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ADAPTING THE IFM FRAMEWORK TO FUNCTIONAL APPROACHES ACROSS DISCIPLINES

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ABSTRACT

Conceptual design is considered one of the most demanding design tasks requiring a joint effort of the involved designers, particularly in interdisciplinary design. The IFM framework intends to support interdisciplinary collaboration of designers, by linking the different functional modelling perspectives, which are prominent in the different disciplines. The presented analysis aims to answer the question, which particular adaptations are required, in order to enable and improve the application of the IFM framework across disciplines. The paper presents a comparison of the framework with established functional approaches proposed in literature. It is shown, in which ways the specific contents addressed in the individual steps of the reviewed functional approaches can be mapped onto corresponding views in the IFM framework. The findings suggest that the IFM framework is interoperable with the reviewed functional approaches without necessitating fundamental changes. Furthermore, specific potentials for the improvement of its applicability across disciplines are derived. Finally, the paper discusses specific adaptations of the IFM framework, in order to improve its applicability.

Keywords: function modelling, conceptual design, integrated system development

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1 INTRODUCTION

Designers strive to provide descriptions of technical systems, which are capable of fulfilling desired functions and requirements, in sufficient detail for their implementation (Chakrabarti and Bligh, 2001). Herein, the term "technical system" encompasses technical products, as well as Product/Service Systems (PSS). 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 of the involved disciplines (Buur, 1990; Erden et al., 2008). Thus, a shared understanding of the technical system under development – including the requirements and its expected functionalities – needs to be established among the involved designers (Alink, 2010).

Function modelling is proposed across disciplines to facilitate early concept development and may support the establishment of such a shared understanding (Erden et al., 2008). However, a large variety of function models is proposed across disciplines, addressing different *function modelling perspectives* (Eisenbart et al., 2012b). Function modeling perspectives refer to the specific information addressed in individual function models; i.e. they relate to the particular content explicitly modelled to represent functions and overall system functionality. They typically employ divergent meanings of function (Goel, 2013), as different meanings of function exist in practice (Eckert, 2013) and among researchers (Vermaas, 2013; Far and Elamy, 2005). As a consequence, the establishment of a shared understanding is hampered, as different meanings and ways of representing function are competing when designers from different disciplines collaborate (Erden et al., 2008).

Various attempts have been made in research to avoid or bridge the existing diversity; so far, however, with limited success (Vermaas, 2013). Designers seem to switch flexibly between alternative meanings and ways of representing function. Accepting this ambiguity is thus seen as a desirable advantage for individual designers to perform function modelling, fitting to their specific needs and reasoning (Eckert, 2013; Alink, 2010): "we see different meanings of function not as an obstacle to functional modelling, but as a critical source of the power of functional reasoning" (Goel, 2013).

The Integrated Function Modelling (IFM) framework developed by Eisenbart et al. (2013) aims at *linking* different function modelling perspectives, prominent in different disciplines, in order to integrate the diverse representations of function, while providing designers with the required flexibility (Eisenbart et al., 2012a). In this paper, the IFM framework is compared against established functional approaches proposed in literature. The derived insights are used to evaluate the applicability of the framework within and across different disciplines and suggest potential adaptations for its further improvement. The presented research is guided by the following research question:

Which particular adaptations are required, in order to enable and improve the applicability of the IFM framework across disciplines?

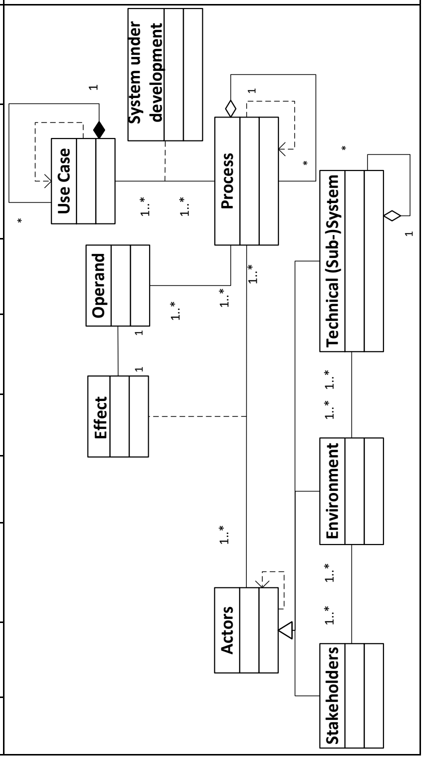
2 FUNCTIONAL APPROACH TO DESIGN

Analysing and evaluating alternative solution concepts based on function considerations, including function modelling, is typically discussed associated to "functional reasoning" and is regarded a fundamental part of human reasoning about artefacts (see e.g. Freeman and Newell, 1971). However, its specific characteristics are interpreted and emphasised in alternative ways by different researchers. Related terms and concepts are e.g. "functional design" or "functional analysis/ synthesis" (Far and Elamy, 2005; Chakrabarti, 1992; Umeda and Tomiyama, 1997, Eder, 2008). Based on a particularly exhaustive, cross-disciplinary comparison, Far and Elamy conclude that "functional reasoning is a collective term for a variety of theories and techniques that enable people to explain the presence and function of artefacts in a containing system; to derive the purpose of the artefact, and to explain how the function can be achieved" (Far and Elamy, 2005, p.77). It seems essentially characterised by iterative synthesis and analysis steps, typically including decomposition of the design problem, in order to support synthesis of potential solutions (Far and Elamy, 2005; Eder, 2008). Systematic design approaches strive to support and guide designers in this specific task by proposing a *functional approach* to design. That typically includes (multiple) function models as well as a specific sequence of steps for the designers to follow, which are intended to guide the generation of the respective function models (Eisenbart et al., 2012a; Chakrabarti, 1992; Chakrabarti and Bligh, 2001). Across disciplines, the proposed sequences may proceed strictly from one step to another or may proceed explicitly iteratively and even in a spiral manner (Eisenbart et al., 2012a). The IFM framework is intended to support function modelling irrespective of the specific functional approach applied.

3 THE IFM FRAMEWORK

The IFM framework consists of associated views onto the functions of a system under development. The different views represent the function modelling perspectives, which are prominent in function modelling across disciplines. A central view (*process flow view*) represents the flow of transformation processes, which is a central perspective in function modelling across disciplines (Eisenbart et al., 2012a). The remaining views are linked to this central view and comprise of matrices, which represent information about the different entities (see Table 1) in the framework and/or their interdependencies.

Table 1: Different entities in the IFM framework

<table>
<tr><th>Entities</th><th>Description</th><th>Domain model of the IFM framework</th></tr>
<tr><td>Use Case</td><td>Different cases of applying the technical system. This is typically associated to the interaction of actors with the technical system under development, which may require subsequent transformation processes to take place.</td><td rowspan="10">
</td></tr>
<tr><td>Transformation process</td><td>Processes executed by actors, which (from the designers' perspective) are part of the technical system under consideration, in order to change the state of actors or of operands. Technical processes are transformation processes related to technical (sub-) systems; human processes are related to stakeholders (thus, including service activities).</td></tr>
<tr><td>Interaction processes</td><td>Representation of interaction processes of actors, which (from the designers' perspective) are not part of a system, with actors, which are part of the system under consideration.</td></tr>
<tr><td>Effects</td><td>Representation of the required physiochemical effects, which have to be provided by actors, in order to enable or support transformation process(es) in changing one state into another state.</td></tr>
<tr><td>States</td><td>Representation of the states of actors or of operands before (input) and after (output) a transformation process.</td></tr>
<tr><td>Operands</td><td>Operands are typically specifications of energy, material, and information.</td></tr>
<tr><td>Technical (sub-) system</td><td>Technical sub-systems encompass technical systems (i.e. technical artefacts and associates services), which are part of the technical system under consideration. They can be composed of more technical sub-systems.</td></tr>
<tr><td>Stakeholder</td><td>Stakeholder comprises (groups of) animate beings affected by or affecting the technical system under consideration (including any related services).</td></tr>
<tr><td>Environment</td><td>Environment includes all active and passive parts of nature in general surrounding the system under development.</td></tr>
</table>

3.1 Associated views on the functions of a technical system

The IFM framework provides a clear structure and allows taking different views onto the functions of a technical system. The views are modular, as individual views may be added or omitted, depending on the specific needs of the involved designers. The adjacent placement (see Figure 1) supports the development of associated views and allows verification of their consistency. The individual views are described in the following.

The ***Process flow view*** qualitatively visualises the flow of sequential or parallel (interaction and/or transformation) processes related to one specific use case. Processes may be modelled associated to time or – in combination with the *state view* – related to flow of operands. The process blocks are spread horizontally from left to right, in order to enable a direct link to the *actor view*.

The ***Effect view*** represents the effects, which enable individual transformation processes. For each process block in the process flow view, a separate effect view may be created. The representation can be similar to the process flow view.

The ***Use case/process dependency (UPD) view*** indicates the involvement of individual processes within different use cases. Dependencies between processes, which hinder their parallel or sequential execution, could affect the operability of use cases in which these processes are involved.

The ***Actor view*** indicates the involvement of specific actors (which – from the designers' perspective may or may not be part of the system under consideration) in the realization of transformation processes. In the respective matrix, information about the particular involvement (e.g. as either "affecting" or "being affected" by a process) may be specified.

The ***States view*** represents the specific states of operands and actors as well as the state changes caused by individual processes. It consists of the *actor state matrix* and the *operand state matrix*. It can also be indicated, if an operand is merely supporting a process without changing its state.

The *interaction view* depicts the specific impacts between actors and operands, as well as among each other, in the realization of processes. Optionally, information about how a specific interaction is embodied may be included; such as 'mechanical contact' between two actors. This view effectively results in an initial system structure or interface matrix, respectively. It thus can provide direct links to models and design activities in subsequent design stages.

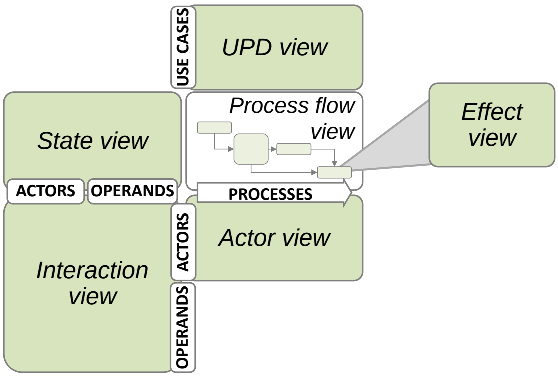


Figure 1: Adjacent views in the IFM framework

3.2 Application

Eisenbart et al. (2013) emphasise that the framework – through its modular and interlinked character – may be applied in various ways. That includes different entry points and alternative sequences of modelling steps (see section 2). Furthermore, the framework deliberately allows embedding alternative function taxonomies, which may, for instance, be related to alternative meanings of function (see e.g. Vermaas, 2013; Alink, 2010). In Table 2 different modelling activities for the application of the IFM framework are presented, which may be iteratively performed.

Table 2: Potential modelling activities in the application of the IFM framework

Use Case definition	…includes the consolidation of the different use cases (and their sub-use cases, if applicable) the system under development is expected to support in the different phases of its life-cycle. The use cases are represented in the respective column in the *UPD view*.
Process flow modelling	…involves modelling separate flows of required processes related to each (sub-) use case. A multitude of alternative process flows may fulfil a use case. While modelling the process flows, the involvement of individual processes in multiple use cases needs to be considered. As described above, modelling and selecting an alternative process flow may be facilitated through considering the required state changes of (supporting) operands and actors in parallel.
Operand state modelling	…includes modelling the state changes of involved operands in the operand state matrix (as part of the *state view*) related to the chosen process flows.
Effect modelling	…involves modelling the required effects related to the specific process blocks or entire flows, respectively.
Actor allocation	…includes allocation of the actors, which are involved in the individual processes, either as affecting or being affected through the delivered effects.
Actor state modelling	…includes modelling the state changes of allocated actors in the actor state matrix (as part of the *state view*) related to the chosen process flows.
Interaction specification	…involves analysing and detailing the specific interactions (i.e. the bilateral impacts) among actors, among operands, and between actors and operands.

In an original design project, modelling may start on a high level of abstraction: defining the use cases, associated processes etc. On the next level of detail, individual process blocks may then be regarded as use cases comprised of sub-processes. These are enabled by technical (sub-)systems, which may again be comprised of general function carriers including any related service operator etc. Function carriers may be subsequently concretised; i.e. they may be represented as a composition of working principles (Pahl et al., 2008). Thus, the framework allows modelling the functions and actors of a system under development from very abstract to very detailed and specific. This can be achieved through detailing created views. Alternatively, associated partial views may be generated, which focus on e.g. the flow of sub-processes related to one specific process block (i.e. "zooming in" on individual process blocks).

4 DIFFERENT SCENARIOS FOR APPLYING THE IFM FRAMEWORK

In the following, it is analysed how the IFM framework may be used and adapted, in order to be applied across disciplines. It is assumed that systematic design approaches proposed in literature – to some extent – represent common practice in their respective discipline, as they typically build on descriptive studies and practical experience of the corresponding authors (Blessing, 1996). That includes the inherent proposed functional approaches. In the following, selected functional approaches, which are considered to represent specific disciplines, are exemplarily compared with the IFM framework. The analysis focuses on the proposed function models and the proposed sequential modelling steps. For the comparison, existing function models provided in the descriptions of the different functional approaches have been remodelled using the IFM framework. It has been analysed which specific views (alone or in combination with others) can be used in each proposed step to represent the specific contents addressed in the provided example models. Based on the derived insights, the reviewed functional approaches are mapped onto the IFM framework. Furthermore, potential conflicts between what is supposed to be modelled in the respective steps and how it can be modelled in the IFM framework are determined, suggesting specific adaptations of the framework.

4.1 Functional approaches in mechanical engineering

The functional approach proposed by Pahl et al. (2008) and related approaches have been adapted and widely taken up in systematic design approaches from mechanical engineering and even from interdisciplinary design (see e.g. Eisenbart et al., 2012a for an overview). Their particular functional approach is frequently discussed in the context of functional reasoning (see e.g. Chakrabarti, 1992; Umeda and Tomiyama, 1997). Essentially, it is characterised by abstraction of the main function of a mechanical system from the requirements specification. Subsequently, the respective sub- and auxiliary functions are established, through iterative decomposition and detailing of the respective main function. Individual (sub-) functions are modelled related to effects and transformation processes on operands, which are to be changed in their states. Decomposition is exhibited until alternative working principles can be allocated for the individual sub- and auxiliary functions.

Considerably different approaches are proposed by e.g. Hubka and Eder (1988; Eder, 2008) and Tjalve (1978). Hubka and Eder clearly separate between the transformation processes related to desired state changes in an external transformation system (i.e. external to any actors) and those internal to the technical system under development. The internal technical processes and effects constitute the desired external transformation process(es). Only the internal transformation processes and effects are referred to as functions. Transformation processes (both internal and external) and effects are modelled related to operands, which are to be changed in their states. Functions (after Hubka and Eder) – typically in interaction with one another – provide the required effect of changing an operand from an initial into a final state in the transformation system, without necessarily being part of a separated flow of operand themselves. In Table 3, the individual steps and related models proposed by Hubka and Eder are mapped to the different views provided in the IFM framework. In an initial step, the different “duty cycles” are consolidated. The concept of duty cycles is to a large extent compliant with *use cases* (as defined in Table 1). Each duty cycle is related to a different transformation system, including related actors, internal and external transformation processes and effects. Eder (2008) differentiates diverse types of functions. From a modelling point of view, this diversification is not essential for this comparison and is thus not considered in this paper.

Table 3: Mapping of functional approach after Hubka and Eder (Eder, 2008)

Step	Description	Related models/views	
		Hubka & Eder	**IFM framework**
1	Establishing the different duty cycles the technical system may encounter in the different life-cycles	*No model*	UPD view (use case column)
2	Establishment of the desirable or required output (operand in final state) of the transformation process	Transformation process structure	Operand state matrix (in state view)
3	Establishment of a suitable transformation process from the desirable output		Process flow view
4	Establishment of an appropriate input (initial state of operand), if needed or considered helpful		Operand matrix in state view
5	Allocating which operator, alone or in cooperation with others, will perform which transformation processes; and which technical system(s) need to be designed		Actor view
6	Choice of technology (i.e. a general technical principle) to enable the transformation process(es), e.g. hydraulic cylinder, mechanical fixture etc.	Technology structure	*– no view –*
7	Establishing what the technical system needs to be able to do (its internal functions and functions performed “cross-boundary”, in cooperation with other operators)	Function structure	Process flow, effect, interaction view
8	Establishing the organs (i.e. function-carriers), which can perform these functions	Organ structure	Actor view

In all reviewed functional approaches from mechanical engineering, transformation processes and effects are not separately modelled, but in fact are combined in the same representation. It may thus be beneficial to adapt the IFM framework and allow combined modelling of process and effect blocks into one view.

4.2 Functional approaches to electrical engineering

Function modelling proposed in electrical engineering most prominently addresses system states and their transformations, in order to derive the necessary (logical) function building elements. This is usually modelled in e.g. state diagrams, petri nets or specified in VHDL. In a few examples, also use case specification is proposed as part of function modelling (see e.g. Dewey, 2000). A specific sequence for function modelling is typically not proposed (Eisenbart et al., 2012a). The different models may be used as alternatives: the designers may choose which models to use and in which way (see e.g. Scheffer et al., 2006; Dewey, 2000, etc.).

Despite the absence of a strict sequence of steps for modelling, functional approaches from electrical engineering may be supported by the IFM framework through its modular set-up of interconnected views, which allows flexibly switching between specific views taken. The different functional approaches can be supported with the IFM framework. Different use cases may be represented using the *UPD view* (IFM). Different system states can be represented in the *actor state matrix* in the *state view* (IFM). State transitions can be modelled as transformation processes in the *process flow view* (IFM).

Depending on the specific situation at hand, each alternative state transition may have to be represented in a new *state view matrix* and associated *process flow view matrix*. This suggests potential for improving the IFM framework: a more concise representation of all the possible transitions between the different system states may facilitate the application of the IFM framework in electrical engineering.

4.3 Functional approaches to software development

One of the most detailed functional approaches proposed in software development is the Rational Unified Process (RUP) (see e.g. Kroll and Kruchten, 2003). It proposes a clear sequence of steps for function modelling with associated models. Function modelling most prominently addresses use cases, transformation processes, interaction processes as well as actor allocation. In RUP, actors include humans interacting with the software system as well as entities within the software systems, such as e.g. databases. A similar approach is proposed in the V-Model XT (IABG, 2006).

The functional approach in RUP is based on a list of services (referred to as "features") the system is expected to offer to a user. Function modelling particularly aims at determining the different external actors (e.g. users) and their interactions with the system as well as particular (alternative) flows of processes which have to be performed within the software system, in order to fulfil the user requests. In Table 4 the essential steps and associated models proposed in RUP are presented and mapped to the individual views in the IFM framework.

Table 4: Mapping of functional approach in the RUP after (Kroll and Kruchten, 2003)

Step	Description	Related models/views	
		RUP	IFM framework
1	Identifying actors	Use case schematic	Actor view
2	Identifying use cases		UPD view
3	Identifying the most important use cases		
4	Identifying and modelling individual steps of the most important use cases	Activity flow diagram	Process flow view
5	Modelling alternative flows in case of error scenarios		
6	Adding pre-and post-conditions of use cases (initial and final system states)	Collaboration diagram; Use case scenario	Actor state matrix in state view
7	Representing the interactions between actors in the realisation of a use case in a sequence diagram		Interaction view

Other authors propose e.g. story boarding or function lists for representing the particular use cases, interaction processes with the system and processes within the system (see Eisenbart et al., 2012a).

Activity flow diagrams explicitly include alternative activity flows, e.g. in case of error scenarios. In the IFM framework these can be modelled in alternative *process flow views*. The inclusion of alternative process flows into one process flow view may provide a similarly concise representation of all the potential alternatives for the different activity flows.

4.4 Functional approach to mechatronic system development

In a few systematic approaches for mechatronic system development, the specific functional approach by Pahl et al. (2008) is proposed. Different functional approaches are proposed by e.g. Buur (1990) or Salminen and Verho (1989). Buur's approach consists of four partial models and builds on Hubka and

Eders's functional approach. For instance, "system states" (Buur) are closely related to "duty cycles" proposed by Hubka and Eder (see above) and thus resemble to use cases in the IFM framework. Transformation functions (Buur) address transformation processes (IFM) related to operands, while purpose functions (Buur) are related to the effects and transformation processes in the IFM framework. In Table 5, Buur's approach is mapped to the IFM framework.

Table 5: Mapping of functional approach after (Buur, 1990)

Step	**Description**	**Related models/views**	
		Buur	**IFM framework**
1	Elaboration of system states and transitions between them	States and transitions	Use case column (UPD view); *no equivalent for transitions between use cases*
2	Establish transformation functions (related to operands) required in different system states	Transformation functions	Process flow view; operand state matrix in states view
3	Establish general purpose functions needed in TS to enable the transformation functions.	Purpose functional structure	Process flow and effect view with associated UPD view
4	Indication of which purpose functions are active in different system states.	Active purpose functions	

The transition from one system state (Buur) into another (step 1) equals a transition between different use cases (IFM). The IFM framework requires adaptation, in order to model these transitions explicitly. Similar to approaches from mechanical engineering, Buur includes transformation processes and effects in the same model.

4.5 Functional approach to service development

In service development service blueprinting is widely proposed to support conceptual design (see e.g. (Alam and Perry, 2002; Edvardsson and Olsson, 1996, and others). Fisher and Schutta (2003) propose block diagrams addressing the specific service process flows. Spath and Demuss (2006) base their functional approach on the VDI guideline 2221 (VDI, 1993). They propose function structures based on Pahl et al. (2008) including step-wise decomposition of the required functions of a service system. Service blueprinting or SADT (Structured Analysis and Design Technique) are subsequently proposed in order to support this decomposition and gradually establish the required service activities (IFM: human processes), performed by the service provider or the customer (IFM: actors) to fulfil the service functions. In Table 6, the approach by Spath and Demuss is mapped to the IFM framework.

Table 6: Mapping of functional approach after (Spath and Demuss, 2006)

Step	**Description**	**Related models/views**	
		Spath and Demuss	**IFM framework**
1	Functional decomposition for the involved technical products	Function structure (after Pahl et al., 2008)	Process flow view and effect view
2	Establish service operators and activities	e.g. service blueprinting or SADT modelling	Process flow view and associated actor view

4.6 Functional approach to PSS design

Functional approaches to PSS primarily propose modelling the required service processes, interaction processes among different actors as well as the different states of actors (particularly the targeted customer). Except for Sakao and Shimomura (2007), none of the reviewed systematic PSS design approaches was found to propose clearly sequential steps for function modelling and the proposed sequences differ greatly. For instance, Aurich et al. (2007) proposes function modelling for service and product related parts in parallel. Maussang-Detaille (2008) proposes pairs of function models for the different parts of a PSS, between which the designer moves back and forth, and which are iteratively refined. The essential steps and related models proposed by Sakao and Shimomura and how they can be mapped to the IFM framework are presented in Table 7.

Table 7: Functional approach by (Sakao and Shimomura, 2007)

Step	**Description**	**Related models/views**	
		Sakao & Shimomura	**IFM framework**
1	Making a preliminary flow model	Flow model	Initial interaction view for initial set of actors
2	Setting the goal of a scenario	Scenario model	Actor state matrix in states view
3	Describing a chain of actions for service receivers	Chain of actions	Process flow view and associated actor view
4	Identifying the goal parameter	Scenario model	Detailed actor state matrix
5	Generating a realisation structure	View model with realisation structure	Detailed actor view

5 IMPLICATIONS

The presented research is guided by the question: *Which particular adaptations are required, in order to enable and improve the applicability of the IFM framework across disciplines*?

5.1 Sequences are different but compatible with the IFM framework

The presented analysis focused on how the specific contents, which are to be modelled in the respective steps of the proposed functional approaches, may be modelled using the different views in the IFM framework (see Tables 3–7). This is illustrated in Figure 2: for each reviewed functional approach, the respectively addressed views in each proposed step are indicated. Each diagram uses the different views related to the proposed sequence of steps as axes; the steps proceed from left to right. Circles represent iterations in modelling with the different views. Iterations can occur within and between individual steps.

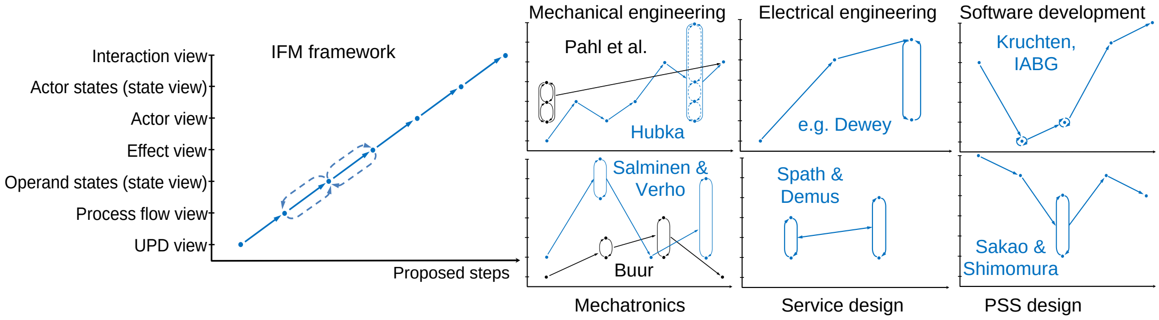


Figure 2: Comparison of functional approaches across disciplines

The comparison illustrates the diversity of the reviewed functional approaches, in terms of the proposed sequence and the specific entry points, i.e. the view(s) addressed in the first step. No single functional approach addresses all the views offered in the IFM framework. The performed analysis supports the claim that the IFM framework can be applied across disciplines. The information addressed in the individual steps of the reviewed functional approaches can be represented using the different views in IFM framework and individual views may be applied in the alternative sequences.

5.2 Required adaptations

Based on the presented analysis, potentials for further improvement of the IFM framework have been identified, which might improve its applicability in interdisciplinary design practice:

- inclusion of the transitions between different use cases;
- a more concise representation of transitions between individual system states;
- combined modelling of effects and transformation processes into one view;
- inclusion of alternative process flows into one *process flow view*.

<u>Inclusion of the transitions between different use cases:</u>

Modelling the transitions between use cases can support the analysis of dependencies and conditions for changing from one particular application of the technical system to another. It is explicitly modelled in Buur's approach.

Eisenbart et al. (2013) explicitly emphasise that the IFM framework may be adapted to the specific needs of involved designers, either by expanding the framework with additional views or through simply attaching specific exiting function models. Using the discussed options, the specific partial model proposed by Buur (i.e. the "states and transitions" partial model) may simply be attached onto the framework. Alternatively, an additional view may be created using a Design Structure Matrix (DSM), which addresses the specific dependencies (e.g. conditions and constraints) and/or possible transitions (e.g. corresponding transformation processes, effects etc.) among the different use cases. This would go much further than what is proposed by Buur and would thus provide designers with further options, than simply attaching Buur's "states & transitions" model. Furthermore, such a DSM-based view could be directly included into the matrix-based structure of the IFM framework.

<u>More concise representation of transitions between individual system states:</u>

In a similar manner, the concise representation of transitions between system states may also be realised in a DSM, which supports the analysis of dependencies and conditions for switching between different states of the system or any related actor. Alternatively, existing function models such as petri-nets, state machines etc., may simply be attached.

Combined modelling of effects and transformation processes into one view:
This would require the integration of both *process flow* and *effect view*, in order to support the application of the IFM framework within corresponding approaches (see above). As described in section 3, transformation processes may be gradually concretised, i.e. exchanged with (a set of) more detailed processes. On the lowest level of abstraction transformation processes may thus be modelled as (sets of) basic physiochemical effects. Effect and process blocks may thus be represented in the same view, provided that they can be modelled related to the same flows of operands.
Inclusion of alternative process flows into one process flow view
The inclusion of alternative process flows within one *process flow view* could facilitate the concise representation of optional process flows e.g. for error scenarios in software development, requiring alternatives for the flow of processes.
As described in section 3, individual process blocks in the *process flow view* are spread from left to right. The inclusion of alternative process flows could be realised by simply adding the corresponding process blocks as parallel processes to the right-hand side of the *process flow view*.
The discussed adaptations aim to improve the applicability of the framework across disciplines. They have successfully been applied while remodelling example models from the reviewed functional approaches. No fundamental changes within the framework seem necessary.

6 CONCLUSION

The Integrated Function Modelling (IFM) framework intends to facilitate interdisciplinary conceptual design by providing different interconnected views. These represent different function modelling perspectives, prominent in the different disciplines and/or their interdependencies. The presented analysis supports the claim that the IFM framework is interoperable with diverse functional approaches proposed across disciplines, thus presumably applicable in these disciplines. It is shown, how the specific contents addressed in the individual steps of the reviewed functional approaches can be mapped onto corresponding views in the IFM framework. The analysis suggests that the framework may indeed be applied in the diverse functional approaches without necessitating fundamental changes. However, specific potentials for further improvement of the applicability have been identified and specific alternative adaptations of the IFM framework are discussed. These include the addition of specific views or expansion of existing ones. Implementing the discussed adaptations may support designers in applying the framework across disciplines. The discussed adaptations have successfully been implemented while remodelling given examples of function models proposed in the reviewed functional approaches. On-going empirical studies address the application of the framework in different companies. The research focuses on which further adaptations may be needed, in order to improve the practical application of the IFM framework. Different design contexts may require very specific adaptions. Further research needs to address, how practical designers can be supported and encouraged in adapting the IFM framework to their specific needs.

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