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A COMPARISON OF DESIGN PROCESS MODELS FROM ACADEMIC THEORY AND PROFESSIONAL PRACTICE

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1. Introduction

As long as engineering and product design have been part of academia, there have been efforts in formulating and validating models of design processes. Depending on specific disciplines, academic backgrounds or the degree of generalisation, these process models differ in focus, content, structure or graphical notation. Although the essence of the design process stages seems to be stable across decades and design domains, there is a recurrent effort in developing the models of design processes. For a recent example, the VDI (Association of German Engineers) and VDID (Association of German Industrial Designers) are reworking the guidelines on product development and industrial design, thus reworking the notions of the corresponding design process models, cf. [Reichert et al. 2014].
The target groups of most design process models are designers or non-designers, either academics, professionals, clients, or students. It is apparent, that due to the different needs, goals and competences of these groups, the (graphical) design process models cannot fit the requirements of all target groups equally. Current (mostly academic) design process models from different disciplines have been analysed and compared recently, cf. [Gericke and Blessing 2012]. Additionally, this paper presents an analysis that compares design process models from academia, professional organisations as well as from professional studios and companies. Recurring critique about academic models claims a difference to processes in industry [Rückert 1997], [Wynn and Clarkson 2005] and others, hence models provided by companies are included in the analysis. Matching and deviating aspects of the models are described. Part of this analysis is a generic notation of the models to be compared. Supported by the analysis of the graphical visualisation of specific aspects such as iteration, duration or scope of stages, the results of the analysis allow recombination and adaption of the models to specific design processes. Accordingly, personal design process models can be developed based on a broad theoretical and empirical basis. This represents the application of the results in industrial design engineering education.

2. Models of the design process

There have been efforts in comparing and generalising the variety of design process models e. g. [Roozenburg and Cross 1991], [Dubberly 2004], [Design Office 2004], [Jänsch 2007], [Gericke and Blessing 2010, 2012], and others, as well as there has been empirical research aiming at the validation of academic models in industrial practice [Woelfel et al. 2012] and many others. While before around 2000, formal discussions have had a focus on linear vs. iterative notations, later on more flexible and multidimensional process models occurred, e. g. [Hugentobler et al. 2004], [Lindemann 2007], [ISO 2011] and others in order to flexibly apply for a variety of different design processes.

More recently, more advanced notions of design process models have been developed in different design domains in order to illustrate certain aspects e. g. of scope (V models, T models, U models etc.), e. g. [Hekkert and van Dijk 2003], [VDI 2004], [Dubberly et al. 2008]. Some of these models have already been considered in research, for example in the analysis of design models from different disciplines by Gericke and Blessing [2012]. From this, it can be concluded, that the more recent models still fit to generic design process stages that can be derived deductively from most process models.

Most process models have been developed in academia or in cooperation between professional associations and academics. Therefore, the target groups of these models can be found in academic researchers and professionals in the industry, but mostly in academic education. Graduate students can be considered being novices or semi-experts in the field of their studies. Process models are to help them understand design processes in general, and guide them through first design projects. Design process models must be easy to understand and easy to follow for educational purposes, which means they are not all-embracingly valid for any potential case. However, many academic models focus on the generalizability for comprehensive reasons. These models tend to be very generic or complex in graphical notion, which makes it harder for novices to understand or follow. Another focus group shall not be discussed in depth in this paper, but must be described briefly: Non-designers read design process models in order to understand design processes. These non-designers can be professional managers, academic psychologists or even lawyers and judges in a trial on design services. Since non-designers have different competences, experiences or needs, they might read design process models not as designers would them expect to.

One particular aspect of design process models that has been discussed in the past was the visibility of the iterative character of design processes and its stages [Pahl et al. 2007]. In consequence, plain linear models have become rare in literature. However, as a study among engineering and industrial design studios showed, design practice usually follows a straightforward process that does not provide too many flexible or iterative options [Woelfel et al. 2012].

Design processes models developed not only due to academic debates. Changes in business organisation, lean management, out-sourcing, virtual product development, or recent prototyping technologies also took effect on design processes and thus design process models may have changed in order to illustrate the coping with current practice. As a recent phenomenon, many design studios changed their operative scope to full-service from analysis and ideation to detailing, modelling and production planning, at the same time offering hardware, software and service design from a single provider. Since the portfolio of these companies has diversified, it becomes relevant to explain the competences and practices. Accordingly, a number of design studios is communicating design process models for a few years.

As a consequence, there are even more design process models being published. The differences are not only for reasons of distinction in itself. New process models and their graphical representations illustrate differing approaches, theoretical streams and a changing practice. Some of the models from design studios and companies aim at visualising the otherness of the specific design processes (and thus services provided by the companies), while the core structure of the design processes may stay similar.

Based on the analysis of engineering design process models, Howard et al. [2008] provided "typical stages of process models from mechanical engineering": *Establishing a need, Analysis of task, conceptual design, embodiment design, detailed design* and *implementation*. Gericke and Blessing [2012] added the use and closeout stages and were able to match the specific stages of process models from nine disciplines to those generic ones. However, most models span from *analysis* to *detailed design* or *implementation* only. Referring to the analysis of Gericke and Blessing, this paper also aims at identifying a common structure from different design process models. While Gericke and Blessing put their focus on the comparison of academic models from different disciplines, this paper focuses on industrial and engineering design and compares models from academia, professional organisations such as the VDI and models from design studios and companies.

In the era of full-service design agencies, globalisation, cyber-physical production systems, and the hype of design thinking, larger design studios started to publish their own design process models recently. At first glance, these seem to differ from the more complex academic process models and are claimed to represent the practice of particular companies broken down to a simplified scheme. Accordingly, it can be assumed that these models represent actual practice – or at least the view of practitioners –, while academic models have been criticised for an asserted mismatch between schematic models and diverse practices [Rückert 1997], [Wynn and Clarkson 2005] and others. Since the models have been published by single companies, it can be expected that these are more specific and less generic; on the other hand, the companies are offering design services to various customers, accordingly a certain degree of generalizability can be asssumed.

3. Comparing models from academia and professional practice

While some of these companies have strong connections to academia, e. g. IDEO, others seem to formulate their process models solely from their professional experience. This can be accepted as a particular empirical approach, despite data basis and method of generalisation is considered being rather intuitive.

However, since these models are mostly formulated for non-designers (i. e. the potential clients of the companies), they might also be appropriate for design education, as we consider design students being novices in the field of design.

In order to understand the differences of diverse design process models from academia, professional organisations and companies not only in terms of graphical notion, an analysis has been accomplished.

The analysis has been done as presented below. Purpose and message of the graphical notions have been analysed qualitatively from graphical notation. The model structures have been analysed and equated with each other in order to compare the stages across different design process models.

Structure and graphical notation

Figure 1 shows the *Basic Design Cycle*, a linear design process model [van Boeijen et al. 2013] with some added iterative loops. This straightforward design process model suggests a linear design process, incorporating phases and stages. Iterative steps are present but seem to be subordinate. The emphasis is on the process stages and their succession. There is no information about the duration, scope or uncertainty in the stages.

Figure 2 shows an example of the more recent V and U models [VDI 2004]. These models have similar components as the linear ones as shown in Figure 1. However, the different graphical notion shifts the emphasis to the feedback or iteration loops. The process does not seem to be too straightforward, there is a kind of delving into the process and emerging with the solution. For outsiders, it is apparent that requirements and solution are explicitly available while the centre process might be inaccessible to them.

Figuratively, the V or U models can be bent even further to form a closed circle. In Figure 3, the model of Human-centred design for interactive systems [ISO 2011] is shown to represent a variety of circular design process models. These models put a very strong emphasis on the iterative nature of design processes in general. In the example, starting point and goal are subordinately illustrated similar to side-notes.

Hugentobler et al. [2004] presented a model that pushes the visibility of the iterative nature of design processes even further. They emphasise iteration of the design process as a macro-cycle as well as iteration within the stages as micro-cycles (Figure 4).

One major point of criticism against the straightforward linear models as shown in Figure 1 was the neglect or at least too little emphasis on iterative aspects of the design process. While the V and U models as well as the circular models take account for this critique by bending the line to more circular shapes, another aspect had not been regarded. Lindemann and colleagues took the need for a more flexible order of the design process stages into account [Lindemann 2005]. As shown in Figure 5, the Munich Procedural Model does not ostensibly suggest one preferred order of the seven phases of the design process. However, at closer sight, a preferred order becomes apparent, illustrated by a thicker line. The model allows the representation of a variety of design processes, neither suggesting a straightforward sequence of the stages, nor putting a dominant emphasis on the iterative nature of the design process. As a consequence, non-designers and novices may find it harder to understand or find the way through design processes by using this model.

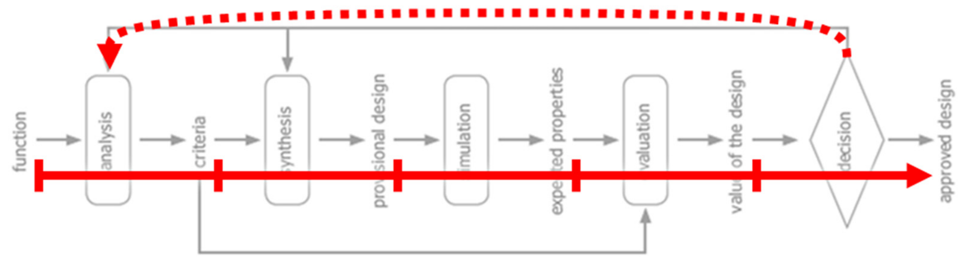


Figure 1. The Basic Design Cycle [Roozenburg and Eekels 1995], rotated. The graphical notation suggests a straightforward linear succession of stages and gates, while iterative feedback is subordinate (emphasis added)

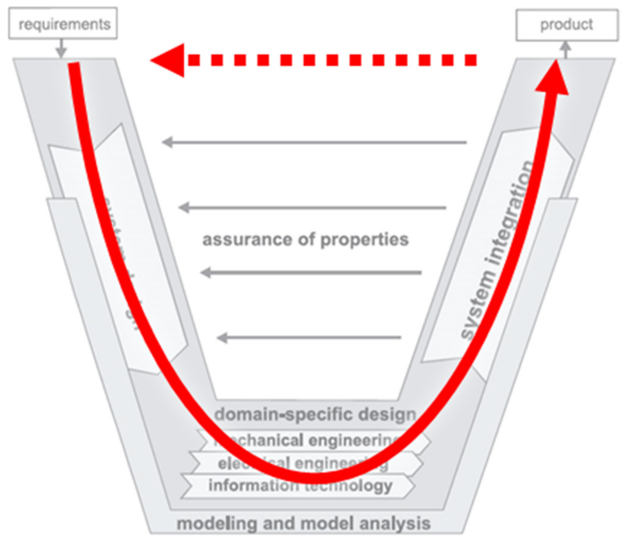


Figure 2. Example of a V design process model [VDI 2204]. More prominent visualisation of optional iteration, levels of abstraction can be guessed (emphasis added)

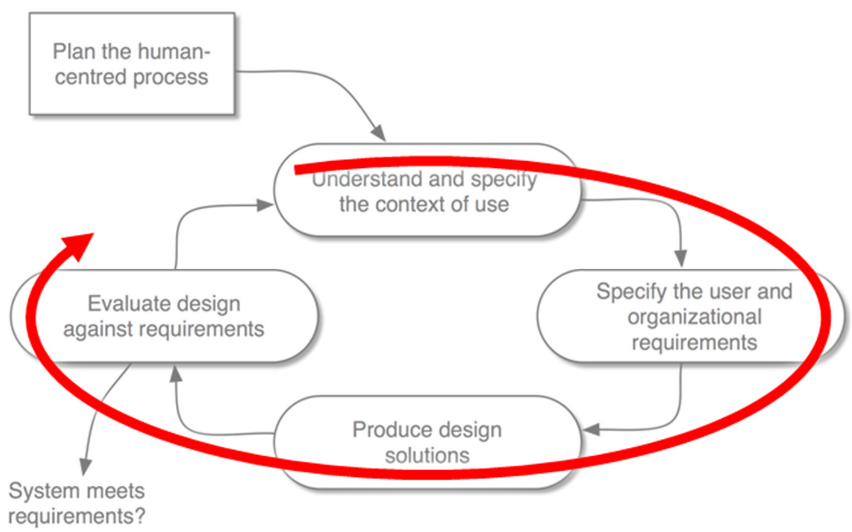


Figure 3. Human-centred design for interactive systems [ISO 2011] illustrating the iterative character (loops) of the design process (emphasis added)

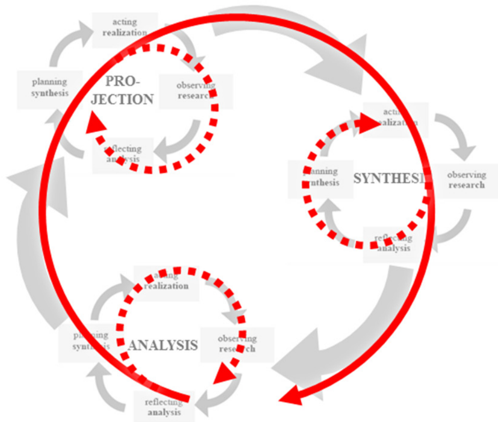


Figure 4. (Hypercyclic) generic design process model [Hugentober et al. 2004] illustrating iterations on macro and micro levels (whole design process and within stages) (emphasis added)

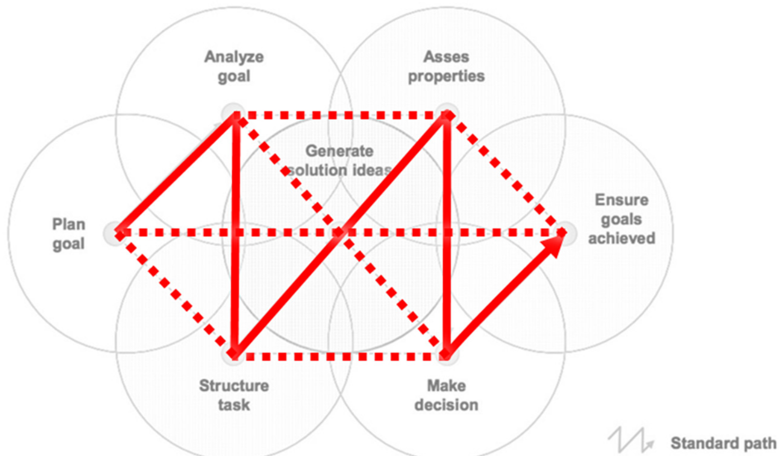


Figure 5. Munich procedural model [Lindemann 2005] illustrating different opportunities regarding the order of design process stages beyond mere iteration (emphasis added)

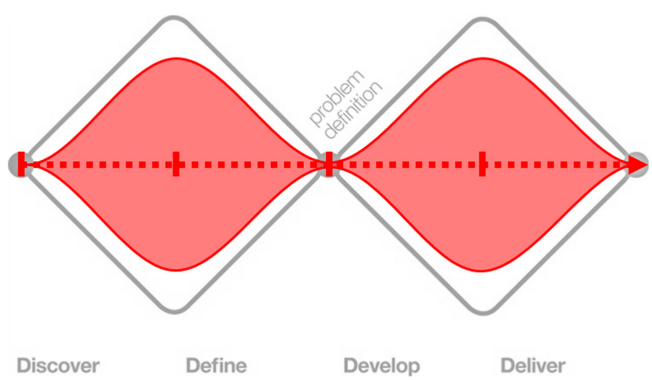


Figure 6. Double Diamond [Design Council 2007], illustrating divergence and convergence along a linear process (emphasis added)

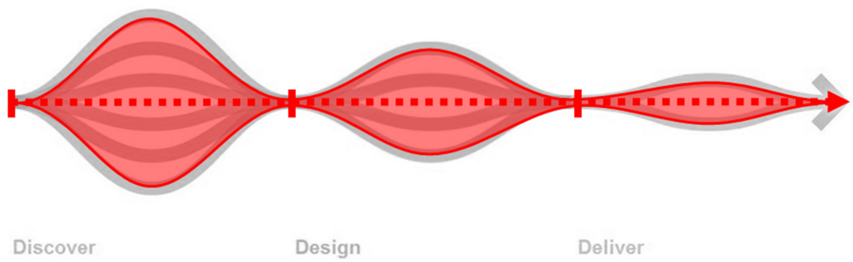
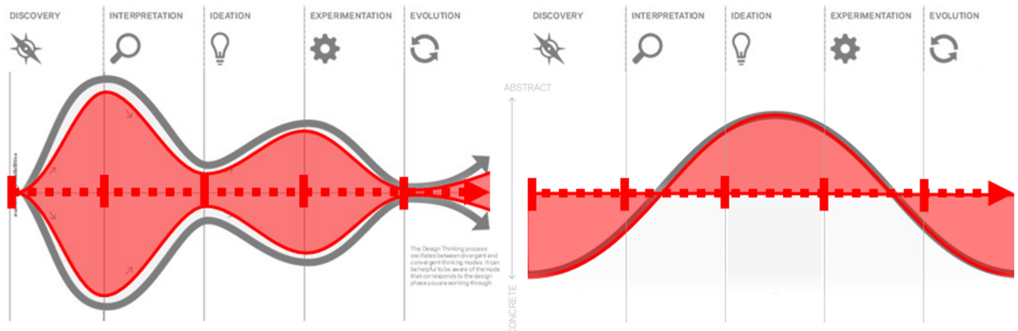


Figure 7. Frog [2014], illustrating different levels of divergence (or scope) along a linear process (emphasis added)



Figures 8. a, b. IDEO [2012] two different illustrations of the same design process model, with emphases on different levels of divergence and convergence (left) as well as abstract (down)/concrete (up) levels along a linear design process (emphasis added)

While the notion of iteration and flexibility is predominant in the debates about (graphical) design process models, further aspects can be illustrated and thus communicated. Figure 6 shows the Double Diamond, a more recent design process model [Design Council 2007], that essentially comprises of four stages and three gates a fixated linear sequence. While at first sight, the models in Figure 5 and Figure 6 are both in double-diamond shapes, the intended emphasis of the visualisation differs. Hence, the model of the (British) Design Council has a close link to traditional linear models such as the one shown in Figure 1. However, by incorporating widening and constraining (or diverging and converging) lines it emphasises the change of scope during the design process. The FROG design process model [FROG 2014] additionally illustrates the degree of divergence (Figure 7), while IDEO's graphical notation in Figure 8a illustrates different levels of divergence and convergence. Figure 8 is an example of a set off different graphical notations of the same design process model, emphasising different facets of the – in this case successive – stages: scope (Figure 8a) or abstraction (Figure 8b).
There are many more design process models from different disciplines and from different domains, cf. [Dubberly 2004]. A more comprehensive analysis of all models could reveal more aspects that have been addressed by the graphical notation of design processes (such as uncertainty, cost, duration, disciplines involved).

4. Comparison based on a linear reference structure

Apart from specific emphases in the graphical notation of the design process models, there are differences in the number, order and explanation of process stages. While Gericke and Blessing provided a respective analysis of design processes from different disciplines with a focus on the process stages, the following section adds a comparison of design process models from academia and industry in the same regard.
In order to allow a comparison of the differently shaped process models, a number of different models from academia, professional organisations and companies have been broken down into basic linear models. Those linear representations could then be matched to deductive generic process stages. In consequence, differences between the models became apparent.

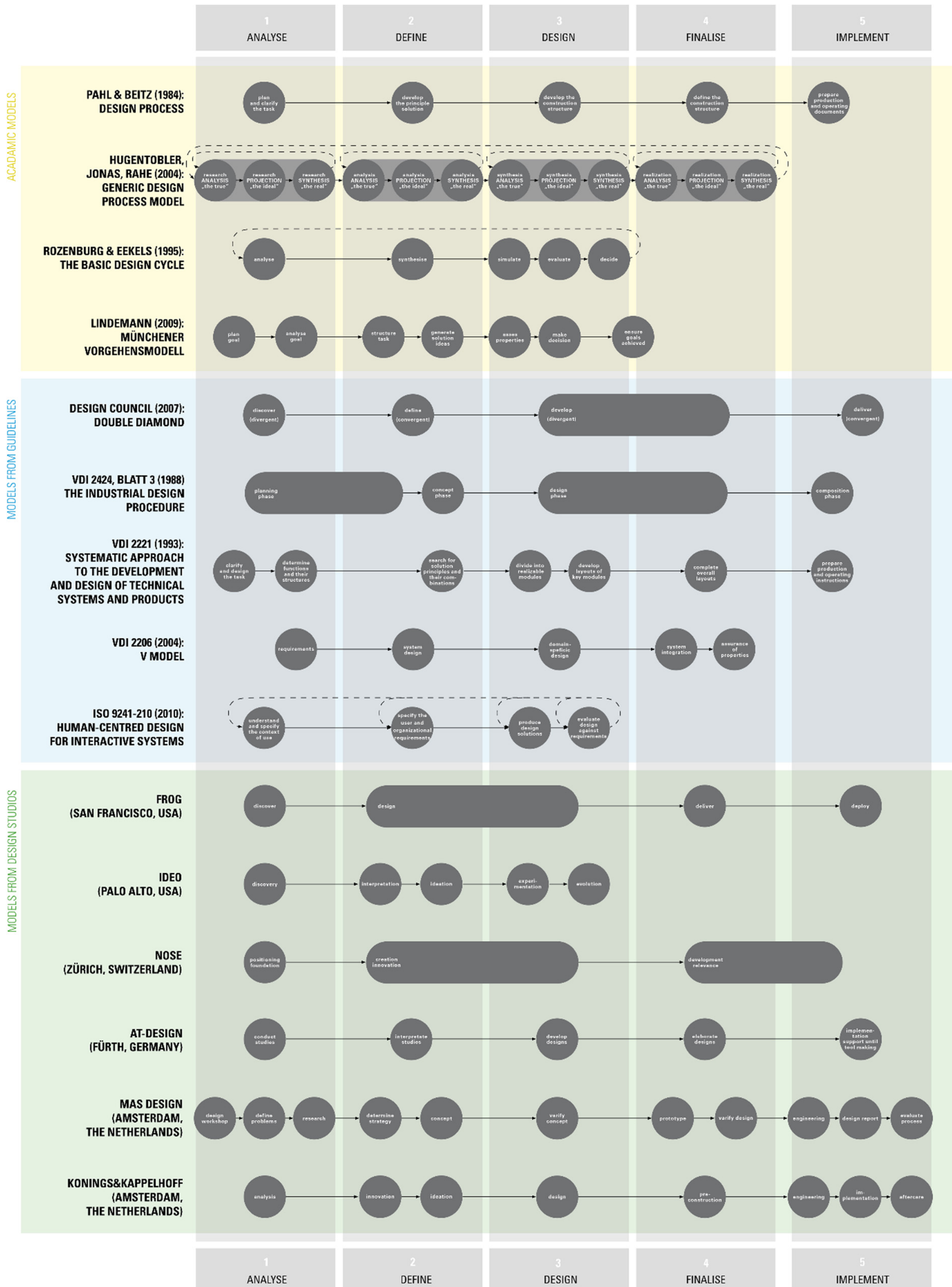


Figure 9. Design process models from academia (yellow, top), guidelines from professional organisations and standards (blue, middle) as well as models from design studios (yellow, bottom). All model stages have been assigned to the general design stages *analyse, define, design* and *finalize*; there is an additional stage *implement*, that is represented only in 9 out of the 15 process models chosen for this analysis

All compared process models have been developed at different periods of time from 1984 until today, during this various academic research was conducted and many discussions regarding process models took place. In spite of this, all compared process models show substantial similarities. When “bent” to a linear structure and sorted into more general stages (derived deductively from the models), most process models easily fit the order of *analyse — define — design — finalise*. While *define* is the stage of synthesis on an abstract level, *design* is synthesis of concrete solutions. Nine out of fifteen analysed models additionally span the stage *implement*. While only one of the academic models [Pahl et al. 2007] covers the implement stage due to its strong connection to industrial basis, there is only one model from companies that does *not* cover the implement stage. Due to its rather consulting and not product-oriented business model, the IDEO design process model does not take finalisation nor implementation into account. As can be seen in Figures 9 or 10, the degree of subdivision differs. However, there is no clear emphasis of subdivision; notwithstanding the count of the specific (sub-) stages, these are spread quite evenly across all five (or four plus additional one) general design stages.

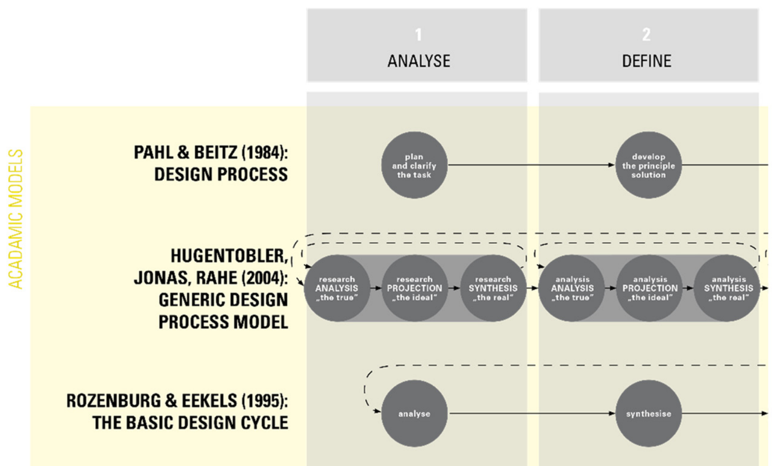


Figure 10. Detailed view into the table from Figure 9, showing the first stages of five process models assigned to the general stages analyse and define. Define is a separate stage prior design due to the degree of abstraction of the synthesis at this stage

5. Discussion

In spite of various different formal representations, all models follow the basic design process framework which results in the four plus one stages as described above. The range of relevance of the models differs. While some models are developed to be general and exhaustive, others are developed to offer intuitive understanding of the design process. While some models stick to standardised notions of flow-charts (Figure 1 or 3), others use options of recent information visualisation trends (Figure 7 or 8). In general, all design process models focus on different aspects: There is obviously a wide range of graphical notations as discussed before (e. g. linear, circular, flexible), they all use different terms for similar content and also their purpose varies from researching design itself to being an instruction on how to proceed in the design process (descriptive and prescriptive models).

One important aspect of the design process, which none of the compared models included, is the amount of time being consumed in each phase. Instead, every phase is standardised regarding their temporal length. Few models visualise »optional« aspects such as widening (search, divergent) and narrowing (evaluation, convergent) the scope (e. g. Figures 6 to 8), or depth of the stages from broad overview to specific methods to be applied (Figure 2).

In simplified terms, the stronger the design process models are rooted in industrial practice, the stronger is the extent to the additional implementation stage. This correlates with previous critique on academic design process models as summarized by Gericke and Blessing [2011].

While the relevance of the design process models from academia and from professional organisations such as the VDI or the British Design Council could be assessed for being representative, the models

from companies exhibit a sample that can surely not be considered being representative for an entire branch. There are many companies intentionally not providing standardised design process models in order to be able to flexibly adjust to different customers. Some of these models are made to communicate certain aspects of the design services offered by the companies, rather than to be representative for many design cases. Also, the models provided by the companies are changing more quickly. FROG and IDEO have published different design process models in the recent years, the latest have not been part of this analysis and should be added.
While most of the academic models concern the development of (physical) products, most of the companies' models also claim to be applicable to the design of services, social or organisational innovation. In this regard, the results refer to the comparability of different disciplines in previous studies, e. g. [Gericke and Blessing 2012], [Woelfel et al. 2012]. Based on the analysis presented in this paper, there is no significant general difference between design process models from academia, professional associations or companies. Considering the strong connections between academia and industry, with professional associations in between, this is no surprise.

6. Outlook

The formulation of new design process models will continue as changes in technology, markets or organisational structures will always have effect on actual design processes. Depending on the target group and the intention, structure, formulation and visual representation must vary. Accordingly, the one and only (generic) design process model satisfying all potential needs will not be developed. However, there is potential for including further information in a graphical way. Developing a graphical notation of design process models therefore may become a task for the specialising discipline of information visualisation. Figure 11 shows an example of this approach, illustrating different aspects of the design process and its stages – e. g. the duration of stages and sub-stages – for educational purposes.

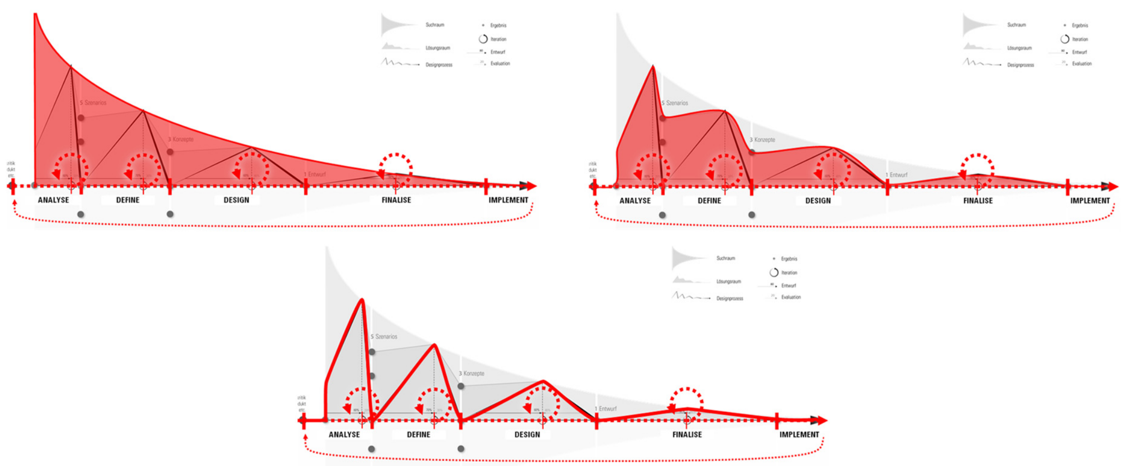


Figure 11. An adaptive multi-layer visualisation of a design process emphasising different duration of design stages, convergence of search space (top left), divergence and convergence of solution space (top right), or focus of the particular design process between multiple concepts, design proposals etc. (bottom). While the graphical notion suggests a largely linear process with iterative loops within the stages, a feedback loop of the whole process can be read indirectly from annotations at start and end [Krzywinski et al. 2016] (emphasis added)

The VDI (Association of German Engineers) and VDID (Association of German Industrial Designers) are reworking the guidelines on product development and industrial design, thus reworking the notions of the corresponding design process models, cf. [Reichert et al. 2014]. Accordingly, in 2016 there will be new (or adapted) design process models claiming relevance that should be analysed and discussed.
As stated above, an analysis as provided in this paper may enable designers (and novices) to configure their own specific design process model. In the future, this will be applied in industrial design

engineering education. In particular, students may visualise design processes of their industrial internship projects in a comparative way. The analysis can easily be extended to more (and newer) design process models. And last not least, the link to stage-specific methods as provided elsewhere, can be added to this scheme. For educational purpose, the emphasis will be on using the potential of the discipline of information visualisation, and complementing the graphical model(s) by illustrating examples (Figure 11).

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