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FUNCTIONAL MODELLING FOR DESIGN SYNTHESIS USING MDM METHODOLOGY

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1 INTRODUCTION

In the early stages of design processes, functional modelling is by many authors recommended as the basis for the creative finding of solutions before defining physical parts [e.g. 10, 4, 8]. For that reason, numerous functional models have been defined, providing the support for creative solution finding and definition of products on basis of functional semantics and descriptions before concepts or physical representations of the products exist [e.g. 4, 8]. Furthermore, an important part of the successful synthesis is the evaluation and validation of defined conceptual solutions, based on barely available detailed information about the product [10, 8].
The Design Structure Matrix (DSM) and related methods have proven to be powerful measures when analysing existing systems [2], nevertheless were only slightly able to contribute to new not yet existing solutions. Latest approaches, such as the Multiple-Domain Matrix (MDM) [9] allow for the integration of different domains, and thus enable the depiction of functional models and their relations as well as their connectivity to different solution principles, desired states of a product and finally parts. This paper shows the combination of the MDM approach and different functional models with the purpose to support the design synthesis process.

2 MOTIVATION

The powerful methodology behind the application of DSM and MDM [2, 9] approaches allows the analysis of systems in various ways. Not only can different systems be accessed equally, but the possibilities for analysis are vast. The MDM approach furthermore allows for the integration of numerous different domains in one model as well as the deduction of indirect dependencies [9]. The analysis of systems by mentioned methods addresses the deficits of existing systems and thus can only support the synthesis process when improving existing solutions. The integration of functional models and other product views into one MDM enables the widening of the solution space, but is still based on the existing system's parts and their interdependencies.
When looking at for example plant engineering businesses or other branches with numerous variants and predefined modules, the customer demand will be fulfilled by novel structures of parts. Current applications of DSM and MDM approaches can only marginally contribute to the solution process in such situations. In a conceptual state, those products will be incomprehensible by existing approaches as the physical domain does not yet exist, the functional domain on the other hand can be analysed and structured but only with insufficient conclusions.
Given these circumstances, a number of authors expanded DSM and MDM methodology to suit the given challenges of design synthesis [3, 6]. Still, these approaches focus on the analysis of models for supporting the design synthesis.
In the following chapters, a selection of these approaches and methodologies will be briefly discussed. In the last chapter, an approach is presented and discussed, more detached from analysis than existing approaches but still aiming to complement the gap of analysis in the design synthesis process, and thus contributing to a more integrated approach.

3 RELATED WORK – SUPPORT OF DESIGN SYNTHESIS

For a brief discussion of only a selection of different approaches for design synthesis, a differentiation was made into the groups matrix-based, function-based and rule-based approaches, being the most relevant categories for the presented research. The compilation is not claiming completeness in sense of classification or exemplarily discussed methods.

3.1 Matrix-based approaches

Being aware of the gap between the need for design synthesis and the analysis with matrix approaches, several authors reduce limitations by expanding the method. De Weck [3] for example introduces the Δ-DSM to model and analyse the difference between the actual and the novel design state on parts level. This approach depends upon a basic product, specified changes to the product and a physical representation of the novel product, at least in a conceptual state based on change propagation. Gorbea [6] adds the functional perspective to the problem and sums different existing solutions up in a Σ-DSM similar to the introduced variant management approach by [1]. Given both functional and structural perspective, a widening of the solution space is achieved within the range of existing solutions by combination of systems. Yet, the introduction of novel solutions or the identification of improvement by the introduction of new technologies is hindered by the close relation to existing solutions. Both approaches – representing only a small section of available matrix-based methods for design synthesis – offer great potential and enhance the capability of the DSM approach during the early phases of product development.

3.2 Approaches based on functional models

On the other hand, methods exist outside the field of DSM and MDM methodology, contributing to a large extent to the support of design synthesis, mostly based on functional approaches and independent of algorithmic procedures or intensive tool-support. Well-known in engineering design research is for example the flow-oriented functional model by Ehrlenspiel [4], allowing for the analysis of systems by consideration of information-, material- and energy-flows from a functional perspective. Being formulated as neutral to technical solutions as possible, the functional model allows for a support of design synthesis based on the differentiation of a product's functions. Further functional modelling methods exist, most of them aiming at the support of creativity, for example the relation-oriented models known of the TIPS methodology or elementary hierarchical models (see [5, 8] for more comprehensive overviews).

3.3 Rule-based methods

As a third perspective on design synthesis, rule-based or grammar-based approaches such as expert systems, FBS systems or design grammars can be mentioned (see [12] for example). Those methods have in common the functional perspective as a starting point and require rules for the coupling of functions as well as the coupling with parts fulfilling the formalized functions. With regard to FBS systems, a behavioural level is added between functions and parts, applying another abstract level above parts level, similar to the "working principles" of Pahl & Beitz [10]. Benefit of the mentioned approaches is the automation of the synthesis process and the definition of possible solutions, nevertheless always based on the information available in the beginning and the defined rules. Being the most automated and algorithm-supported methods, rule-based methods require a lot of information in the beginning of the process, with the results reflecting the information input. An increase of information content can be expected anyway by the fulfilling of the required formal norms when dealing with the method. Nevertheless, a similar effect can be expected from the formerly mentioned approaches as well.

4 FUNCTIONAL MODELLING FOR DESIGN SYNTHESIS USING MDM METHODOLOGY

This chapter will sum up briefly the remaining challenges, present the developed approach, results of application and is followed by an outlook on accompanying and further research in the last chapter.

4.1 Challenges

One of the main remaining challenges is the gap between design synthesis and analysis. As the overview has shown, numerous methods exist, supporting either the synthesis by methods, models, and automated procedures, or are supporting the analysis by structural considerations of parts and functions. A formalized exchange between analysis and synthesis methods to enable for example the reducing of solutions during synthesis does not yet exist in a generic form. As a second downside, existing methods are not systematically able to support the definition of novel solutions but are based on existing products of at least the same family. Finally, a sufficient level of abstraction is required when applying a new approach successfully, allowing for the definition of novel solutions but as well the enhancement of existing products.

4.2 Approach

The presented approach utilises existing methods for functional modelling, such as the flow-oriented model by Ehrlenspiel [4] and transfers the resulting functional models into matrix notation. Based on this transformation into a Multiple Domain Matrix, the dependency between operations and states can be extracted and analysis of structures can be conduced. The widening of the solution space can be accomplished by adding more possible functional principles to the matrix, enriching the possibilities to achieve desired states. Source for these can be compendiums of working principles such as [7, 11]. Components can be added if available and/or defined and interrelated with the functions as well as parameters (e.g. degree of efficiency). In addition, undesired and harmful functions can give further insight and focus for analysis and solution finding.

4.3 Results

The application of the method has shown that novel solutions can be supported by the abstract description of a system's functions, allowing for the identification of design alternatives and the comparison thereof. Depending on the parameters integrated into the model, possible concepts can be evaluated. Within the range of existing design variants, a suitable solution can be chosen depending onto the situation, while the solution space can be widened in case of urgent demand.

5 CONCLUSION AND OUTLOOK

The presented method shows promising results and has been applied in a rather small system with little generic scope. The extension of the method by harmful functions, system components and further automated synthesis support will show how a generic approach can be defined, and how applicable results be achieved from the analysis and synthesis. Further examples will include the plant engineering branch, rail break controls and other automotive systems.

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10TH INTERNATIONAL DSM CONFERENCE

Functional Modelling for Design Synthesis Using MDM Methodology

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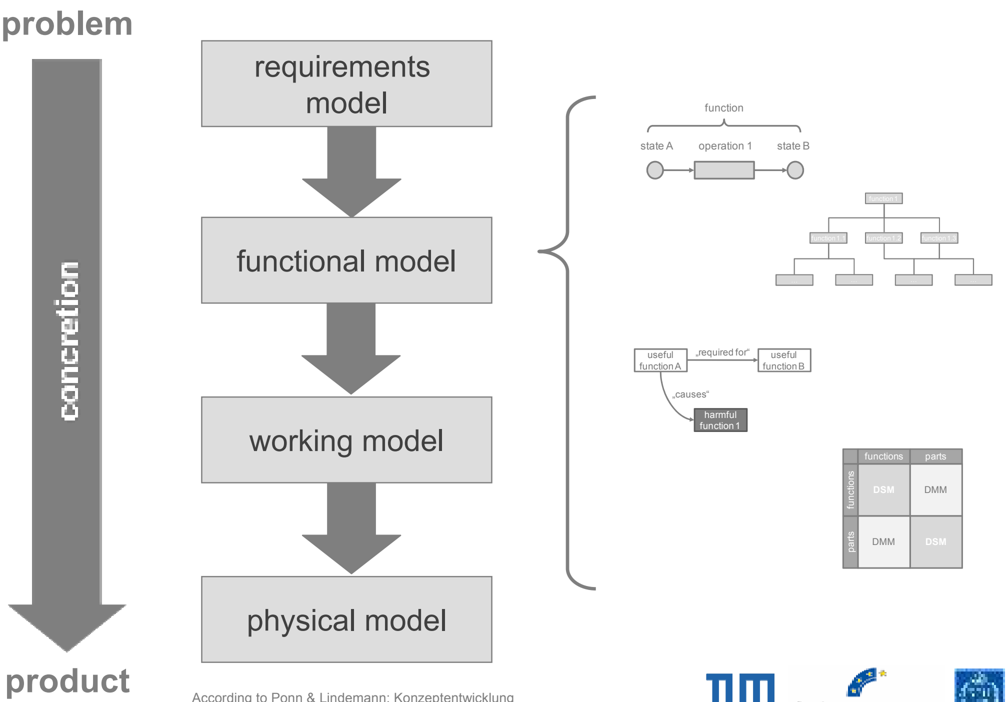
Motivation

Situation
- powerful matrix-based analysis approaches exist, lacking synthesis support in sense of providing alternatives
- existing automated synthesis approaches lack analysis and universality
- „classic" synthesis approaches supply a framework for creativity

Aim
- close the gap between analysis and synthesis
- combine powerful approaches

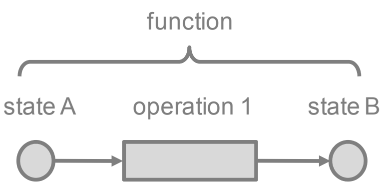
Hypothesis
- matrix-based approaches as a profound basis for design analysis
- functional views on abstract level allow for systematic solution finding
- design synthesis can be supported and prepared by matrix-based depiction of actual situation and solution space

Design Synthesis – Classical Approach

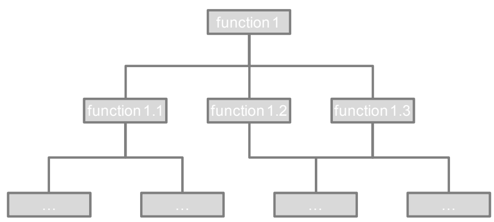


According to Ponn & Lindemann: Konzeptentwicklung und Gestaltung technischer Produkte. Berlin: Springer, 2007

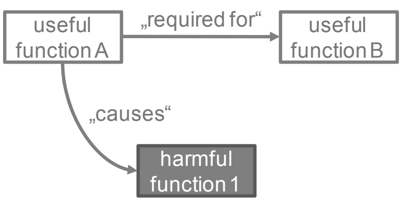
Functional Modelling – Examples



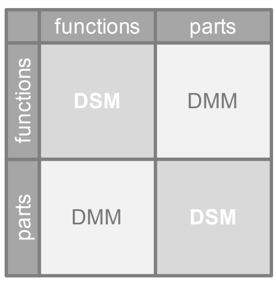
Flow-oriented [Ehrlenspiel 2007]



Hierarchical [Lindemann 2005]



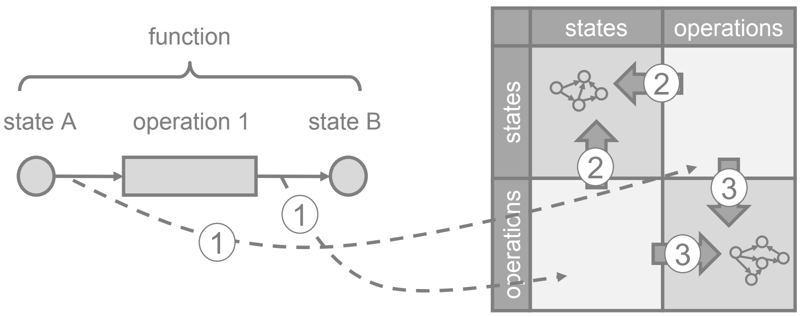
Relation-oriented [Lindemann 2005]



Structural [Maurer 2007]

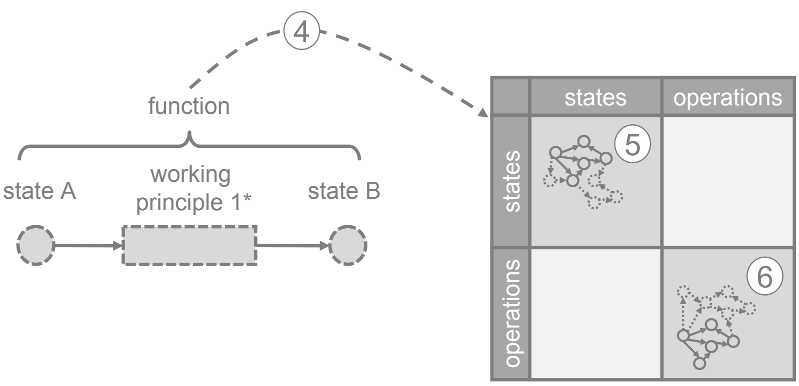
Support of Synthesis with MDM – Principle

1. Deduct dependencies between operations and states
2. Calculate dependencies between states
3. Calculate dependencies between operations



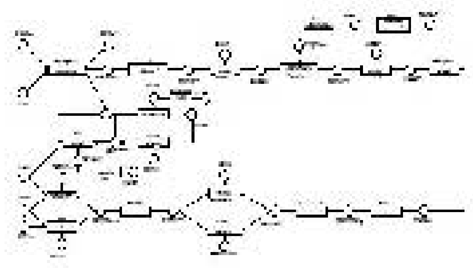
Support of Synthesis with MDM – Principle

4. Widening of solution space by adding working principles
5. Analysis of desired state transformations (alternative paths)
6. Identification of alternative solutions (operations)

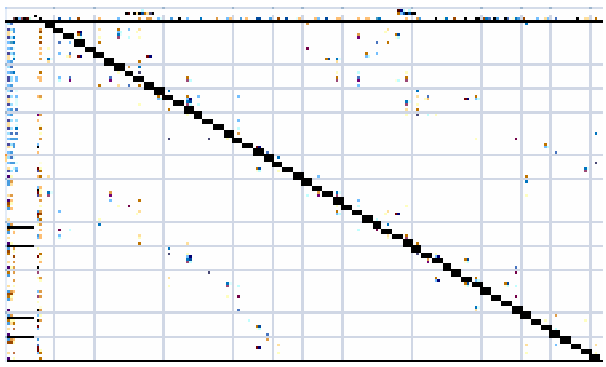


*Sources for Working Principles e.g.:
Ponn & Lindemann: Konzeptentwicklung und Gestaltung technischer Produkte. Berlin: Springer, 2007.
Lauer et al.: Support of the Development Process by a new Approach using Multiple Views on Physical Effects. The FISITA World Automotive Congress, Munich, 2008.

Support of Synthesis with MDM – Exemplary Application



Flow-oriented model of a parallel hybrid vehicle powertrain



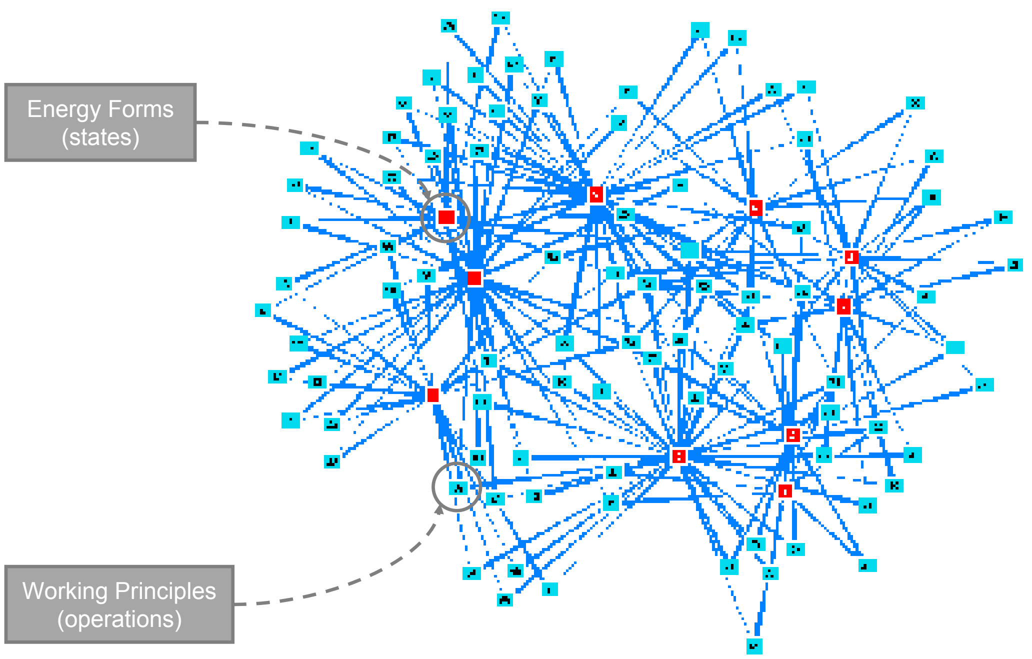
Derived MDM containing operations and states

Example:
Parallel Hybrid Powertrain (Creation of MDM)

Remarks:
- DSM views calculated from DMM dependencies
- Focussing on one existing concept
- Other variants might be added*

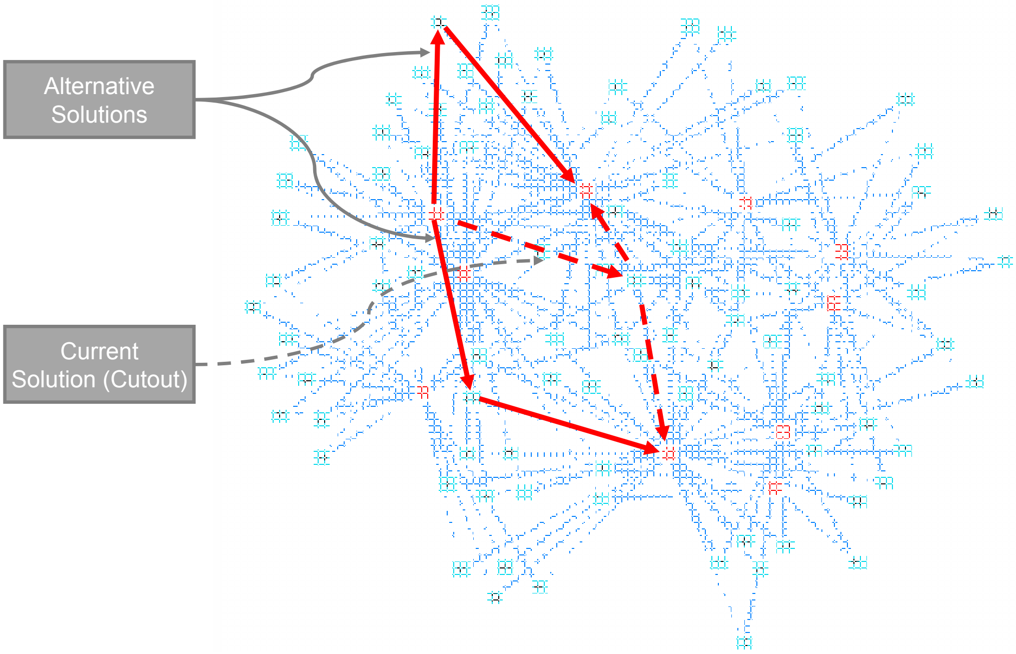
* see Gorbea, C., Spielmannleitner, T., Lindemann, U., Fricke, E.: Analysis of Hybrid Vehicle Architectures using Multiple Domain Matrices In: Proceedings of the 10th International DSM Conference, Stockholm, 2008.

Support of Synthesis with MDM – Solution Space (Graph depiction)



Following Lauer et al.: Support of the Development Process by a new Approach using Multiple Views on Physical Effects. The FISITA World Automotive Congress, Munich, 2008.

Support of Synthesis with MDM – Actual Solution and Alternatives

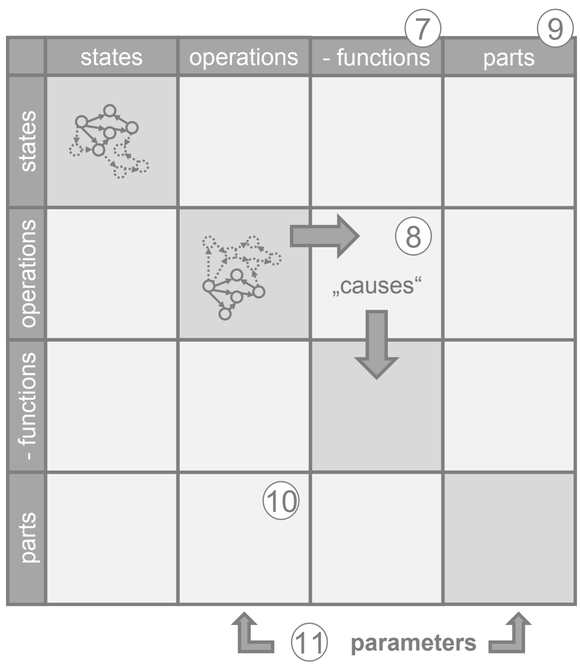


Support of Synthesis with MDM – Extensions

7. Adding harmful or undesired functions (“- functions”)
8. Interrelate “- functions” with operations to identify design focus/conflicts

9. Components can be added if available and/or defined and
10. interrelated with the functions

11. Parameters of operations (e.g. degree of efficiency) and parts (e.g. weight, cost etc.) support the evaluation process



Conclusions

Results

- promising results by the possibility to work thoroughly and systematic through solution space
- possibility to integrate solutions of different levels of abstraction by matrix depiction and combination of operations, functions and parts
- identify unwanted side-effects and alternative solutions therefore
- reasonable decision making by transparency of available solutions

Future Work

- comprehensive evaluation of different solutions not possible satisfactory
- accessibility for automated design synthesis would allow for handling of solution space and defining rule-sets
- evaluation of the methodology by realisable technical solutions as a result of application
- application of different analysis criteria in different domains and interpretation thereof