INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 05 MELBOURNE, AUGUST 15-18, 2005

# AN INFORMATION-CENTRED APPROACH TO THE DEVELOPMENT AND IMPLEMENTATION OF DESIGN METHODS

Markus Weigt

## Abstract

Success of design processes depends on synergistic interaction of cognitive performances of human beings, support by information technology, and integration into corporate structures. Complexity and impact of design processes require comprehensible methodical support of the development and implementation of design methods.

This paper presents an information-centred meta-methodological framework for the development of design methods and their implementation into design processes. Focusing on information conversion as a common and connecting element of psychological, organisational and technological aspects of design processes, application of the framework supports operative design activities as well as design process management activities. Unlike existing approaches to method selection and adaptation, information properties are focused in addition to information types. A unified conceptual and methodological foundation ensures consistency between meta-level and object-level of method development.

Using a design process initiated by internal product planning as an example, this paper demonstrates the definition of conceptual method schemata as abstract method models, and discusses their stepwise concretion towards applicable methods. As a result, a conceptual method schema is presented, which provides increased understanding of the origin of the principal requirements for engineering design.

*Keywords: Design process, information process, method development, product requirements*

## 1. Introduction

Effective and efficient design processes are of primary importance against the background of competitiveness in globalised markets, where innovation, reduction of product development cost and time-to-market, and general manageability of product and organisational complexity pose challenges for today's enterprises.

A process approach, i.e. managing design activities and related resources as a process, is an appropriate way of organising and managing how design activities create value for enterprises, customers and other parties [6]. The complexity of these activities requires their definition, implementation, measurement, monitoring and control to be methodically supported in a comprehensible and reliable way. To this end, top-down and bottom-up approaches exist.

Existing top-down approaches to this area provide generic activity-based [5, 15, 17] or gate-based prescriptive process models [3, 8]. Activity-based process models have deficiencies with regard to their practical application. With concretion and flexibility of methods conflicting, they are often insufficiently concrete towards their adaptation to product-specific or company-specific constraints. Gate-based process models, on the other hand, do not focus on methodical support of operative design activities.

Other existing approaches focus on the selection, adaptation and application of methods of work [1, 9, 11, 18]. These bottom-up approaches incrementally optimise the design process by providing methods to support operative design activities, including their adaptation to some extend.

Methodological support of top-down development and implementation of design methods and of bottom-up optimisation by increasing the efficiency and effectiveness of operative design activities is currently not sufficient. Process models and methods of work are often still not transparent for practitioners regarding their working principles and thus lack acceptance or can not be applied to their full potential.

This paper addresses these issues by means of an information-centred meta-methodological approach to the development and implementation of design methods. Focusing on information as a common and connecting element, it supports operative design activities as well as design process management activities. Unlike existing approaches to method selection and adaptation, information properties are considered in addition to information types. A unified conceptual and methodological foundation ensures consistency between meta-level and object-level of method development.

# 2. Conceptual foundation

## 2.1 Methods and processes

The development of appropriate design methods and their implementation into the design process is an integral part of design process optimisation.

A *method* can be defined as a set of instructions, whose execution under given conditions sufficiently ensures the achievement of an intended objective [13]. A *process* can be defined as a set of interacting activities, which transforms inputs into outputs [6]. While methods support the achievement of intended objectives, their actual achievement requires a transition from abstract instructions to concrete activities, i.e. implementation of methods as processes (see Figure 1).

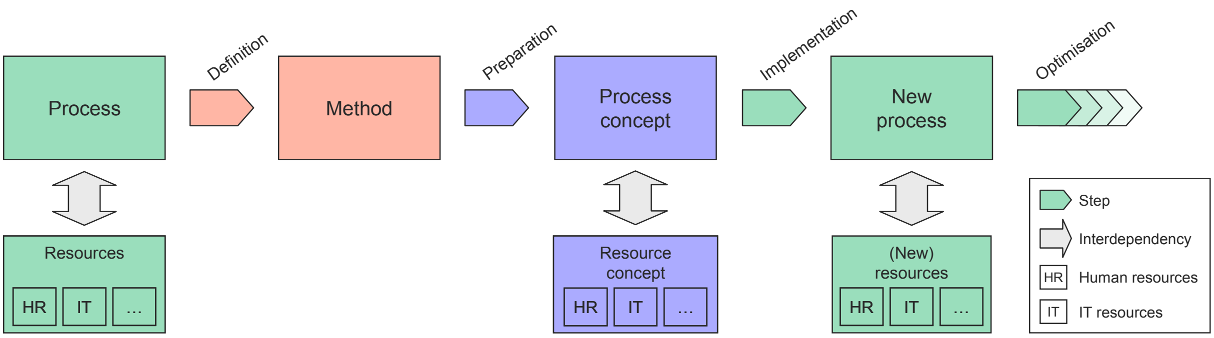


Figure 1. Interrelations of methods and processes

Successful application of a method depends on situational circumstances being consistent with the scope of the method [13]. As a result, executing a method often requires its adaptation according to specifics of the task at hand. Furthermore, especially in the context of implementation in industrial practice, adaptation is needed according to existing or planned resources and their consumption (considering qualitative and quantitative aspects of human, IT and other resources), and organisational structure and process manageability requirements (e.g. suitable for gate-based process management).

Adaptation of methods concerns methodological content as well as formulation. Examples for adaptation of methodical content are Gallery method and 6-3-5 method derived from Brainstorming [2, 15]. Regarding formulation, methods are preferably formulated as principles, procedures or templates. Deliverable-oriented concretion and re-formulation facilitates the implementation and management as gate-based processes.

A method that has been sufficiently prepared for implementation as a process with respect to its content and formulation is defined as a *process concept.*

## 2.2 Meta-level and object-level of method development

The objective of method development and implementation in general is process optimisation. According to the definition of processes of [6], such optimisation activities constitute a process themselves. Its objectives, inputs, outputs and constraints are more abstract compared to the process that is focused (see Figure 2).

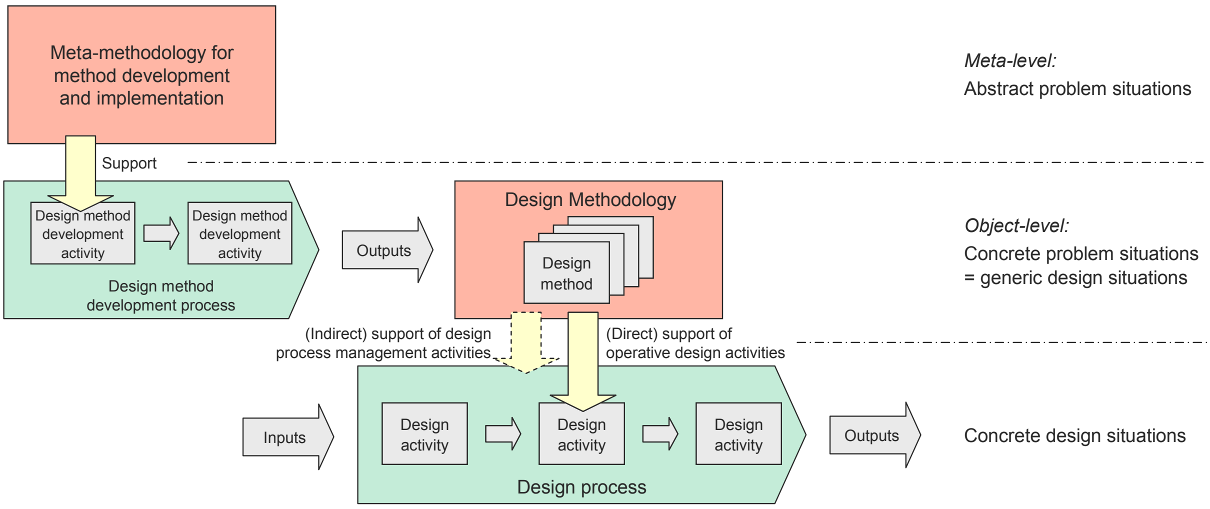


Figure 2: Meta-level and object-level from a meta-methodological perspective

For example, design processes confront designers with tasks, i.e. concrete design situations. Design methods are supposed to support execution of these tasks while being valid for a significant class of tasks [13]. For this reason, design methods consider as their objectives generic design situations. For example, they consider the clarification of tasks or the development of function structures in general, rather than the clarification of one specific design task or the development of one specific function structure.

A meta-methodology for the development and implementation of methods relates to process optimisation as a design methodology relates to the design process. Like a design methodology, the meta-methodology is supposed to be generally valid, i.e. the development of design methods is one of its several possible applications. With respect to this, such a meta-methodology considers as its objective abstract problem situations as design methodologies consider generic design situations. From the perspective of the meta-methodology, generic design situations can be regarded as concrete problem situations, i.e. instantiations of abstract problem situations.

## 2.3 Information conversion in the design process

The most relevant input of the design process is the design task as assigned to the design department. It can result from internal product planning or customer order [15]. The objective of the design process is to produce as output a solution according to this task. The success at this depends on synergistic interaction of cognitive performances of human beings, integration into existing corporate structures, and support by information technology. Connecting element of these crucial psychological, organisational and technological factors is *information*. In respect thereof, the design process is regarded as an information process in the context of this paper.

Problem solving activities are an essential part of the design process [15]. The resulting *psychological aspects* of information conversion are well covered by the existing methodological approaches to the area of engineering design. The specifics of cognitive processes are generally considered. An important elemental sequence in such cognitive processes is the TOTE unit [12]. All cognitive processes can be reduced to this elementary pattern. In complex cognitive processes such TOTE units are multiplicatively sequenced or cascaded. Designing is a complex problem solving activity, where information is acquired, processed and output iteratively, incrementally increasing the information level approaching the solution [4, 15].

*Organisational aspects* of information conversion in the design process are especially relevant in the context of Simultaneous Engineering, Concurrent Engineering, supplier/OEM relationships and process/project management. Organisational aspects are interrelated to the flow of information between different processes or between human, IT and other resources of the same process. Regarding other processes from the perspective of the design process, logically upstream, downstream and parallel processes can be distinguished (see Figure 3).

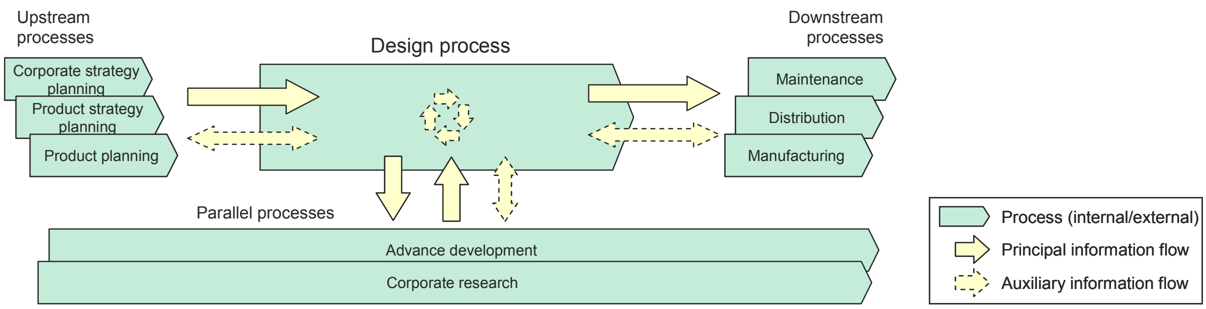


Figure 3. Exemplary information flows related to the design process

This logical view of informational interdependencies of processes does not necessarily correspond to a chronological view, since in industrial practice these are often continuous processes.

Regarding the type of information transferred, according to its relevance, *principal information* and *auxiliary information* can be distinguished. Principal information is directly related to the objective of the process. The principal information flow consists of information inputs, which are transformed into outputs. Such inputs and outputs are coming from or being directed towards other processes. Auxiliary information is indirectly related to the objective of the process, enabling, supporting or optimising the principal information conversion. An example is information that results from monitoring, feedback or tracking activities in the context of continual process improvement [6, 7, 8], or operative information of organisational relevance.

The diversity of IT systems currently available to designers is a direct response to requirements concerning *technological aspects* of information conversion in the design process. These aspects concern the need for non-mental representation of the design object and related information, which results from:

- Process complexity requires human-human interaction (division of labour, teamwork, collaboration) or human-machine interaction (e.g. with manufacturing technology).
- Product complexity requires designers to focus on partial problems during design, other parts of the design object need to be temporarily factored out of the designer's consciousness.

In this paper, technological aspects are considered by referring to the *form* of information, organisational aspects by referring to the information *fluency*, and psychological aspects by referring to the *content* of the information processed.

# 3. Information-centred method development and implementation

## 3.1 Constraints for the development and implementation of methods

Since design methods support information conversing activities required to fulfil specific tasks, the relevant constraints concerning the development of such methods are primarily task-specific constraints. Whether corporate constraints have to be considered for method development, and the relative importance of task-specific and corporate constraints depends on how generic or specific to an organisation the design task is. When preparing a design method for implementation and implementing it into the design process, the relative importance of corporate constraints increases (see Figure 4).

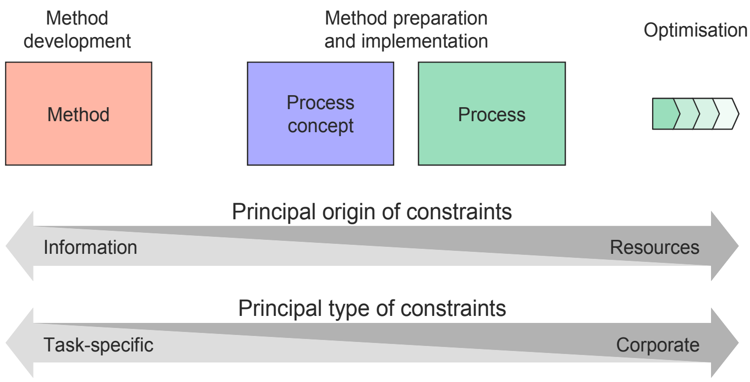


Figure 4. Origin and type of constraints for the development and implementation of design methods

*Task-specific constraints* result directly from properties of content, fluency, and form of the information processed. For example, complexity of informational content can require a design method to include mechanisms of structuring into sub-problems and consolidating partial solutions; uncertainty of informational content might require a design method to support handling a range of solution variants according to the margin of uncertainty. Limiting consideration of constraints for method development to immediately task-specific ones generally facilitates wide areas of validity, but decreases method concretion.

*Corporate constraints* result from properties of all types of corporate resources (human, IT and others), and from corporate attitudes [14].

Task-specific and corporate constraints are either of restricting, or of supporting nature. Restricting constraints limit the potential of a solution or impose requirements that a solution has to fulfil. Examples are the need to process unreliable or incomplete input information, or technological and cost limitations. Supporting constraints increase the potential of a solution, e.g. the introduction of new technology, or above average qualified and motivated personnel.

With all types of constraints, it has to be considered whether they determine what solutions can possibly be achieved, or how a possible solution can or must be achieved. During the stage of method development, e.g. the restricting, content-related constraint "amount of information to be processed is very large" can result in a method requirement "fully suitable for computer processing". This directly determines a property of possible solutions, which have to be algorithmic methods. Whereas the restricting, fluency-related constraint "information to be processed is only available personal and distributed" requires the method to include appropriate steps to consolidate the information before further processing.

## 3.2 Information process components

Regarding the design process as an information process and considering its relevant technological, psychological and organisational aspects, components of information processes oriented towards information conversing activities can be defined. Such components can be used for top-down and bottom-up approaches to method development and implementation. They provide building-blocks for defining conceptual method schemata and serve to model activities in information process analysis.

Information process components can be classified according to the nature of the underlying operation and their objectives.

The types of *operations* to be considered depend on the granularity of the concrete problem for which a method is developed. For generic situations including a significant number of different activities or several process steps, consideration of the following is suggested:

- Analysis (identification of properties of information)
- Acquisition (active gathering of new information)
- Consolidation (changing information properties)
- Definition (production of new information)

Concerning the *objectives*, the following aspects of information can be distinguished:

- Process relevance (principal or auxiliary information)
- Directivity (input or output information)
- Information conversion aspect (relating to content, fluency or form)

Combinations of these operations and objectives yield abstract descriptions of information conversion activities. The following are examples for information process components and corresponding activities related to task clarification within the design process:

- "Acquisition of principal information input with respect to content": Performing customer interviews or product use analysis with regard to customer wishes.
- "Consolidation of principal information input with respect to form": Merging the results from several different customer interviews into one overview document.
- "Consolidation of principal information input with respect to content": Interpreting the results of customer interviews to formulate and weigh explicit customer wishes.

- “Definition of principal information output with respect to content”: Identify implicit customer wishes based on the results of the product use analysis.
- “Consolidation of principal information output with respect to form”: Formulation of a structured requirements list from given explicit and implicit customer wishes.
- “Definition of principal information output with respect to fluency”: Determination of the addressee for the requirements list.

Not all activities yielded by this systematisation are possible combinations. For example, according to the approach presented in this paper, information input is regarded as a given constraint and therefore cannot be the subject of defining operations without extending the scope of method development and implementation to include other processes. Also, acquiring operations cannot refer to the fluency and form aspects of information.

The result of this analysis is a set of 26 information process components, emerging from appropriate combinations of operation and objective, with regard to a specific aspect (see Figure 5).

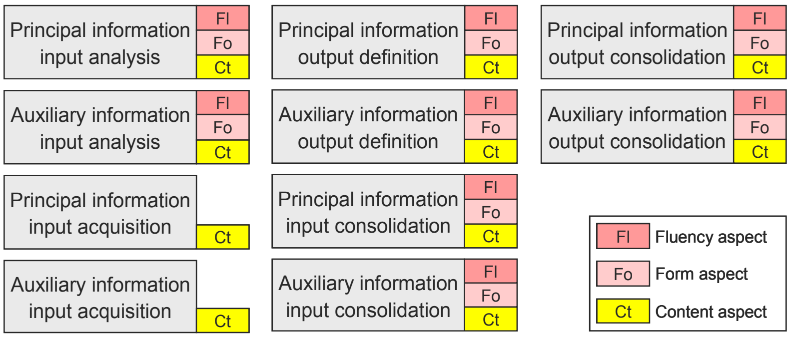


Figure 5. Information process components

The development and implementation of design methods constitute an information process alike to the design process. Therefore, information process components can be used at meta-level and at object-level, i.e. to describe activities relating to the development and implementation of design methods (meta-level) and to design process activities (object-level). As a consequence, these components are *used* for method development, e.g. as conceptual method schema building blocks, and they also constitute activities that are *performed* in the context of method development (see Figure 6).

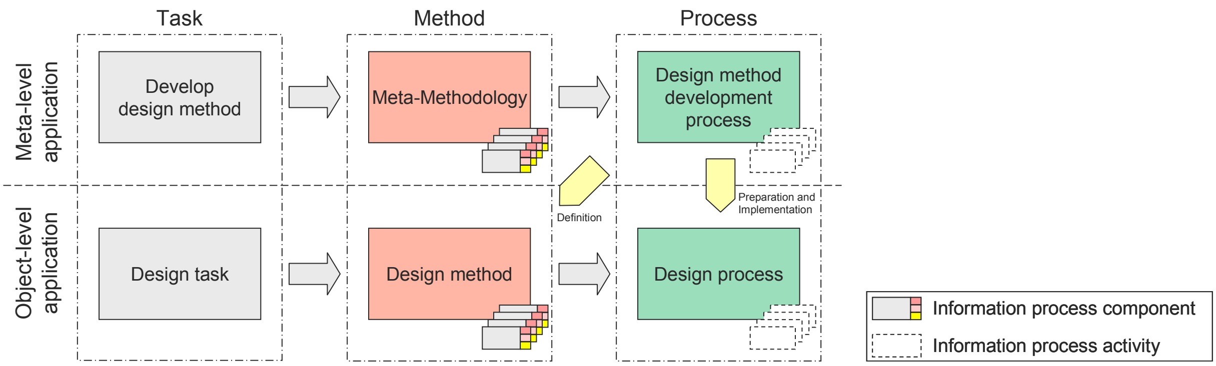


Figure 6. Meta-level and object-level application of information process components

While the types of operations remain identical, the objectives of these operations are more abstract at meta-level than at object-level. For example, a *design method development activity* of "principal information analysis with respect to content" is concerned with abstract properties of information, e.g. properties like dynamics or uncertainty in the case of market trends. A *design activity* of "principal information analysis with respect to content" is concerned with the analysis of the actual content, e.g. an existing trend towards environmentally friendly products in a specific market segment.

## 3.3 Meta-methodological framework for method development

The meta-methodology proposed in this paper provides a generic procedural framework for the development and implementation of methods of work for engineering processes, e.g. the design process. It is structured into the principal activities of analysis, acquisition, consolidation, and definition. These activities are performed iteratively as required. The principal objectives of these activities change in the course of the process according to the relevant constraints (see Figure 7).

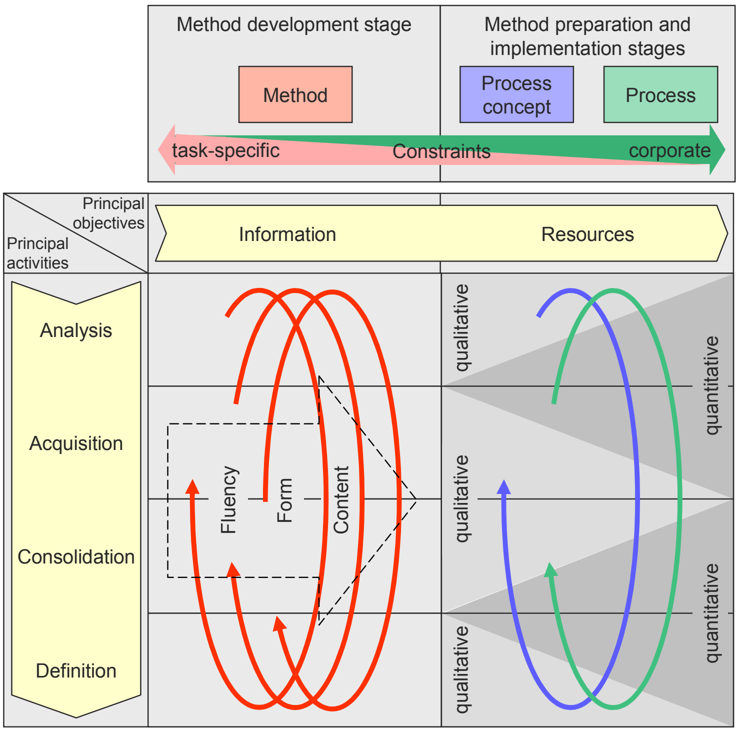


Figure 7. Meta-methodological framework for the development and implementation of methods

In the stage of method development, the principal objective is information, with the focus shifting from fluency to form to content with ongoing completion. Information process components are used to develop a conceptual method schema, i.e. a set of abstract information conversion activities logically interrelated by information inputs and outputs.

A conceptual method schema outlines the method to be developed and provide a starting point for concretion according to abstract properties of the information, whose conversion the method is supposed to support. Such property-oriented concretion of conceptual method schemata is methodologically related to the concept of generally valid functions as proposed by [10, 15], an approach providing a classification of functions according to affected characteristics of inputs and outputs of technical systems.

Focusing on the properties of information aids in the definition of elementary tasks and working principles of methods. For example, informational complexity requires measures of complexity reduction. Adequate methods will often include mechanisms of subdivision, classification, structuring and recombination. Design methods for analysis and goal definition generally have these qualities, e.g. requirements lists and functional structuring. For another example, dynamics or uncertainty of input information can require consideration of the potential variance, thus considering a field of possible solutions instead of a single one.

The result of these steps is a first idea of how to transform input into output. Iterative refinement includes increasingly detailed description of the relevant abstract properties of the information being processed. The appropriate degree of refinement depends on technological, organisational and psychological aspects of the future process to be implemented, e.g. data interfaces, organisational and operative structure, and complexity of the required cognitive processes.

The result of this refinement is an increasingly detailed network of information conversing activities, logically interrelated by information flows with increasingly detailed properties. Because of the detailed description of the information inputs, information outputs and activities, the definition of the concrete transformation of inputs into outputs is facilitated. This establishes a transition from a method schema to a method, a concretion of "what" a method is supposed to achieve towards "how" this can be achieved.

Corporate resources are of principal relevance during the preparation and implementation stage (see Figure 7). The focus shifts from qualitative aspects (resource capabilities, e.g. practitioner qualification and experience) to quantitative aspects (resource capacity and consumption, e.g. practitioner workload). Depending on the type of method, corporate attitudes also need to be taken into consideration, especially in the implementation stage.

The meta-methodological framework can be applied to top-down and bottom-up approaches of process optimisation. Top-down process improvement, i.e. starting with the development of a new method, can be required because of substantial changes in the relevant task-specific or corporate constraints. For bottom-up, incremental improvement of process performance, the same activities and objectives are used, but focusing on an analysis of the constraints and possible process alterations on a detail level.

# 4. Exemplary application in the context of task clarification

To give an overview of the application of the meta-methodology in a generic top-down approach, the stage of method definition will be discussed. Appropriate preparation of the task clarification stage in the context of a design process starting with internal product planning is used as example. Focusing on the key issues, select aspects of information acquisition with respect to content will be considered. No distinction will be made between principal and auxiliary information conversion, and internal and external processes.

## 4.1 Conceptual method schema definition

Starting point for method development is an analysis of the fluency of the respective information process. It needs to be identified from which processes or systems information input will be received, and which processes will receive information output. The main source processes for information required to determine product requirements are corporate and product strategy planning processes (see Figure 8).

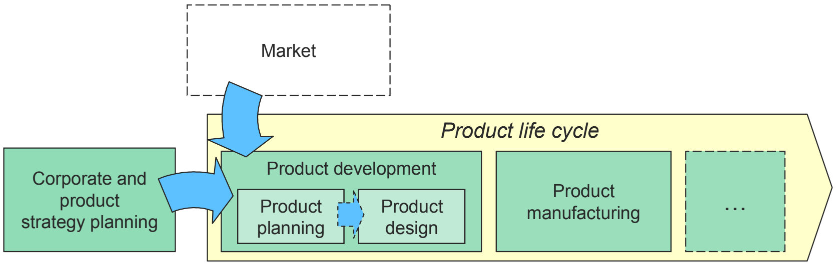


Figure 8. Information fluency analysis with focus on product planning

A promising product concept is determined as the required output of the process, i.e. an outline of a potentially successful product including its main desired properties. This output is directed at the subsequent design process. Considering factors relevant to the success of the concept, it can be assessed that acquisition of market-related information is required in addition to and according to strategic information. Because strategy-relevant information is usually represented unstructured and distributed, consolidation of strategic information is needed to substantiate this additional acquisition. Furthermore, it is advisable to consolidate the output according to the needs of the subsequent (design) process. Based on this analysis, a conceptual method schema can be defined (see Figure 9a).

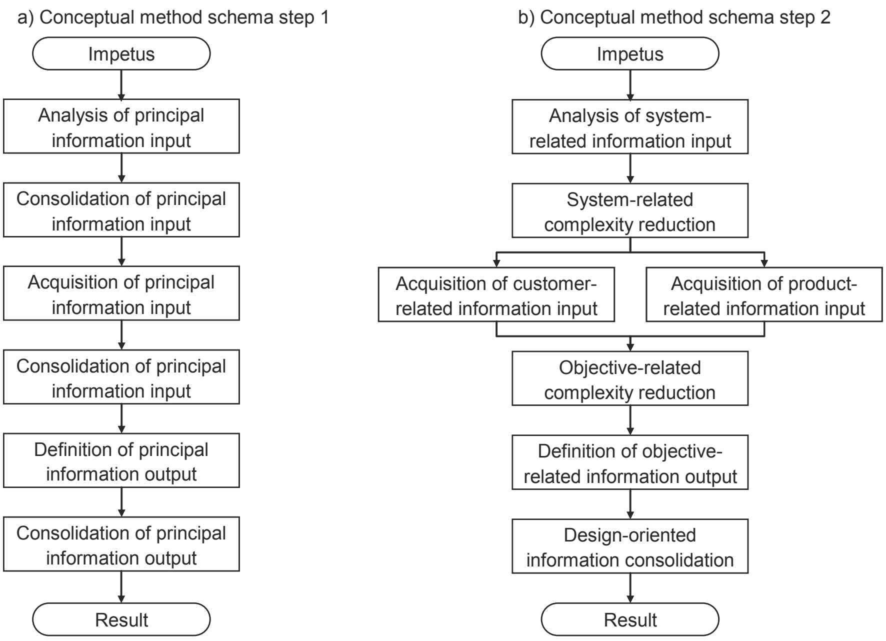


Figure 9. Conceptual method schemata for product planning to initiate the design process

## 4.2 Conceptual method schema concretion

At meta-level, the fundamental nature of the principal information input with respect to its content needs to be determined. Strategic information input relates to the enterprise acting within its environment, which is considered as a *system*. Most relevant elements of this system are *customers* and *products,* both own and competitors', respectively. Handling the *complexity* of this system and related information conforming to *strategic objectives* is the main challenge for further information processing. Information output consolidation has to meet the needs of the subsequent design process, taking into consideration e.g. the established methods for task clarification. According to this, the conceptual method schema can be concretized as depicted in Figure 9b.

## 4.3 Method selection, adaptation and development

Further concretion of the conceptual schema takes a top-down structuring approach to handle informational complexity. It includes alternate analysis and complexity reduction steps, which enable approaching in adequate steps the definition of core requirements of the future design object. The main properties determined this way serve as starting point for task clarification in the design process (see Figure 10a and Figure 10b).

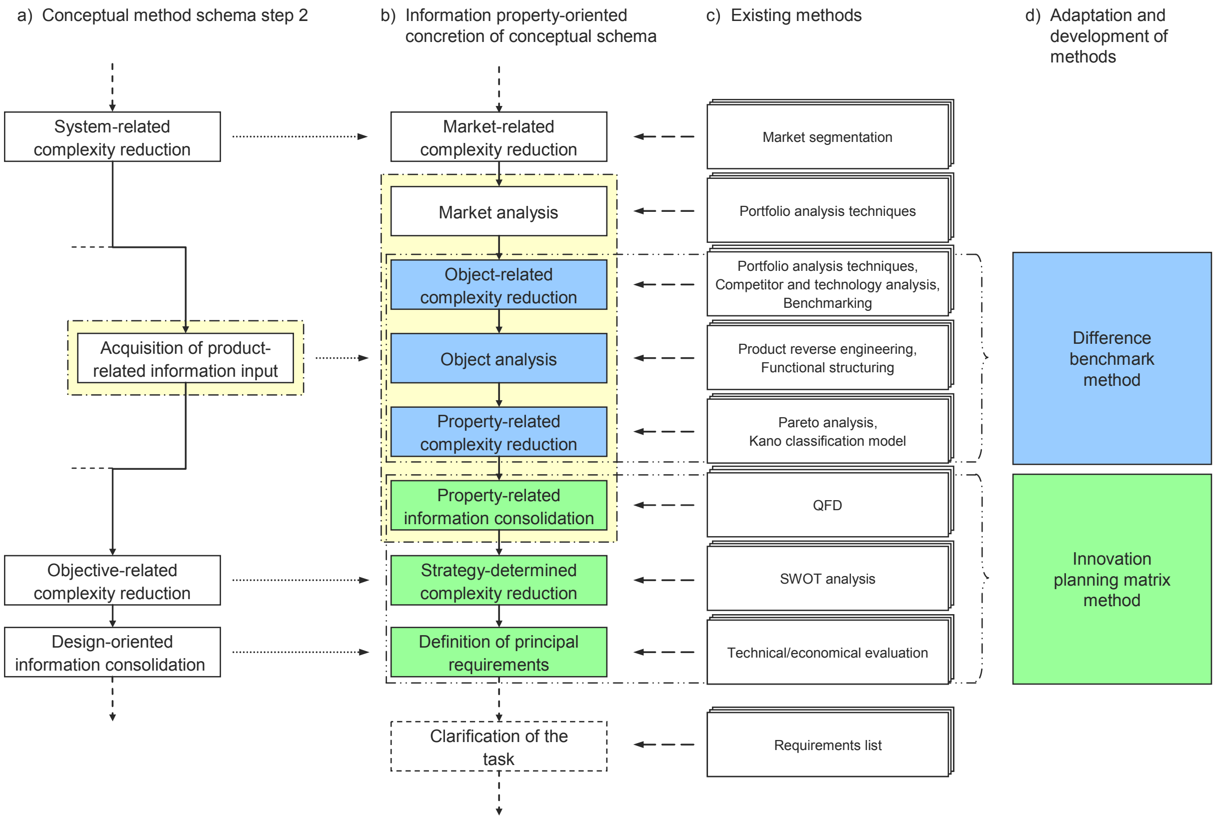


Figure 10. Procedure of method development in the context of task clarification

Focusing on properties of the information to be processed makes the working principle of potentially applicable methods evident. In this case, an effective and efficient interaction is required between steps of determination of properties (analysis) and addressing these properties (complexity reduction) on different levels of granularity.

On the one hand, this enables proper evaluation of the applicability of existing methods (see Figure 10c). If no adequate method is available, adaptation or new development of a method should be considered. Such adaptation and development are facilitated by the fact that the required function of the method (according to the abstract properties of the information to be processed) and the context of its application are known, as well as deficiencies of existing methods in this context.

Concerning the initial steps of market-related complexity reduction and market analysis, available methods like Market segmentation and Portfolio analysis techniques are satisfactory without need for adaptation, since application can efficiently provide the required effect and information of appropriate granularity.

With regard to the subsequent activities of product analysis (object-related complexity reduction and object analysis), method adaptation is advisable, using a combination of working principles from different methods, e.g. Benchmarking, and Competitor and technology analysis. The result is even improved since the activity of property-related complexity reduction, which is not directly related to product analysis, can be integrated, using the Kano classification model to create the *Difference benchmark* method (see Figure 10d). This method identifies congruencies and differences between potential competitive products, thus ensuring acceptance within the chosen market segment and unique selling points to successfully distinguish the product within the segment.

Concluding, a strategy-determined definition of a target system for the subsequent design process is necessary, defining the principal requirements for potentially successful products with respect to technical and economical aspects. To this end, the identified congruencies and differences need to be consolidated, which requires their structured documentation. Methodical support for such property-related information consolidation is unsatisfactory, because the respective methods (e.g. QFD) require more detailed and precise information than is generally available at this stage of product development. Therefore, a new structuring method is suggested, favourably integrating the strategy-determined definition of a target system for the design process. This *Innovation planning matrix* method (see Figure 10d) enables a structured documentation of desired product properties without requirements concerning the level of detail and precision, and allows evaluation against strategic criteria, and to assess technological and economical feasibility and potential.

These principal requirements provide cornerstones of a conceptual frame for a new product, and thus ensure that product design can efficiently proceed complying to necessities of corporate strategy and the market[1].

# 5. Conclusions

The meta-methodological framework proposed in this paper supports the information-centred development of design methods and their implementation into design processes. Main benefits of this approach are the following:

- *Transparency* of working principles of methods required for the transformation of informational inputs into outputs is increased. This enables assessment of applicability of existing methods, the determination of measures for their adaptation, and the development of new methods. Increased understanding of the working principles of methods improves method usability and acceptance, and effectiveness and efficiency of their practical application.
- Detailed description of information input, output and transformation enables to accurately assess, which information is required for the respective activity. Therefore, process activities can be assigned to appropriate resources in a way *optimising the information* flow between them, e.g. by transferring between resources only information actually required.
- Inputs and outputs of design activities being described in necessary detail support comprehensible *definition of decision gates*. Since the interdependencies of processes become transparent, definition of gates can appropriately consider parallelisation of process steps. Inputs and outputs that do not receive the formal status of gates can be

---

[1] The Difference benchmark method and Innovation planning matrix method are part of a product planning methodology that has been developed according to the approach presented in this paper, and successfully applied in cooperation with the automotive supply industry [16].

used to facilitate team-internal measures of timely identification and countering capacity shortages.

By establishing an information-centred view onto design processes, the framework supports operative design activities as well as design process management activities. Thus it enables consolidation of existing process-related approaches from the areas of engineering science, management science and quality management.

The focus on information conversion results in a broad applicability of the meta-methodological framework. Current work focuses on the design process, future work will expand the scope towards Product Lifecycle Management. It will address the analysis of new technologies and methods to assess consequences for method development and implementation, with the aim to guide their introduction into industrial practice, such as Virtual Engineering.

## References


[1] Braun, T. & Lindemann, U., "Supporting the Selection, Adaptation and Application of methods in product development", Proc. of the 14th International Conference on Engineering Design 2003, August 19-21 2003, Stockholm, Folkeson, A., Gralen, K., Norell, M. & Sellgren, U. (Eds.), Stockholm: Design Society, 2003.

[2] Daenzer, W. F. & Huber, F. (Eds.), "Systems Engineering", Zurich: Industrielle Organisation, 2002.

[3] Cooper, R. G., "Winning at new products", New York: Perseus, 2001.

[4] Doerner, D., "Problemloesen als Informationsverarbeitung“, Stuttgart: Kohlhammer, 1987.

[5] Ehrlenspiel, K., "Integrierte Produktentwicklung", Munich: Hanser, 2002.

[6] ISO 9000:2000, "Quality management systems – Fundamentals and vocabulary", 2000.

[7] ISO 9001:2000, "Quality management systems – Requirements", 2000.

[8] ISO/TS 16949, "Qualitaetsmanagementsysteme – Besondere Anforderungen bei Anwendung ISO 9001:2000 fuer die Serien- und Ersatzteilproduktion in der Automobilindustrie", Berlin: Beuth, 2002.

[9] Karlsruhe University (Ed.), MAP-Tool, Internet: http://www.uni-karlsruhe.de/~map.

[10] Krumhauer, P., "Rechnerunterstuetzung fuer die Konzeptphase der Konstruktion", PhD thesis, Technical University Berlin, 1974.

[11] Lindemann, U., "Methodische Entwicklung technischer Produkte", Berlin: Springer, 2005.

[12] Miller, G. A., Galanter, E. & Pribram, K., "Plans and the Structure of Behavior", New York: Holt, Rhinehart & Winston, 1960.

[13] Mueller, J., "Arbeitsmethoden der Technikwissenschaften", Berlin: Springer, 1990.

[14] Rueegg-Stuerm, J., "Das neue St. Galler Management-Modell", Bern: Haupt, 2003.

[15] Pahl, G., Beitz, W., Feldhusen, J. & Grote, K. H., "Konstruktionslehre", Berlin: Springer, 2003.

[16] Seidel, M., "Methodische Produktplanung", PhD thesis, Karlsruhe University, 2005.

[17] VDI 2221, “Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte”, Dusseldorf: VDI, 1993.

[18] Zanker, W., “Situative Anpassung und Neukombination von Entwicklungsmethoden”, PhD thesis, Technical University Munich, 1999.

Dipl.-Ing. Markus Weigt
Institute for Applied Computer Science in Mechanical Engineering (RPK)
Karlsruhe University (TH)
Adenauerring 20
76131 Karlsruhe
Germany
Tel.: +49 721 608-7958
Fax: +49 721 661138
Email: weigt@rpk.uni-karlsruhe.de