knowledge - propositions about the design process
Know-how - prescriptive propositions	Design know-how	Knowledge about the design process
Theory - descriptive propositions	Theory of technical systems	Theory of design processes

Ahmed distinguishes two types of knowledge (Table 2) following Evbuoimwan`s idea [Evbuoimwan 2007]. Product knowledge dealing with the artefact to be designed opposed to process knowledge, which is concerned with the activity of designing itself [Hubka 1982].

Table 2. Process and product knowledge classifications [Ahmed 2005]

	Explicit	Implicit	Tacit
Process knowledge	Explanations about the process	Understanding about the process	Intuition about the process
Product knowledge	Explanations about the product	Understanding about the product	Intuition about the product

Venselaar [Venselaar, 1987] suggests in a further distinction of knowledge that it can be divided into domain-specific knowledge and knowledge about general processes (see Table 3). Each of those types of knowledge distinguishes between four other types of knowledge. Declarative knowledge describes facts and procedures for special domains, procedural knowledge is knowledge about "how to undertake some action". Situational knowledge offers insights into the context in which knowledge should be used and, finally, strategic knowledge that "is described as knowledge of processes that are systematic and consciously invoked to facilitate the acquisition and utilisation of knowledge" [Ahmed, 2005].

Table 3. Distinction of knowledge [Venselaar 1987]

	Domain-specific knowledge		General Process
	Basic knowledge	Domain knowledge	
Declarative knowledge	Knowledge of facts and formulas	Knowledge of design facts and methods	Knowledge of methods to optimise the process

Procedural knowledge	How to use these facts and formulas	How to use these design facts/methods	How to use these design facts/methods
Situational knowledge	When and where to use this basic knowledge	When and where to use this design knowledge	When and where to use this process knowledge
Strategic knowledge	Knowledge of algorithms and heuristics of relevant domains	Knowledge of heuristics in solving design problems	Knowledge of algorithms and heuristics in problem solving

Based on these and other findings, Ahmed tried to identify the meaning of data, information and knowledge for designers. In order to determine which knowledge is necessary or must be captured to support the engineering design process, "a total of 24 knowledge types required by engineering designers working in the aerospace industry were identified prior to [her] interviews. The final coding scheme consisted of […] 24 categories describing [three types of knowledge]: process knowledge, product knowledge and management knowledge" [Ahmed, 2005].

In practice, the afore mentioned distinction of knowledge, inter alia by Ahmed, (explicit, implicit and tacit) is often too rigid. Therefore, Snowden (Europe director of the institute for knowledge management) developed the ASHEN concept that arranges knowledge in five categories. It is easier to reveal and to manage the flow of knowledge with respect to this procedure in daily practice. The five categories are [Snow, 2000]:

- **A**rtefacts: Documented knowledge items – explicit things which can be handled and managed.
- **S**kills: The ability of doing something which one can learn by practising.
- **H**euristics: Systems and rules of thumb, used by experts in case of uncertainty or for fast decision making. They can be codified, but can never be used without precaution.
- **E**xperience: Observation or acquaintance with facts or events.
- **N**atural talent: An innate gift and therefore unlearnable personal talent.

Contrary to this, Mandl and Reinmann-Rothmeier differentiate between five types of knowledge: social, metacognitive, strategic, procedural and domain-specific knowledge. Social knowledge represents social skills and competencies. A distinction is made here between intrapersonal (ability for self-perception and assessment) and interpersonal competence (ability for concerted action). Metacognitive knowledge is knowledge about the consciousness which strategy should be used while solving a problem. Strategic knowledge involves problem-solving strategies for tasks with no existing general solutions. Procedural knowledge offers awareness what to do in a given situation. And, finally, domain-specific knowledge represents knowledge about facts and occurrences while dealing with a task or solution [Lehner, 2009].

Amelingmeyer [Amelingmeyer, 2002] takes the next step and develops a structuring model that adds some elements to the normal consideration of general knowledge which allocates knowledge to its knowledge carrier as well as considerations about the availability of knowledge depending on several aspects. Table 4 shows the structuring model based on Amelingmeyer. Knowledge which can be classified into its level of reference, degree of explicity, field of knowledge and reference to the company. Two types of knowledge – skill-linked knowledge and action-linked knowledge – can be distinguished especially with regard to the knowledge in a company [Amelingmeyer, 2002]. Knowledge carriers are those elements in which knowledge manifests itself. The availability of knowledge indicates how (to what extent) a company can apply knowledge and/or its correlative knowledge carrier for corporate goals.

Table 4. Basics of a structuring model in accordance with Amelingmeyer

Knowledge (structured according to the type of knowledge)	Level of Reference	Skill-linked knowledge (awareness)
		Action-linked knowledge (ability)
	Degree of explicity	Explicit knowledge
		Implicit knowledge
	Field of knowledge (structured according to …)	Scientific field
		Field of application/domain

		Management by criteria
	Reference to the company (structured according to …)	Field of application within the company
		Company specificity of knowledge
		Degree of novelty for the company
		Relevance for the company
"Knowledge carrier"	Personal knowledge carrier	Expertise
		Methodical competence
		Personality and social competence
	Material knowledge carrier	Print-based knowledge carrier
		Audio-visual knowledge carrier
		Computer-based knowledge carrier
		Product-based knowledge carrier
	Collective knowledge carrier (distinction between …)	Levels within the company
		Formal and informal knowledge carrier
Availability of knowledge (depending on …)	Relationship of the knowledge carrier to the process	
	Location of knowledge carrier	
	Legal regulations	
	Given situation	
	Existing meta-knowledge	

Thel [Thel, 2007] provides a detailed structure of product development knowledge by defining six ontologies that are related to each other by means of a superior ontology, each representing a part of product development knowledge. Concrete product development knowledge appears as so-called "*knowledge item*" classified in one of the sub-ontologies. He observes (in compliance with the authors) that there is no standardised definition for knowledge types and that general approaches in literature have common ideas. His proposed structuring model is shown in Table 5.

Table 5. Structuring model in accordance with Thel

Structure and procedure knowledge	General	
	Specific to a company	
	Specific to a person	
Expertise	Discipline knowledge	Mechanics, physics, chemistry, ...
	Knowledge of companies	Standards, guidelines
	Standardised knowledge	General standards and guidelines
Product knowledge	existing product knowledge	Database, ,experience of engineers
	newly developed product knowledge	Processible/non-processible data

He identifies three categories of knowledge: Structure and procedure knowledge, expertise and product knowledge. Structure and procedure knowledge represents knowledge about the design process itself. The expertise constitutes knowledge that is also known as know-how, basic knowledge or structured knowledge. Product knowledge describes knowledge about products and designs. Table 5 lists the other sub-levels of his model.

2.2 Result

As mentioned initially, there is no consistent taxonomy of knowledge due to its multidisciplinary character. Different aspects are in focus, depending on the point of view and objectives. The next chapter offers the development of a structuring model for knowledge within the product development process while keeping in mind the fields of application mentioned in chapter 1. The analysis and research in chapter 2.1 and others show that nowadays structuring models of knowledge do not evince which knowledge is dominant in which field in the product development. There is also no way to show

the relationships and dependencies between each knowledge type. Hence, a more specific structure of product development knowledge is required and must be generated.

3. Development of a structuring model for product development knowledge

A major difficulty while developing a structuring model for knowledge within the product development process is the differentiation of the individual terms to each other and also an inconsistent terminology in literature with regard to a professional as well as a linguistic level (i.e. *english: "tacit knowledge"* means knowledge that cannot be externalised, contrary to *german: "tacit knowledge"* that represents communicable, but not communicated knowledge).
Based upon these general approaches, the terminologies introduced in chapter 3.1 allow the development of a consistent structuring model for product development knowledge. Chapter 3.2 presents the final general theoretical model.

3.1 Terms for knowledge in the context of product development

- **Type of knowledge:** The type of knowledge describes the specific/thematic domain represented by the knowledge – for example, specialised knowledge, product knowledge, methodical knowledge etc.
- **Character of knowledge:** Characteristic properties (implicit, explicit, individual, collective, intern, extern, etc.) describe the type of knowledge.
- **Form of knowledge:** Form of occurrence of knowledge – Text, formula, figure, rule, etc.
- **Location of knowledge:** Defines the origin of the knowledge – Person, database, department, etc.
- **Knowledge quality:** Subsequently, the knowledge quality should provide an answer for the question, if the company possesses the "correct" knowledge. However, the meaning "correct" is not discussed in this article. It has been suggested that an increasing knowledge quality contributes to the success of a product. But in this case as well, the question about the "success" remains. It has to be defined how to interpret success – as an increasing efficiency/effectiveness of product development process or even something else.

The demand that correct knowledge has to be at the right time at the right place in an adequate form is not the task of a structuring model, it should rather be born in mind in current knowledge management systems. Following considerations focus primarily on knowledge types and secondarily on their characteristics.

3.2 First general structuring model

The types of knowledge in Table 6 (first left column) are the result of an intensive literature research and represent, from the author's point of view, those knowledge types which are theoretically relevant in the product development process. The first row shows the four phases of the product development process in accordance with Pahl/Beitz [Pahl, B., Beitz, W., "*Engineering Design – A Systematic Approach*", Springer, Berlin, 2003], specified in the second row (specific stages of the PDP). A first theoretical investigation provided an allocation of each knowledge type to the specific phases, as required (shown in Table 6). Hence, each knowledge type will be introduced (reduced form for the paper.

- **Expert knowledge:** Expert knowledge includes the hidden cognitive abilities. It stands for a profound understanding of a specific domain.
- **Normative knowledge (know-why):** Normative knowledge refers to a more particular determination about why to do something and what is the motivation behind to reach a specific objective.
- **Specialised and factual knowledge:** Specialised knowledge describes the necessary knowledge in a specific field. Factual knowledge is a special characteristic of specialized knowledge and encompasses knowledge about facts (static knowledge of terms, objects, relations, etc.), actions, procedures or processes, which are conscious and could be verbalised [Wiater, 2007].

Table 6. Knowledge correlating with the phases of the product development process – in detail

phases of the product development process (PDP)	planning					conceptual design					embodiment design							final design		
specific stages of the product development process / types of knowledge	Analyse the market and the company situation	Find and select product ideas	Formulate a product proposal	Clarify the task	Elaborate a requirements list	Identify essential problems	Establish function structures	Search for working principles and working structures	Combine and firm up into concept variants	Evaluate against technical and economic criteria	Preliminary form design, material selection and calculation	Select best preliminary layouts	Refine and improve layouts	Evaluate against technical and economic criteria	Eliminate weak points	Check for errors, disturbing influences and minimum costs	Prepare the preliminary parts list and production and assembly documents	Elaborate detail drawings and parts list	Complete production, assembly, transport and operative instructions	Check all documents
expert knowledge					■			■			■	■		■		■				
normative knowledge	■	■	■	■	■		■	■		■				■						
specialised and factual knowledge	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
experience knowledge	■	■				■	■	■		■	■		■	■	■	■		■		■
episodical knowledge		■				■	■	■	■		■					■	■			■
practical knowledge	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■
strategical and methodical knowledge		■	■	■			■	■	■	■	■	■	■	■						
special kethodical knowledge		■		■	■		■	■		■	■	■		■		■				
operational knowledge			■	■		■	■	■			■		■		■			■		
conditional knowledge		■			■			■			■									
management knowledge	■	■		■					■		■	■								■
product knowledge	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
market knowledge	■	■	■	■	■															
customer knowledge	■	■	■	■	■				■	■		■		■						■

- **Experience knowledge:** Experience knowledge represents the wealth of experience which a person has. It can be built up by repeating an action in the process of time.
- **Episodical knowledge:** Episodical knowledge refers to memories which are linked to an assigned situation, for example to events or actions and their circumstances [Wiater, 2007].
- **Practical knowledge (know-how):** Describes knowledge about what to do in a particular situation under given conditions [Wiater, 2007].
- **General methodical knowledge:** Knowledge that includes general procedures which are not linked with determined knowledge fields (but can be used instead of different situations). It can be classified in relation to its objectives (problem-solving, reducing complexity, market strategies etc.).
- **Special methodical knowledge:** Knowledge that is necessary for the usage of methods and procedures, containing all necessary instruments for solving a task.
- **Operational knowledge:** Operational knowledge is the ability to solve problems in practice. There are three different types: intuitive (talent), knowledge based on experiences or given procedures.
- **Conditional knowledge:** Conditional knowledge defines time and reason for doing something. The context influences the situational actions.

- **Management knowledge:** Management knowledge contains standards and rules for division of labour, for authority and disciplines as well as specific organisational instruments for personnel management. It defines how to process with product and expert knowledge.
- **Product knowledge:** Product knowledge includes all knowledge about an existing or planned product (for example functions, functional principle, price, manufacturing costs, the benefit a product has to solve a specific problem, the help in choosing the adequate technologies in accordance with economical and ecological effort, etc.). In addition, it defines *the actual state* and the *target state* of planning of the product development.
- **Market-/Customer knowledge:** Market knowledge can be defined as knowledge relevant for the decision in which markets companies are operating. Related customer knowledge provides information about the companies' customers.
- **Business strategy knowledge:** The business strategy knowledge comprises the general strategy of a company (market-strategy, financial strategy, visions, objectives, etc.).

An unequivocal distinction between the types of knowledge is not always possible despite of the theoretic differentiation. Taking their strong links and connections into account, the general structuring model – presented in Figure 2 – has been developed. A "Black-Box" represents the superior product development process. The formerly introduced types of knowledge can be classified into two categories in accordance with their characteristic properties for the product development. On this occasion, the market-/customer knowledge, the strategic knowledge and the business strategy knowledge describe the "administrative" aspects of a company. The latter type of knowledge has been added due to newer investigations and has to be confirmed as relevant for the PDP in future work. The product knowledge cannot be assigned to one of the two categories and represents a linkage between them. This knowledge subsumes all information and correlations of the future product and is mainly influenced by the category "administration". It should be stated that the administration controls the right side (see Figure 2) by using the product knowledge for supplying basics and targets of the product development.

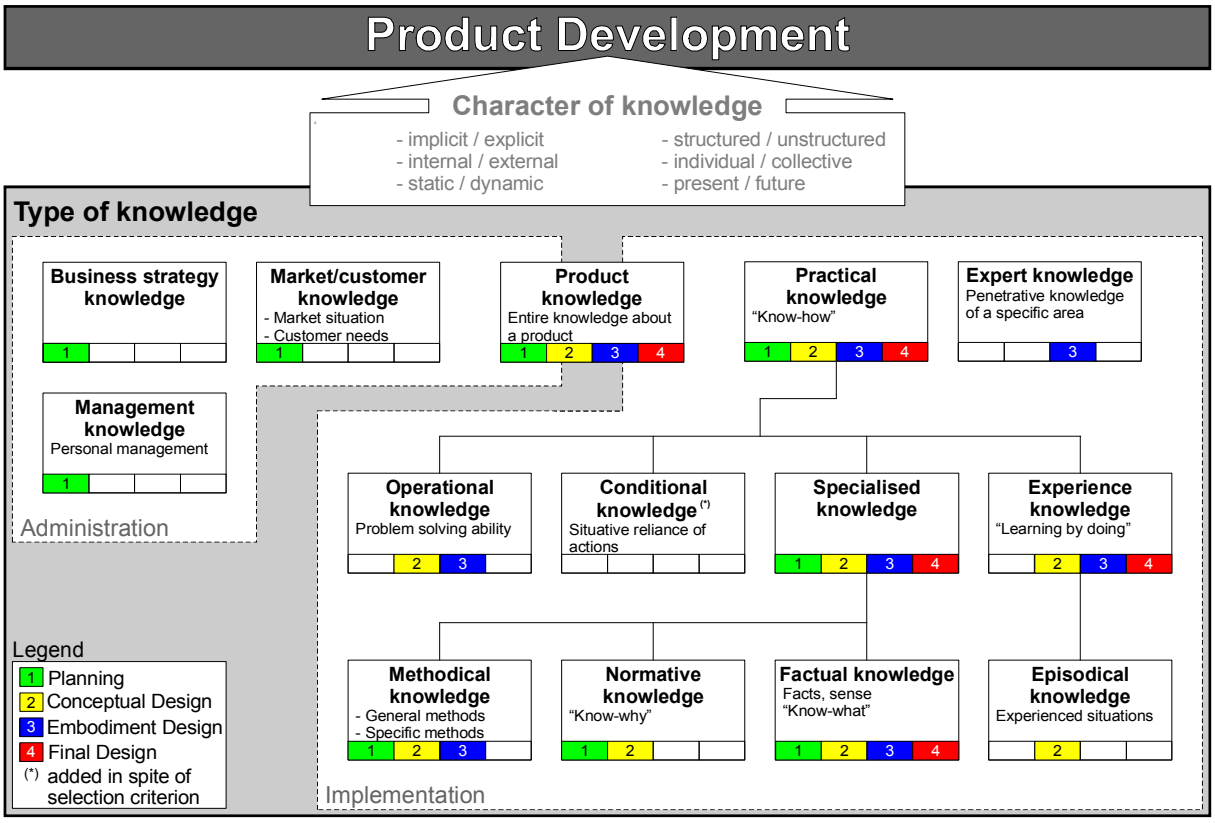

Figure 2. General structuring model - Theory

The second category "implementation" (the right side of the figure) includes the remaining types of knowledge. The chosen hierarchical structure should not be misunderstood on the one hand as a systematic order and on the other hand the displayed interconnectedness should not be misunderstood as a priority. Some knowledge types rather represent superior types that can be classified partially in sub levels. Numbers at each knowledge type box in Figure 2 point out the theoretical significance of the corresponding knowledge type within the product development process (in accordance with the 4 phases). The significance is determined by a majority occurrence in each phase (depending on the specific phases). The significance between each knowledge type is not taken into account. In compliance with this rule, the conditional knowledge doesn't seem to be relevant for the PDP in contrast to the definition of the relevant types for the PDP (has been considered as important). This discrepancy probably originates in the assumed well structured and methodical procedures within the product development and must be included in a further work.
The results for Figure 2 can be summarised as follows: The presented knowledge types "enter" the product development in their typical characteristic. As a result, all knowledge types can be classified into two categories: Administration and implementation. Both categories are in turn linked by the product knowledge. The interconnectedness of the individual types of knowledge shows coherences as well as which types of knowledge can hardly be separated from upper types (because they are subsets). The current assigned numbers symbolise the significance within a particular phase of the product development process.

4. Empirical study of the theoretical structure of knowledge within the PDP

This chapter presents the first results of an empirical study. Based on the developed theoretical structuring model in chapter 3, a first evaluation of those results has been carried out during a survey at a university chair. The objective of this study (five personal interviews) was to detect the engineer's need of knowledge during the PDP and to compare these results with the theoretical results. Table 7 shows Table 6 in a modified and more general form. In each phase, the left column illustrates again the theoretical results (light grey) and in contrast, the right side represents the results out of the empirical study (dark grey). The compliance rate of the results stands at 70 %. A non-significance of three types of knowledge for designers has been revealed: episodical, conditional and the management knowledge. Decisions are mainly based on experiences instead of being linked to a special assigned situation, like episodical knowledge. Conditional knowledge is not important for the PDP as assumed in chapter 3. The interviewed designers did not have tasks concerning management responsibility. This is probably conform to the majority of designers and their daily work. As a result, the management knowledge can also be neglected in additional deliberations.

Table 7. Knowledge correlating with the phases of the product development process – general

types of knowledge	planning		conceptual design		embodiment design		final design	
	theory	empiricism	theory	empiricism	theory	empiricism	theory	empiricism
expert knowledge								
normative knowledge								
specialised and factual knowledge								
experience knowledge								
episodical knowledge								
practical knowledge								
strategical and methodical knowledge								
special methodical knowledge								
operational knowledge								
conditional knowledge								
management knowledge								
product knowledge								
market knowledge								
customer knowledge								

The study has yielded the structure shown in Figure 3. In addition to the chosen visualisation in Figure 2, Figure 3 contains a statement about the relations between the knowledge types (represented by arrows). Two types of relations can be distinguished: *defines* and *influences*. Furthermore, the linkage intensity is considered, but only more perceptible linkages have been taken into account (thin line).

Especially strong forms are represented with a thick line and the additional word "strong" in the legend. This kind of presentation allows a more comfortable differentiation of hard, separable types of knowledge. Hence, it can be stated as an example that experience and specialised knowledge have a stronger influence on expert knowledge than on practical knowledge. It can be observed that experience knowledge "*influences*" other types of knowledge whereas specialised knowledge "*defines*" the practical knowledge and the expert knowledge. Due to the circumstance mentioned above, specialised knowledge has the higher significance for the PDP. It can be recognised that the influence is depending on the phase. For example, expert knowledge only influences knowledge if it occurs in the same phase (cf. Figure 3). This prerequisite is valid for expert knowledge in phase 3, for practical knowledge in phase 2 and 3.

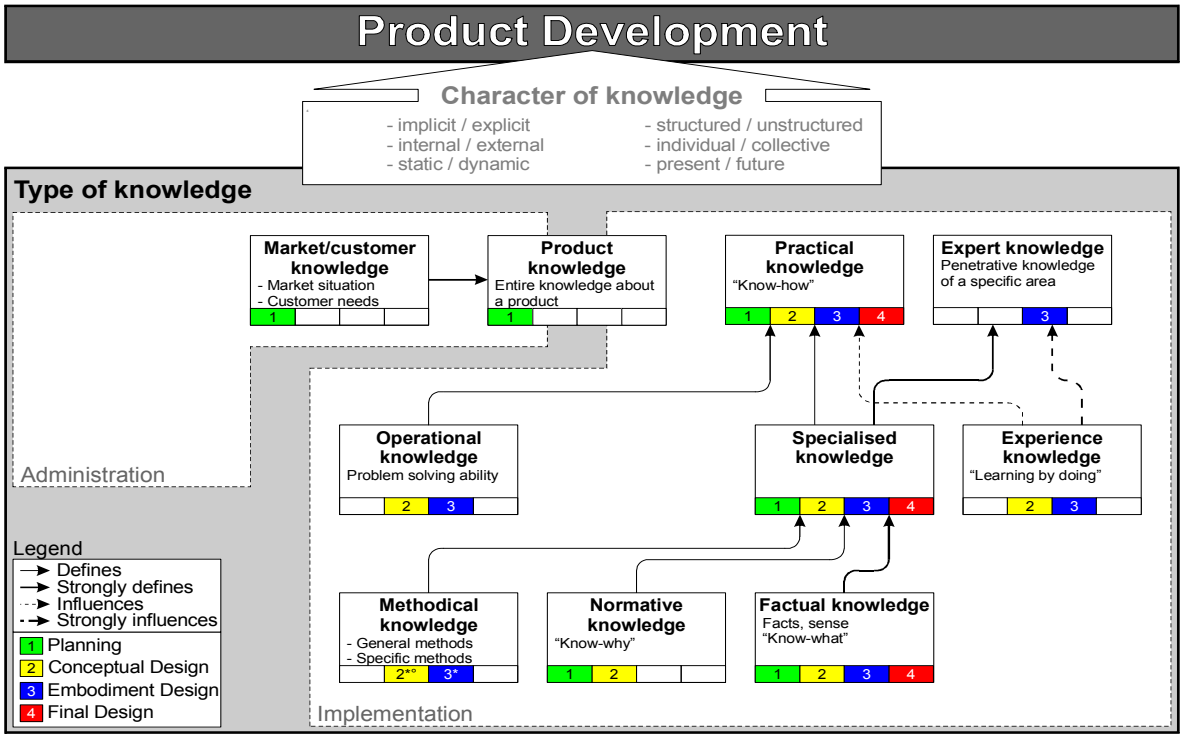

Figure 3. General structuring model – adapted

An additional analysis investigated the progress of the characteristics of the knowledge types within the PDP (based on the empirical study). The part of extern and future knowledge decreases with an advanced PDP, while the part of structured, individual and static knowledge increases. The final design phase is not depicted, because of any sufficient number of results by the use of the surveys.

5. Conclusion

Summing up the results of this paper, a general structuring model of knowledge for the PDP has been successfully developed. Theoretical results have been optimised due to first empirical studies in an academic environment. Further analyses, especially in industries, have to follow. The current structuring model (shown in Figure 3) represents a concept that satisfies the requirements of the fields of applications mentioned in chapter 1. In particular, the evaluation can be based on the presented types of knowledge.

It is important to emphasise that the designers' needs correlate strongly to their activities. A CAE-engineer prioritises other main points than a materials science engineer or an expert in mechanics of materials. However, a designer does not generally deal with each phase of the PDP. Knowledge types have to be assigned to their associated location – preferably a person in the company. The developed model mainly represents the development task at university chairs and has to be verified and adapted to the tasks an engineer has in industries. A deficit of actual structuring models is the insufficient analysis about which knowledge is necessary in which phase of the PDP. Therefore, the developed

structuring model represents an approach that subdivides relevant knowledge types into two categories (administration and implementation) and shows their interconnectedness, relations and significance within the product development process.

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