An Analysis of Functional Modelling Approaches Across Disicplines

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AN ANALYSIS OF FUNCTIONAL MODELLING APPROACHES ACROSS DISCIPLINES

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AN ANALYSIS OF FUNCTIONAL MODELLING APPROACHES ACROSS DISCIPLINES

ABSTRACT

Authors across disciplines propose functional modelling as part of systematic design approaches, in order to support and guide designers during conceptual design. The presented research aims at contributing to a better understanding of the diverse functional modelling approaches proposed across disciplines. The article presents a literature review of 41 modelling approaches from a variety of disciplines. The analysis focuses on what is addressed by functional modelling at which point in the proposed conceptual design process, i.e. in which sequence. The gained insights lead to the identification of specific needs and opportunities, which could support the development of an integrated functional modelling approach. The findings suggest that there is no such shared sequence for functional modelling across disciplines. However, a shared functional modelling perspective has been identified across all reviewed disciplines, which could serve as a common basis for the development of an integrated functional modelling approach.

Keywords: *functional modelling, functional modelling approaches, cross-disciplinary, literature study*

1. INTRODUCTION

The functions of a technical system allow users to draw value from the system by using it for a certain purpose (Tan et al. 2007). Design strives to generate descriptions of technical systems, which are capable of fulfilling required functions related to ever-growing customer expectations, in sufficient detail for their implementation (Blessing 1994, Chakrabarti and Bligh 2001, Eder 2008). Technical system development increasingly requires the integration of different technologies, necessitating a closer collaboration of experts from different disciplines. The term “technical system” used in this article encompasses both technical products and Product/Service Systems (PSS). Particularly the conceptual design stage, i.e. the transition from a design problem to an early solution concept, is considered to be among the most demanding design tasks (Blessing 1997). It requires a joint effort and the establishment of a shared understanding of the technical system under development – including the design problem and expected functional capacities – among the involved designers (Valkenburg 2000, Kleinsmann 2008).

Across disciplines, systematic design approaches propose functional modelling, in order to support and guide designers during conceptual design (Blessing 1997, Eisenbart et al. 2011). Integrated functional modelling may thus considerably support the establishment of the required shared understanding and facilitate cross-disciplinary collaboration during conceptual design. However, such a generally accepted approach for integrated functional modelling has not been established. Consequently, the exchange of expertise is hindered, as different understandings and different ways of representing function are competing when designers (of different disciplines) collaborate (Buur 1990, Müller et al. 2007). The specific way functions are represented is bound to the particular understanding of function applied, as Eckert (2013) and Goel (2013) highlight. Diverse understandings of function (Crilly 2010, Carrara et al. 2011, Vermaas 2013) and a large variety of functional models (Eisenbart et al. 2012, Erden et al. 2008) can be found across, but also within different disciplines.

This article presents the results of an extensive literature study on proposed functional modelling approaches from a variety of disciplines and discusses needs and opportunities for an integrated functional modelling approach. The presented research aims at contributing to a better understanding of functional modelling approaches proposed in different disciplines.

The following section discusses the ambiguity related to the understanding of function and the way functions are represented in research and related to its practical application. Section 3 presents a review of functional modelling approaches proposed in literature from a variety of disciplines. Focus is put on the addressed content (*functional modelling perspectives*) and the proposed sequence for functional modelling, if multiple functional models are proposed. The results of the analysis are discussed in section 4. Finally, the implications of the derived needs and opportunities are discussed in section 5.

2. AMBIGUITY RELATED TO FUNCTION

Despite the centrality of function to technical system development "[…] function lacks a single precise meaning. It is a term that has a number of co-existing meanings, which are used side-by-side in engineering" (Vermaas 2011). Various definitions of function exist (see e.g. Crilly 2010, Carrara et al. 2011) and a shared understanding of function has not been established among researchers (see e.g. Ullman et al. 1992, Umeda and

Tomiyama 1997, Chandrasekaran and Josephson 2000, Far and Elamy 2005) or even among practitioners from the same discipline (Eckert 2013, Alink 2010). The different authors agree that this ambiguity is problematic in the collaboration of different designers as it may considerably hinder communication about individual functions and expected system functionality.

2.1 Co-existence of different perspectives on function

The divergent understanding of function in research has resulted in a large variety of functional models proposed in literature across disciplines (Eisenbart et al. 2012). In an exhaustive literature study Eisenbart et al. (2012) analysed a total of 70 functional models (54 original models plus variants proposed by different authors). The considered models originate from mechanical engineering (24 models), electrical engineering (8 models), software development (12 models), mechatronic system development (10 models) as well as service and PSS design (16 models). The analysis led to the identification of different *functional modelling perspectives*, which are described in Table 1 taking the example of a welding robot using welding tongs. Functional modelling perspectives relate to the particular content addressed by individual functional models, i.e. they relate to what is explicitly modelled in a specific functional model, in order to represent individual functions and overall system functionality.

Table 1: Functional modelling perspectives

states	Representation of the states a system can be in, or of the states of operands before (input) and after (output) a transformation process. Operands are typically specifications of energy, material, and information.
	The welding robot changes the state of metal sheets (operands) from "loose" to "welded", while the state of the welding tongs (system) changes from "open" to "closed".
	Typical example: process structure (Blessing and Upton 1997).
effects	Representation of the required physiochemical effects, which have to be provided to enable, respectively support, the transformation process(es) changing one state into another state.
	Within the welding robot electrical energy needs to be transformed into rotary movement to close the welding tongs.
	Typical example: function structures (see e.g. Pahl et al. 2008).
trans-formation processes	Representation of the processes executed by stakeholders or technical systems, which (from the designers' perspective) are part of the technical system under development in order to change the state of the system or of operands. *Technical processes* are transformation processes related to technical systems, while *human processes* are related to stakeholders (thus, including service activities).
	The welding robot needs to "move into position" and "close the welding tongs" in order to connect the metal sheets. Transformation processes require various physiochemical effects to be provided by technical systems or stakeholders.
	Typical example: technical process structure (Hubka and Eder 1988).
interaction processes	Representation of interaction processes of stakeholders or of other technical systems, which (from the designers' perspective) are *not* part of a system, with stakeholders or technical systems, which *are* part of the system under consideration.
	If the robot is sold to a customer, without services associated to it, "exchange electrodes", "type in position information", etc. are regarded as interaction processes with the system.
	Typical example: service process model (Watanabe et al. 2011).
use case	Representation of different cases of applying the technical system. This is typically associated to the interaction of stakeholders or another technical system with the technical system under development, which triggers, respectively requires subsequent processes to take place.
	A potential use case associated to the welding robot is a user requesting the robot to "display the position of the end effector", which includes several sub-processes (e.g. measuring position, processing data, etc.) within the robot.
	Typical example: use case schematic (see e.g. Kroll and Kruchten 2003).
technical system allocation	Representation of the role of a technical system, which is supposed to perform or enable a (sub-)set of required *effects* or *processes*, either as part of the technical system under consideration or by interacting with it.
	Changing the electrodes of the welding tongs e.g. may be executed by another robot.
	Typical example: technical process structure model (Hubka and Eder 1988).
stakeholder allocation	Representation of the roles of different stakeholders, which may be users benefitting from a system or operators contributing to the system, e.g. through executing required processes or providing resources, etc.
	In the PSS context, a service associated to the welding robot, may involve stakeholders like operators to change the electrodes or companies to deliver new electrodes, etc.
	Typical example: SADT modelling (see e.g. Maussang-Detaille 2008).

Individual functional models frequently address multiple functional modelling perspectives and Eisenbart et al. (2012) suggest that several functional modelling perspectives are more prominent than others within the different disciplines. For instance, the proposed functional models in mechanical engineering seem particularly concerned with technical processes and effects. These are typically structured hierarchically and/or related to flows of operands (typically specifications of material, energy or information), which are to be changed in their state. In contrast, software and PSS development seem to focus on transformation and interaction processes performed by different stakeholders in relation to different use cases. As part of the presented research in this article, it will be analysed more thoroughly, which specific functional modelling perspectives are particularly prominent within individual disciplines.

2.2 Studies on functional modelling in practice

Ambiguity in the use of function not only seems to persist in research, but particularly in how designers approach functional modelling in practice. Eckert (2013) presents the results of an interview study and experiments, which suggest that practical designers do not employ a clearly defined understanding of function. As a consequence, different understandings of function get mixed and are employed inconsistently during functional modelling (see also Alink 2010, Alink et al. 2010). In the presented experiments designers essentially switched between understandings of function as related to the purpose of technical systems, flows of operands or transformation of states. They typically did not differentiate between function and intended behaviour. Also, the inclusion of unintended behaviour seems dependent on the individual designer.

Designers tend to make assumptions about the potential solution to a design problem and model the functions of the system accordingly (see e.g. Blessing 1997, Eckert et al. 2010). Thus, within the developed functional models – rather than strictly applying suggested functional taxonomies[1] – individual functions have been formulated on an inconsistent level of abstraction and related to different understandings of function (Alink 2010). Difficulties with the application of functional taxonomies in practice are also discussed by Ahmed and Wallace (2003) and van Eck (2010). Alink (2010) emphasises that while they are moving towards a potential solution concept, designers in fact *need* to be able to describe functions on different levels of abstraction or concreteness. The functions of a potential solution concept need to be modelled as concretely as possible, in order to determine required auxiliary functions (Albers et al. 2010).

Essentially, designers often seem to feel restricted in modelling and reasoning about functions when strictly applying functional modelling as proposed in systematic design approaches (Alink 2010, Blessing 1997). Rather, they preferred modelling functions in a way fitting to their particular needs (with a particular potential solution in mind).

2.3 Implications

While many researchers have strived to determine one generally accepted understanding of function (Vermaas 2013), designers in practice seem to switch flexibly between alternative understandings and ways of representing functions. Allowing ambiguity is thus seen as a desirable advantage for individual designers to perform functional modelling fitting to their specific needs (Eckert 2013, Alink 2010, Vermaas 2013 and Carrara et al. 2010), i.e. fitting to their current strain of reasoning: “we see

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[1] Functional taxonomies are specific methods for formulating functions related to a given level of abstraction and understanding of function. Typically, these use verb and noun combinations.

different meanings of function not as an obstacle to functional modelling, but as a critical source of the power of functional reasoning[2]" (Goel 2013).

This suggests that an integrated functional modelling approach needs to link what individual designers represent in their models (i.e. the addressed functional modelling perspectives) irrespective of ambiguous understandings of function these are based on. Such an integrated approach could facilitate joint functional modelling and support the establishment of a shared understanding in interdisciplinary design projects, while at the same time provide designers with the flexibility they require.

3. ANALYSING FUNCTIONAL MODELLING APPROACHES

"Functional models of complex systems and functional reasoning about the systems are closely intertwined" and functional modelling is proposed to support functional reasoning of designers (Goel 2013). Eisenbart et al. (2012) found many of the functional models proposed within systematic design approaches to be building up on each other. A proposed sequence of functional models is intended to guide designers in their reasoning towards a potential solution concept (Chakrabarti 1992, Eder 2008), while individual synthesis and analysis steps related to individual modelling activities are typically highly iterative. Such a sequence of functional models further implies moving between the respectively addressed functional modelling perspectives. The term

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[2] "Functional reasoning" relates to the analysis and synthesis activities of designers in the gradual determination of a potential solution to a given design problem, supported through functional modelling (Goel 2013, Far and Elamy 2005, Chakrabarti 1992, Chakrabarti and Bligh 2001 etc.).

“functional modelling approach” is used henceforth, in order to encompass the proposed functional models (with the inherent modelling perspectives these address) and the proposed sequence for modelling, i.e. the sequence in which the respective models are proposed.

The research presented here aims at contributing to a deeper insight into functional modelling approaches proposed across disciplines. Functional modelling perspectives or proposed modelling sequences, which are common across disciplines, may provide a suitable starting point for the development of an integrated modelling approach. The presented research strives to determine the typical (or most prominent) modelling perspectives and proposed modelling sequences in the different disciplines. The research is guided by the questions:

- *Which functional modelling perspectives are addressed within the different disciplines and which are most prominent*?
- *What kind of sequence (if any) is suggested for considering the different functional modelling perspectives in the different disciplines and is there a shared one across*?

3.1 Research approach – coding scheme

The analysis focuses on systematic design approaches that explicitly propose functional modelling. In total, 41 functional modelling approaches are analysed each proposing between 1 and 5 different functional models. The approaches originate from mechanical engineering, electrical engineering, software development, service development, mechatronic system development and PSS design.

The individual functional models proposed in the different modelling approaches are coded based on the modelling perspectives identified by Eisenbart et al. (2012) (see Table 1). That means, it is analysed which functional modelling perspective is represented in the respective models. If multiple perspectives are addressed in a model, the perspective(s) are highlighted (black filling in cell), which drive the associated modelling activities (if applicable). Further, implicitly addressed perspectives are marked with an “o”, as described in Table 2.

3.2 Functional modelling approaches in different disciplines

Table 2 shows the functional models, their succession and the modelling perspectives they address for a few examples of the reviewed systematic design approaches. Their succession of the models in the respective rows corresponds to the proposed sequence in the individual modelling approaches. The column “proposed models” includes the particular models the individual functional modelling approaches are based on and result in, respectively. Not all of these are functional models themselves. For instance, functional modelling proposed by Pahl et al. (2008) is based on a requirements list and results in a working structure, which is represented in a morphological matrix (see Table 2). The inclusion of these models indicates the individual context for which functional modelling, related to the different approaches. In the following, the findings are presented based on examples from each reviewed discipline.

3.2.1 Mechanical engineering

In mechanical engineering, functional modelling proposed by Pahl et al. (2008) (and related approaches) has been adapted and taken up by various authors from mechanical engineering (see e.g. Roozenburg and Eekels 1995, Stone and Wood 2000, Ulrich and Eppinger 2008, etc.) and interdisciplinary system development (e.g. Spath and Demuss 2006, VDI 1993, VDI 2004, Cross 2008). Pahl et al. (2008) focus on the effects, which are necessary to transform an initial state into a desired state within a technical system. Frequently, a set of individual effects is encompassed as a transformation process.

Approaches which are considerably different from Pahl et al. are proposed e.g. by Hubka and Eder (1989) and Tjalve (1978). These approaches (and related ones) propose modelling the required transformation processes (totally external to the technical product under development) to change operands from an initial into a final state. Subsequently, the required technical processes and effects within the technical product are derived, which enable the external transformation processes. Therein, human operators are also modelled, who either substitute transformation processes or deal with the system as a whole. Furthermore, additional technical systems, either performing or supporting individual transformation processes, are allocated within functional modelling. The proposed sequence for modelling differs slightly between the two authors.

Table 2: Examples of functional modelling approaches

empty does not apply; not included
black cell driving aspect
grey cell functional modelling perspective is explicitly addressed

x functional modelling perspective is explicitly addressed in the model
(x) functional modelling perspective *may* be included
o implicitly addressed in functional model
x* changed states included after each operation

	Authors	Proposed models			Functional modelling perspectives						
					States	**Effects**	**Transformation processes**	**Interaction processes**	**Use case**	**Technical system allocation**	**Stakeholder allocation**
Mechanical engineering	**Pahl et al. (2008)**	**based on**	requirements list, overall problem formulation		**comment:** *Functional decomposition in a tree model is not compulsory*						
			(function tree)		x	x	(x)				
			function structure		x	**x**	(x)				
		results in	morphological matrix								
	Hubka and Eder (1988)	**based on**	requirements list								
			technical process structure		x		**x**	o		x	x
			function structure		(x)	**x**	x	o		x	x
		results in	Organ structure, morphological matrix								
	Tjalve (1978)	**based on**	requirements list								
			alternative (manual) process flow models		x		**x**	o			
			man/machine separation list					(x)		**x**	**x**
			process/function chart		x	x	**x**	x		x	x
		results in	function means tree				**x**			**x**	
Electrical engineering	**Dewey (2000) - EDA**	**based on**	performance and constraints specification		**comment:** *Different functional models can be used alternatively*						
			state diagrams	*in parallel/ alternatively*	**x**				(x)		
			function table			**x**		o			
			petri nets		**x**						
			VHDL description		x		**x**		o		
		results in	circuit diagram								
Software development	**Kroll and Kruchten (2003)**	**based on**	problem statement								
			feature list				**x**	x	o		
			Use case schematics				**x**	x	**x**	x	x
			Use case description				x	x	x		x
			Sequence diagram				**x**	x			x
			Activity/event diagram				**x**	**x**			x
		results in	initial system structure/architecture								
Service development	**Spath and Demuss (2006)**	**based on**	requirements list, initial system structure		**comment:** *SADT and FAST used alternatively, resulting in blueprint*						
			Function structure		x	**x**	o				
			FAST	*alternatively*	x		x			**x**	
			SADT		x*		**x**	x		x	(x)
			Service blueprint		o		**x**	o		x	x
		results in	module structure								
Mechatronic system development	**Buur (1990)**	**based on**	requirements list								
			state transition model	*iteratively*	x				**x**		
			(active) purpose fcts. model				**x**		x		
			transformation fcts. model			**x**			x		
		solution	*expanded* function means tree			**x**	**x**			x	
	Salminen and Verho (1989)	**based on**	requirements list		**comment:** *Presented succession is not* ***strictly*** *proposed*						
			function tree				**x**		x		
			events list				**x**	x		x	x
			context and flow diagram		x		x	x		**x**	**x**
			state transition diagram		**x**		x		(x)		
		results in	principle solution table (after Koller)								
PSS design	**Maussang-Detaille (2008)**	**based on**	customer needs								
			inter-actor network							**x**	x
			function list (decomposition)				**x**				
			FAST (general)	*alternatively*			**x**	(x)		**x**	
			SADT (use activity)		x*		**x**	x		x	(x)
			FAST (function and solution allocation)				**x**	(x)		**x**	
			Functional block diagram (FBD) (internal modelling of system with principal elements)				x	x		x	**x**
		results in	SADT - activities within the system		x*		**x**	x		x	(x)
			FBD (detailed system modelling)				x	x		x	**x**
	Sakao and Shimomura (2007)	**based on**	initial scenario model		**x**						x
			flow model								**x**
			scope model		**x**						
			scenario model (transition graphs)		**x**						x
			chain of actions				**x**	x		o	o
		results in	view model (function tree and realisation structure)		**x**		**x**			x	

3.2.2 Electrical engineering

In electrical engineering, functional modelling is prominently process-oriented, addressing the particular switching sequences (e.g. in relation to the signal flows) within different use cases and different system states. While all reviewed systematic electrical engineering approaches propose a stepwise overall design process, functional modelling involves alternative functional models addressing different sets of functional modelling perspectives. A specific succession is not clearly proposed (see e.g. Scheffer et al. 2006, Dewey 2000, Bleck et al. 1996 etc.). The designers may choose which functional models to use and in which particular succession.

3.2.3 Software development

In software development, functional modelling strongly focuses on interaction processes with the system as well as transformation processes executed by the system. Kroll and Kruchten (2003), for instance, start by listing the processes the system is supposed to enable and to offer the user (see also Schwaber 2007), while successive functional models focus on the particular use cases and transformation processes, while gradually giving more detail (see also V-Model XT in IABG 2006). They include a representation of the interaction processes of a user with the system as well as the triggered transformation processes executed by the system.

3.2.4 Service development

Functional modelling in service development prominently seems to focus on modelling transformation processes executed by humans (often in conjunction with the use of technical products), as well as the allocation of technical systems and stakeholders. Spath and Demuss (2006) propose service blueprinting in order to support functional modelling, while other authors frequently propose it for later design stages, in particular concept development, thus addressing the solution rather than the functions the solution has to fulfil (see e.g. Bullinger et al. 2003; Fähnrich and Meiren 2007, etc.).

3.2.5 Mechatronic system development

In mechatronic system development, the VDI guideline 2206 (VDI 2004) proposes a function structure similar to Pahl et al. (2008). Buur (1990) proposes iterative modelling of the different system states, effects, and transformation processes, associated to different use cases, using multiple functional models. Finally, the required effects and processes are allocated to different technologies and solution concepts within a function means tree.

Salminen and Verho (1989) propose sequential functional models. In particular, system states, transformation processes, interaction processes with the system as well as stakeholder and technical system allocation are addressed. Several functional modelling perspectives are distributed among two or more functional models, which – irrespective of their sequential proposition – implies that the designer will have to move between different functional models iteratively. Changes made to one functional model, may affect another model.

3.2.6 PSS design

Except for Sakao and Shimomura (2007), none of the reviewed PSS design approaches was found to propose a sequential functional modelling approach and the different approaches differ greatly. The proposed functional models prominently address transformation processes, interaction processes with the system, as well as the different states of the user and the system.

Within PSS design, e.g. service blueprinting, SADT[3] and FAST[4] modelling, are often are proposed for different design stages of the system development process. In some approaches, these models are used to independently model the function in one design stage and the concept in another; in other approaches they support the transition from function to concept. Within this transition, the models are refined and gradually stakeholders and technical systems are allocated. Iterative refinement of functional models, leading to a spiral design approach, is explicitly proposed by e.g. Brezet et al. (2001), and – to a lesser degree – Watanabe et al. (2011) and Maussang-Detaille (2008).

3.3 Comparing functional modelling approaches across disciplines

The findings suggest that the functional modelling approaches proposed in design literature form different disciplines differ greatly. That includes the considered functional modelling perspectives (addressed in the respective functional models) and how designers are supposed to move between individual functional models (i.e. between the inherent functional modelling perspectives). The results are summarised in Table 3.

There seems to be no shared sequence for moving between individual functional modelling perspectives across disciplines and the individual modelling approaches use alternative starting points. Even within the different disciplines a great diversity can be found. The reviewed systematic design approaches from mechanical engineering,

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[3] Structured Analysis and Design Technique (SADT)

[4] Function Analysis System Technique (FAST)

software, and service development, which propose multiple functional models, typically propose a sequential modelling approach. In PSS design and mechatronic system development mostly iterative functional modelling approaches were found or alternative paths are proposed. In PSS design, in addition, spiral approaches can be found.

Table 3: Comparison of functional modelling approaches from the different disciplines

number entries	amount of functional modelling approaches that were found to explicitly address the respective functional modelling perspective
grey cell	most prominent functional modelling perspective(s) in the individual disciplines

			Functional modelling perspectives						
Discipline	**Σ consulted approaches**	**Typical proposition of functional models**	**States**	**Effects**	**Transformation processes**	**Interaction processes**	**Use case**	**Technical system allocation**	**Stakeholder allocation**
Mechanical engineering	13	sequentially	**10**	**11**	**13**	**4**	**1**	**4**	**2**
Electrical engineering	4	as alternative, parallel	**4**	**2**	**4**	**0**	**1**	**0**	**1**
Software development	7	sequentially	**2**	**0**	**6**	**5**	**3**	**4**	**4**
Service development	6	sequentially	**1**	**1**	**6**	**1**	**0**	**6**	**6**
Mechatronic system development	6	iteratively, (sequentially)	**4**	**1**	**6**	**4**	**0**	**5**	**5**
PSS design	5	as alternative, iteratively, (spiral)	**5**	**4**	**5**	**1**	**2**	**2**	**1**

The findings suggest that the *transformation processes perspective* is always one of the most prominent – or even the single most prominent – modelling perspective within all reviewed disciplines. Thus, it is prominent across all the disciplines.

While mechatronic system development and the sub-disciplines mechanical engineering, electrical engineering, and software development focus on *technical* processes, service development focuses on *human* processes. In PSS design both types are prominent. Nevertheless, even in mechanical engineering some authors particularly stress the inclusion of humans as operators into the system (e.g. as “man-machine systems”, see Andreasen 1992) and thus into functional modelling.

4. DISCUSSION

The presented analysis aims to answer the question, what kind of functional modelling approaches are proposed across disciplines, with regard to the proposed sequence of functional models and the addressed functional modelling perspectives.

4.1 Hindered communication

The identified diversity in functional modelling approaches proposed across disciplines supports the general picture of diversity and ambiguity associated to the concept of function. The presented literature study further suggests that depending on the respective author the same model may in fact serve entirely different purposes in technical product development; for instance, as it the case with service blueprinting. Designers, who have been introduced to discipline-specific functional modelling approaches, may not be aware of the modelling perspectives relevant to designers from other disciplines or how the respective functional models are used.

All these different issues support the assumption that communication between individual designers is hindered, particularly across disciplines. It seems, the particular points in time at which specific information is shared, have to be managed to reduce the risk of miscommunication and ensure information can be adequately shared. In order to support the integration of functional modelling in interdisciplinary system development, an integrated modelling approach needs to cope with the existing diversity.

4.2 Needs and opportunities for integrated functional modelling

The largest diversity in the proposed functional modelling approaches was found in those cases, when particularly many functional modelling perspectives are to be integrated, such as in mechatronic system development and PSS design. Looking across different proposed functional modelling approaches, no shared sequence for moving between the different modelling perspectives seems to exist. Furthermore, individual designers in practice tend to change between specific perspectives taken as highlighted in section 2. An integrated functional modelling approach thus needs to enable switching between taken modelling perspectives flexibly; allowing different entry points and moving between individual modelling perspectives in alternative successions.

The conducted literature study further suggests different sets of functional modelling perspectives, which are particularly prominent within the different disciplines (see Table 3). The *transformation process perspective* has been identified to be prominently addressed across all reviewed disciplines. Modelling the required transformation processes (both human and technical) may, hence, serve as a common basis in an integrated functional modelling approach. Linking the remaining modelling perspectives through the shared *transformation process perspective* may enable interlinking and translating between the different modelling perspectives taken by designers at a specific point in the development process.

The analysed functional modelling approaches – from the point of view of the representation – did not differentiate between intended or unintended functionality of a technical system, which resembles to design practice (see Alink 2010).

Finally, embedding different ways of formulating functions needs to be enabled in an integrated functional modelling approach, in order to make it adaptable to a variety of applications, as discussed above (see e.g. Alink 2010).

A modelling approach, which intends to implement the presented insights, is the *integrated functional modelling (IFM) framework* proposed in (Eisenbart et al. 2013).

4.3 Limitations

The presented research is based on the assumption that the approaches proposed in design literature are taught to designers or incorporated in design guidelines and – at least subconsciously – influence design practice. The comparison has been based solely on the analysis and interpretation of the functional models proposed in systematic design approaches as described and illustrated in literature. In some cases, however, few or no examples and limited descriptions of the proposed models were available.

5. CONCLUSIONS

As the main design decisions are taken when conceptualising a technical system, a shared understanding among the involved designers of the system under development is essential. Integrated functional modelling may serve as a basis for the establishment of such a shared understanding across disciplines. It is shown that such an integrated modelling approach needs to link the different functional modelling perspectives relevant to the different disciplines, while at the same time provide designers with the flexibility they require. The article presents the results of an extensive literature study on functional modelling approaches proposed across disciplines. The conducted study led to the identification of specific needs and opportunities for the development of an integrated modelling approach.

The derived insights suggest that individual modelling approaches are specific in relation to the addressed functional modelling perspectives and related to how to move between them. The diversity is particularly large in interdisciplinary system development approaches. However, the *transformation process perspective* is most prominently addressed in functional modelling approaches across all reviewed disciplines. Modelling the transformation processes may, hence, serve as a common basis for the development of an integrated functional modelling approach. Depending on which additional modelling perspectives are needed in a specific design project, these need to be included and linked to the transformation process perspective. Thus, such an approach could potentially enable addition or omission of modelling perspectives depending on whether these are needed in a specific system development project.

Providing the designer with a functional modelling approach, which is capable of linking the different functional modelling perspectives through a shared perspective, may improve the designers' understanding of functional modelling and reasoning outside their own expertise. An expansion of the available vocabulary to describe the content of functional modelling and the particular approaches (sequence) associated to it, hence, may positively influence the comprehension of cross-disciplinary functional modelling. However, with respect to the diverse approaches related to moving between different functional modelling perspectives, such an approach explicitly needs to be able to support functional modelling irrespective of the particular direction it is approached.

Future research needs to address the specifics of such an integrated functional modelling approach. Research is also needed to address which functional models – and hence, which functional modelling perspectives – are de-facto relevant to designers from different disciplines in practice.

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