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TOWARDS THE NEXT GENERATION OF DESIGN PROCESS MODELS: A GAP ANALYSIS OF EXISTING MODELS

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Abstract

Companies that follow a reference process are usually more successful. Over the last decades many different reference process models have been developed primarily in academia. Nevertheless, many approaches have not been adopted in practice. The paper analyses the most known reference models according to discipline, knowledge area, considered design stages, scope, included design approaches, provided meta information, flexibility and guidance for implementation. The results of this research show that the analysed reference models are unable to cover the whole breadth of the proposed classification scheme. There is also a lack in guidelines and support for implementation. Meta information is missing in all reference process models to facilitate a flexible and straightforward implementation into a company specific reference process. Specific research questions are derived from the analysis regarding the development for the next generation of design reference models concluding in expectations for future solutions.

Keywords: Evaluation, Design process, Process modelling

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1 INTRODUCTION

The definition of process models or its characteristics are still under discussion in the academic and the practitioner scenario (Gericke and Blessing, 2012). One can say that a reference model is the term used to denote a generic process model of a specific domain, i.e. a process model that should be used as a reference or a benchmarking for a company. Fettke et al. (2006) also refer to these models as universal models, generic models or model patterns. In this paper, we assume that generic reference models are representations of business processes containing best practices of an application area, which have a set of generic guidelines to be adapted for use in various contexts (Fettke et al., 2006).

The adoption of process models in design process is considered as one of the top relevant best practices (Cooper, 2001). The results of the 2013 PDMA survey shows that less than half of their sample companies reported to have a formal, cross-functional design process (Markham and Lee, 2013). The survey also revealed that the so-called "best performing companies" use formal processes significantly more often than the "rest" (67% in the Best versus 41.8% in the Rest). Indeed, Costa et al. (2013) found out that even though the benefits of reference models are widely accepted, the "lack of process vision" and "lack of knowledge of new product development best practices" are still recurrent issues in most of organizations.

Hypotheses for this underutilization might be the lack of knowledge of the companies regarding process models and/or the inadequacies of the available models. Indeed, Gericke and Blessing (2011) pointed out several open aspects of the current design models, e.g. the creative process is not sufficiently represented, transdisciplinary team-work is not sufficiently supported by current approaches, they do not explain the rationale of the proposed processes and don't provide enough support on how to perform design activities, only what to do.

An open question is: how should the next generation of design process model be envisioned? This study is part of a research project aimed to define the characteristics of new references models for design processes, and subsequently develop a proposal for the next generation reference models. In order to achieve this goal a thorough understanding of the current design model characteristics is needed. The objective of this paper is to present the results of the classification of design models focused on (a) the analysis of the content coverage, (b) the level of the granularity of the information provided, and (c) how the issues of implementation are addressed.

The paper is structured as following: the next section presents a brief review of process models, and then the research methodology is described. The classification scheme is detailed out in session four, which is followed by the analysis of the design process models. Finally, the discussion and further studies are presented in section six.

2 DESIGN PROCESS MODELS

In order to supply practitioners with best practices a large number of design models were published. According to the survey of Gericke and Blessing (2012) more than 124 design process models can be found in literature. It is unreasonable to deny the positive aspects of the publication of such a large amount of models, but the quantity of models generates a new challenge for organizations, which is how to select the most appropriate model.

The team selecting any process model, including design models, should take into consideration the current state of design process, strategic direction, and how the team envision the future use of their process models. Regarding the use of design process models, Browning et al. (2006) listed 17 different purposes, among them are: to define standard and preferred activities, to visualize, understand, analyse, and improve processes; to identify appropriate activities and deliverables for the project and set project schedule and secure formal commitments.

Fettke and Loos (2003) indicate that a classification of business process models can assist companies in the selection of a reference model. According to these authors in order to make an effective selection, one must have "a good understanding of the reference models available for the target domain".

Gericke and Blessing (2012) developed a classification scheme based on procedures proposed by Blessing (1996) and Wynn and Clarkson (2005). The proposed classification for design models aims at analysing the commonalities and differences of design process models across disciplines. The classification scheme presented interrelates the dimensions of: type of support; stage vs. activity-based models; problem vs. solution-oriented models; design focused vs. project focused models; and abstract

vs. procedural approaches. These authors found out a fragmentation of the existing work related to discipline specific content and an unequal evolution of design practice and design methodology.
Models can be prescriptive and/or descriptive. A prescriptive process model "tells people what work to do and perhaps also how to do it" whereas a descriptive model "attempts to capture tacit knowledge about how work is really done" (Browning et al., 2006). Reference models are prescriptive models, which should be used as a blueprint to define a specific process model for a company. Ultimately, a specific process model can be used as a second reference for project planning during design process. They provide a common vocabulary of a generic design process to all design teams. At the same time the design process model "provide reminders of what should be accomplished at or before certain points in any process" (Clarkson and Eckert, 2005).
Another perspective that should also be analysed is the process model dimensions that can assist its instantiation by companies. Looking from this perspective raises research questions such as: How flexible is a reference model? Which kind of meta-information is provided by a reference model? How much implementation support do the models provide?
The next section is aimed to explain the research methodology applied to develop the classification scheme of this paper.

3 RESEACH METHODOLOGY

The research was held by a group headed by two specialists with industry and academy background, working in the area for more than thirty years. The international team was also composed by masters and doctorate students that research the design process. In order to analyse the design references models available in literature through the lens of its coverage, level of granularity of information and guidance for implementing in company, this work uses the procedure proposed by Fettke and Loos (2003) to develop a classification system of reference models. The procedure contains five phases. The first phase - *Inception* - is aimed to plan the development of the classification system, including the purpose and the precision of the classification system. The second phase - *Elaborate characteristics* - is focused on the definition of a set of potential criteria able to be used to analyse the reference models. The third phase - *Specify classification scheme* - from the potential set of criteria, this phase defines a classification scheme with a set of options ready to analyse the reference model. The goal of the fourth phase - *Test* - is to evaluate the classification scheme by analysing the proposed reference models using the classification scheme generated. Finally, the last phase - *use and maintenance* - is aimed to use the classification scheme in a systematic way based on the experiences and improvement opportunities identified on the test phase. It is worth noting that the last phase is still ongoing, therefore this paper only presents the first four phases of the procedure.
The classification system proposed to analyse design process models is explained in the next section.

4 DESIGN PROCESS MODEL CLASSIFICATION SYSTEM

This section presents the results of the first four phases of the procedure aforementioned. The approach adopted in the first step to identify and select the design process models had an exploratory bias. First, the classics (most cited) design process models were selected and then, a second group of recently published studies was selected, so that some new tendencies could be pointed out.
Twenty-one design process models were selected: Andreasen and Hein (1987), Clark and Fujimoto (1991), Pugh (1991), Wheelwright and Clark (1992), VDI 2221, Ulrich and Eppinger (1995), Chrysler et al. (1995), Baxter (1995), Clausing (1998), Cooper (2001), VDI 2206 , Crawford and Di Benedetto (2005), Morgan and Liker (2006), Lindemann (2009), Albers (2010), Tan (2010), Gausemeier et al. (2012), Ehrlenspiel and Meerkamm (2013), Feldhusen and Grote (2013), Müller (2014) and Vajna (2014).
The identification and definition of the criteria were done in an iterative way. It started from the categorization and comparison studies proposed by Gericke and Blessing (2011, 2012), which analysed design process models across disciplines. We kept the categories discipline and design stages. However we divided the category discipline into two groups: discipline and design approach, and added knowledge areas in the classification scheme.
The second iteration was aimed to identify criteria regarding the implementation of the models and the level of granularity of the information. This way, a final set of criterion was defined as following: content coverage (discipline; knowledge area; design stage; scope of development; and design

approach), granularity of the information provided (meta information) and implementation (flexibility and guidelines).
Each criterion was decomposed on a set of options that describes the main characteristics of reference models in order to support the analysis. Most of the options were not of an exclusionary type. Only for the criteria flexibility and implementation guide just one option could be selected during the analysis.
In the next section, the results of the analyses of the design process models are reported.

5 DESIGN PROCESS MODELS CRITERIA ANALYSIS

The analysis of each criterion is available on the following sub sections. Each sub section presents an introduction on the criterion description and its importance. It is analysed how the criterion is present in the reference models. Trends detected and noticeable shortcomings from the analysis of the sampled reference models are also exhibited in the analysis. The results of the analyses of the design process models are summarized in Figure 1.

5.1 Discipline

This criterion is related to the focus of the reference models, it means the engineering domains addressed. In the cases that there was not a clear mentioning of the disciplines presented on the reference model, we looked for examples, methods and activities that could indicate a presence of a discipline.
Firstly, it is noteworthy that the reference models within the sample concentrates on the development of physical products. The twenty-one reference models have included the mechanical engineering domain. The second most popular domain is electrical engineering, followed by aeronautical engineering. Even with the trend of developing product-service systems (PSS), just Crawford and Di Benedetto (2005), Tan (2010), and Müller (2014) include the service design domain. The lack of service design might be explained by the publication year of the reference models analysed in this study, most of them were published before PSS became a trend. It's also observable that the reference models that include software engineering have grown in the past years.

5.2 Knowledge area

This criterion concerns the areas of the company covered by the model. All reference models analysed comprise the product engineering/design knowledge area. The second most popular knowledge areas are process engineering/design and idea and knowledge management. The most complete reference model from the knowledge areas criterion point of view is Clark and Fujimoto (1991) and Wheelwright and Clark (1992) with nine of thirteen knowledge areas, and Cooper (2001) and Vajna (2014) with eight.
Only about half of the reference models analysed include: project and portfolio management, quality management, marketing and communication management, people management and organization as knowledge areas. Less than a third of the models include the industrial design, aesthetics and ergonomics and the technology management knowledge area. The least popular areas are business process management, supplier management, sustainability management and service engineering/design. Interesting to note that in order to implement a design process model in a company, the knowledge related to manage business processes is of utmost importance.
Gericke and Blessing (2012) concluded that current reference models do not sufficiently support the transdisciplinary teamwork. Our analysis evidence a lack of coverage of both disciplines and knowledge areas within the models, which might contribute for this insufficiency for supporting transdisciplinary work, inherent to the design process.

5.3 Design Stage

A design stage is based on the state of the product under development (Blessing 1996). This criterion supports understanding how much the process models covers activities related to the product life cycle. In this analysis, we were not looking for the titles of the stages, since that is not a consensus among the authors. Our attention was towards the identification of activities related with each design stage, from the fuzzy front-end to the end-of-life planning.

			Andreasen and Hein (1987)	Clark and Fujimoto (1991)	Pugh (1991)	Wheelwright and Clark (1992)	VDI 2221 (1993)	Ulrich and Eppinger (1995)	Chrysler et al. (1995)	Baxter (1995)	Clausing (1998)	Cooper (2001)	VDI 2206 (2004)	Crawford and Di Benedetto (2005)	Morgan and Liker (2006)	Lindemann (2009)	Albers (2010)	Tan (2010)	Gausemeier et al. (2012)	Ehrlenspiel and Meerkamm (2013)	Feldhusen and Grot (2013)	Müller (2014)	Vajna (2014)
Content	Discipline	Mechanical Engineering	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Electronical Engineering	●	-	●	●	-	●	●	●	-	●	●	●	●	●	●	-	●	-	-	-	-
		Software Engineering	-	-	-	-	-	-	-	-	-	●	-	●	-	●	●	●	-	-	-	-	●
		Civil Engineering	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Aeronautical Engineering	●	-	-	-	-	●	-	●	-	-	-	-	●	-	-	-	-	-	-	-	-
		Service Design	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-	●	-	-	-	●	-
		Industrial Design	●	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	-	-	-
	Knowledge Area	Product engineering / design	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Process engineering / design	●	●	●	●	-	●	-	●	-	-	●	-	●	●	●	●	●	-	-	●	●
		Service engineering / design	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-	●	-	-	-	●	-
		Industrial design, esthetics and ergonomics	●	-	●	●	-	●	-	●	-	-	-	-	-	-	-	-	-	-	-	-	-
		Idea and Knowledge Management	-	●	-	●	●	●	-	-	-	●	●	●	●	-	●	●	●	●	●	●	●
		Marketing and Communication Management	-	●	●	●	-	-	-	-	-	●	●	●	●	-	-	-	-	-	-	-	●
		Technology Management	-	●	-	●	-	-	-	-	-	●	●	●	-	-	-	-	●	-	-	-	-
		Project and Portfolio Management	-	●	-	●	●	●	-	●	-	●	-	●	●	●	-	●	-	-	●	-	-
		Business Process Management	-	-	●	●	-	-	-	-	-	●	-	-	-	-	-	●	-	-	-	-	-
		Quality Management	●	●	●	-	●	-	-	-	-	-	-	-	●	-	●	-	-	●	●	-	●
		Sustainability Management	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	-	●
		People Management and Organization	●	●	-	●	-	-	-	-	-	●	-	●	●	●	-	-	-	●	-	-	●
		Supplier management	-	●	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	●
	Design Stage	Front-end / Product Planning	●	●	-	●	●	●	●	●	-	●	●	●	●	●	●	●	●	●	●	●	●
		Requirement Definition	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Conceptual Design	●	●	●	●	●	●	●	●	●	●	●	●	-	●	●	●	●	●	●	-	●
		Embodiment Design	●	●	●	●	●	●	●	●	-	●	●	●	●	●	●	●	●	●	●	●	●
		Detailed Design	●	●	●	●	●	●	-	●	●	-	-	●	●	●	●	●	●	●	●	●	●
		Production Preparation	-	●	●	●	●	●	●	●	●	-	●	●	●	-	●	-	●	-	●	●	●
		Commercialization	-	-	●	-	-	-	-	-	-	●	-	●	-	-	●	●	-	-	-	-	●
		Use	-	-	-	-	●	-	●	-	-	-	-	-	-	-	●	-	-	-	●	-	●
		End-of-life	-	-	-	-	●	-	-	-	-	-	-	-	-	-	●	-	-	-	●	-	●
	Scope of development	Technology Development	-	-	-	●	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	-
		Product Development	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Service Development	-	-	-	-	-	-	●	-	-	-	-	●	-	-	-	-	-	-	-	-	●
		Business Development	-	-	-	-	-	-	-	-	-	-	-	-	-	●	●	●	-	-	-	●	-
	Design Approach	Lean Design	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-
		Design for Six Sigma (DfSS)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Ecodesign	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	●
		PPS	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-	●	●	-	-	●	-
		Systems Engineering	-	-	-	-	●	-	-	●	-	-	●	-	-	-	●	-	●	-	-	●	●
		Integrated Product Development	●	●	●	●	-	●	●	-	●	●	●	●	-	●	●	●	●	●	-	●	●
		Agile Product Development	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	●	-	-
		Lifecycle Engineering	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	●	-	-

Figure 1 - Classification system for design process models

			Andreasen and Hein (1987)	Clark and Fujimoto (1991)	Pugh (1991)	Wheelwright and Clark (1992)	VDI 2221 (1993)	Ulrich and Eppinger (1995)	Chrysler et al. (1995)	Baxter (1995)	Clausing (1998)	Cooper (2001)	VDI 2206 (2004)	Crawford and Di Benedetto (2005)	Morgan and Liker (2006)	Lindemann (2009)	Albers (2010)	Tan (2010)	Gausemeier et al. (2012)	Ehrlenspiel and Meerkamm (2013)	Feldhusen and Grot (2013)	Müller (2014)	Vajna (2014)
Level of Detail	Meta Information	Activity	●	●	-	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		Information and Artifacts	●	-	-	-	-	●	●	●	●	●	●	●	●	●	-	-	●	●	●	-	-
		Approval Criteria	-	-	-	-	-	-	-	-	-	●	-	●	-	-	-	-	-	-	-	-	-
		Gate	-	-	-	-	●	-	-	-	-	●	●	●	-	●	-	-	-	●	●	-	-
		Method / Technique	-	●	●	●	-	●	●	●	●	●	●	●	●	●	-	●	●	●	●	●	-
		Required ICT tool	-	●	-	●	-	-	-	-	-	●	-	●	●	-	-	●	●	-	●	-	-
		Event / State	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-
		Required knowledge	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Roles	-	●	-	●	-	●	-	-	-	-	-	-	●	-	-	●	-	●	-	-	-
		Metrics	-	-	-	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	-
		Examples	●	●	●	●	-	●	-	●	●	●	●	●	-	●	●	●	●	●	●	-	-
		Practices	●	●	●	●	-	-	-	●	-	●	●	-	-	-	-	-	-	●	-	-	-
Implementation	Flexibility	One fixed version	-	●	-	-	●	-	●	-	●	-	●	●	●	-	-	-	-	-	●	-	-
		More than one fixed version	●	-	●	●	-	-	-	●	-	●	-	-	-	-	-	-	-	-	-	●	-
		Different fixed versions based on typology	-	-	-	-	-	●	-	-	-	-	-	-	-	●	●	●	●	-	-	-	●
		Rules for instantiation / customization	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	●	-	-	-
	Guidelines	No implementation guide	●	●	●	-	●	●	-	●	-	-	●	●	●	-	●	●	●	●	●	●	●
		Implementation guide without maturity mode	-	-	-	●	-	-	●	-	●	●	-	-	-	●	-	-	-	-	-	-	-
		Implementation guide with maturity model	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Figure 1 - Classification system for design process models (Continued)

It is noteworthy that the early stages of the design process have been considered as a consensus by the authors. However, there is still a lack of knowledge regarding the last stages, what suggests a potential negligence in dealing with the product lifecycle as a whole when developing products. It means that majority of the selected referenced models are addressing only the front-end/project planning stage until detailed design. There is no consensus regarding the inclusion of the production preparation stage, even though most part of them does so. Only few reference models comprehend commercialization, and even less of them include usage and end-of-life planning stages. Of the twenty-one models analysed only Albers (2010) and Vajna (2014) comprise all the design stages of the product lifecycle.

5.4 Scope of development

This criterion addresses how broad the consideration of development activities is, based on the coverage of technology, product, service and business development. More than developing new products, it is expected that the reference models support the interface to the development of new services, business and technologies related to the product in question.

Because of the criteria adopted to select the design process models in this research, all the reference models have product development included in their scope. The technology development is incorporated only in the scope of process models of Wheelwright and Clark (1992) and Cooper (2001). It is worth noting that the most recent design process models have neglected this important issue. The same is happening with service development, which is only included in Chrysler et al. (1995), Crawford and Di Benedetto (2005) and Vajna (2014). In the case of business development we can notice that some of the most recent reference models have incorporated it in their scope, but there is still no consensus within the sampled authors.

It's important to emphasize that we did not seek specifically for technology, service or business development process models. However, it does not justify the absence of interfaces with these processes. This broader scope is extremely important to guarantee the long term competitiveness of companies, facing the fast technological advancement resulting in smart products (Rijsdijk and Hultink, 2009), the rise of mass collaboration (Panchal and Fathianathan, 2008; Baldwin and von Hippel, 2011) and PSS (Paiola et al., 2013).

5.5 Design approach

A design approach is considered in this study as a general philosophy that may include many practices, methods and tools that complement each other and are commonly studied and applied in a joint manner. The options settled for this analysis represent the most relevant design approaches. Although some of these design approaches have similarities and overlapping concepts, we decided to analyse them separately because each one was originated in a particular context.

Integrated Product Development, which is defined as an approach that creates overlaps and interactions between activities in the design process (Gerwin and Borrowman, 2002) is the most popular approach in our sample. Systems Engineering, which is defined by the DAG (2000) as an interdisciplinary approach that encompasses the entire technical effort to ensure parts, subsystems and support equipment to function together as intended, is the second most popular design approach, but it is present in less than a third of investigated reference models. Other approaches emerge during the 2000s, such as Product Service System (Crawford and Di Benedetto, 2005; Tan, 2010; Gausemeier et al., 2012; Müller, 2014), Agile Product Development (Gausemeier et al., 2012; Feldhusen and Grot, 2013), Lifecycle Engineering (VDI 2221, 1993; Tan, 2010; Feldhusen and Grote, 2013) and Lean Design (Morgan and Liker, 2006). In the past years, the Ecodesign was introduced in the systematic design process models (Feldhusen and Grot, 2013; Vajna, 2014), strengthening the attention given to environmental issues. The reference model that contains the larger number of approaches is Gausemeier et al. (2012) including Integrated Product Development, System Engineering, Agile Product development and PSS.

The PDMA survey shows that DFSS and Lean Design have been largely used by successful enterprises (Markham and Lee, 2013). Yet, both were the most neglected approaches according to our analysis. This fact leads us to the following question: why don't most recent reference models include these design approaches? It is important to note that the reference models that consider Ecodesign do not deal with PSS according to the analysis. It contradicts the definition of PSS as a combination of eco-designed products and related services on different phases of the product life cycle (Mont, 2002). Should authors of eco-design and PSS integrate both when developing reference models?

5.6 Meta information

This criterion addresses how thorough the reference model is and deals with the level of detail of the models in terms of content decomposition. This is the criterion that represents the level of granularity of information within the reference models in the proposed classification scheme. The most popular meta information presented in the design process models are activity, method/technique, examples and information and artefacts. These are the type of information which is basic for developing a reference model according to the sample.

The analysis show that after Cooper (2001) launched the concept of gates, this practice has been adopted for many of the investigated authors. Something worth pointing out is that some of these authors indicate the moment to perform phase gates, however they do not present the approval criteria (VDI 2221, 1993; VDI 2206, 2004; Lindemann, 2009; Ehrlenspiel and Meerkamm, 2013; Feldhusen and Grot, 2013). Only Cooper (2001) and Crawford and Di Benedetto (2005) include both of these meta information.

Regarding the presence of required ICT tools, we highlight Clark and Fujimoto (1991) as vanguardists. Even though this practice has become more common, it is still not a consensus between the authors. The less popular meta information present in the investigated models are roles and metrics. Both of them are considered important for the design process effectiveness (Costa et al., 2013), however they still lack proper attention.

What draws the attention is that some of the recent investigated models do not include meta information that are commonly found on reference model. It may be because authors try to include constantly increasing content, therefore sticking on a high-level of information provision.

5.7 Flexibility

Reference models are used to support the creation of process model instances, i.e. development of a specific design process model of an organization. Therefore, an important attribute of a reference model is the capacity of being instantiated according to the companies' contingencies. In other words, a good process model takes into account the different needs of companies and can be customized for different projects of one singular company. We have looked for the proposition of different versions of the models, based on a primary categorization found in the literature reviewed.

Analysing this criterion, an evolution of the design process models is notable. The older ones are based on fixed versions, some of them presenting only a single version and others presenting more than one version. However, the new generation of reference models have been adopting typologies to support the implementation in different contexts. A next step, just observable in Ehrlenspiel and Meerkamm (2013) is a reference model that contains a set of rules to support the instantiation and customization for specific projects due to a flexible choosing of the path in the model depending on constraints and objectives. However the most recent models in our sample do not follow this trend of providing this level of flexibility.

5.8 Guidelines

The ability to implement an instance is crucial to manage business processes. In this way, this criterion is related to the support provided by the design process models to aid companies in getting their customized design process models implemented. Also it is related to the support given for continuous improvement of the design process. Within the reference model analysis the availability of rules and advices on these processes were evaluated.

This analysis identified a huge gap regarding the implementation of design process models. Most of the investigated models do not present a guide for the implementation, even among the recent developed ones. There are still few authors that cared to facilitate the implementation (Wheelwright and Clark, 1992; Chrysler et al., 1995; Clausing, 1998; Cooper, 2001; Lindemann, 2009) by providing a guide. There is still a lot of space towards facilitating the implementation of specific reference models in companies. Maturity models to analyse the capability of a specific company to manage the design process along with support to business process management would probably help companies to have a formal, cross-functional design process.

6 DISCUSSION AND FURTHER STUDIES

As part of a research project towards the next generation of reference models for the design process, it is important to envisage this study through the perspective of practical and theoretical relevance of reference models proposed (Fettke et al., 2006). As mentioned, the construction of the classification scheme and analysis must be observed through the lens of content coverage of design process models, the type and level of detail of information provided in the reference models, and the support for customizing and guiding the implementation of design process models.

Through the viewpoint of content coverage, in order to comprise the design process on its largest extent, it is expected the reference model are classified on the largest amount of option for each of the first five criteria. The results of our analysis show the reference models are unable to represent the whole extent of the proposed classification scheme on coverage. It brings two major questions: Is it possible for reference models to cover the whole extent from the coverage viewpoint? Should a single model cover it all?

Through the viewpoint of granularity of the information provided, the first point to stress out is it should not be mistaken with the formalism used to represent the process model. Our focus is on the constructs, or meta-information, that was used for creating the reference model. The results help on understanding the meta information that are most used in literature, thus the kind of information that is available for being implemented in reference models in companies. This envisions the possibility of information models and modules for customizable reference models. Another challenge is to allocate all the coverage of design process models to a set of meta-information.

Apart from the information available and how it is organized on the reference models, through the viewpoint of implementation, authors need to focus on the flexibility and implementation of the proposed reference models. In one hand, focusing on rules for customizing the model is necessary, so that a particular instance can be created for an organization. In the other hand, models need to better support business process management, supporting the adoption and improvement of the design process. Combining the development of modules for customizable reference models and guidance for implementation would lead to promising results towards the next generation of reference models. Apart from the modules, a next step is to provide the best way to represent and structure these complete, flexible and ready to implement reference models.

It is important to point out this work covers the procedure proposed by Fettke and Loos (2003) to phase four. Something that limits the study, as it was mentioned, is the quantity of reference models and their selection. From the point of view of consistency some improving points related to the options for the criteria were identified such as separating the project and portfolio management knowledge area and front-end from the product planning design stage. According to Fettke and Loos (2003), the building process of the classification scheme is cyclic; thereby an important aspect is to keep track of gaps in the classification scheme. This ensures the constant analysis of the design process models through the point of view of user needs, helping practitioners to select and implement suitable design process model in literature.

All knowledge related to generic design process models should in any circumstances be ignored. An interesting path would be to organize the knowledge created by institution, associations, experts and researchers so that companies are able to easily adapt according to their conditions and necessities. The proposed classification scheme can be used as initial effort in this direction. Towards the next generation of reference models for the design process need to include a meta perspective like the Engineering Operating System introduced by Stark et al. (2014), which integrates four perspectives: 1. Process and Organisation, 2. Engineering Activities, 3. Data and Information models and 4. IT-Implementation. Furthermore, future solutions could include not a single reference model but a collection of models with the same formalisms and constructs that include technology, product, service and new business development. Another issue is the vision of defining models based on the combination of building blocks / modules that allow the instantiations of model versions for a specific organization that consider specific needs of the design process models users. ICT tools are essential resources for accomplishing many design activities in some industries and development stages in the product life cycle. The connection to ICT tools and functions (as meta information) to other model's meta information could support the fast implementation of complete solutions which could also communicate to other companies' reference models.

As a major limitation, we point out the necessity of deepen the studies on finding other relationships between the limitations of current generic design process models and the proposal of a new generation. While with the proposed classification scheme several views from generic design process models are describable, to interpret this views it seems necessary to define the objectives of using specific process model in organizations. As future developments, we consider valuable to identify criteria for this next generation of process models, since the scheme proposed is mostly derived from already available process models in literature.

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