Design methods and factors influencing their uptake in product development companies: A review

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DESIGN METHODS AND FACTORS INFLUENCING THEIR UPTAKE IN PRODUCT DEVELOPMENT COMPANIES: A REVIEW

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1. Introduction

Product development companies are under pressure to produce high quality products that satisfy requirements from different stakeholders including end-users. This requires them to improve the efficiency and effectiveness of their product development processes. Design methods are necessary to support these companies to improve their product development processes, and thereby in producing high quality products (Blessing and Chakrabarti, 2009).

Many modern design projects are complex, and the old conventional ways of working may not be suitable in such projects as these ways can be ineffective and inefficient (Cross, 2000). Studies reported in e.g. Booker (2012) on a sample of design methods in product development show that these methods enhance the performance of companies in terms of cost reduction, better product quality and faster lead times. With due considerations to nunanced views on the effectiveness of design methods and process models (e.g. Bender 2004), the dominating view in academia is that design methods are instrumental in the success of product development companies in a highly competitive global economy. Design methods enhance decision quality, supports team-working, offer design performance metrics, improve communication, and in general help to increase the success rate of new products (Herrmann et al. 2004, Yeh et al. 2010).

While there are several advantages of using design methods in the product development process, their uptake in companies is limited and lower than one might expect (Birkhofer et al. 2001; López-Mesa and Bylund, 2011; Booker, 2012). There is a wide variety of literature related to factors that influence the uptake of design methods in companies.

1.1. Motivation for a review and framework

There is a large amount of literature related to design methods, their purposes, their different forms (e.g. guidelines, tools, approaches, etc.), and factors influencing their uptake in companies. The literature reports different definitions and meanings of design methods. To date, this literature has not been synthesized. This has resulted into a number of ideas that have remained fragmented and have not been connected despite their complementary nature.

In addition to the lack of a comprehensive literature review on the above subject, there is no synthesis of factors influencing the uptake of design methods in companies. Consequently, there is a lack of an overall and coherent perspective on the factors that affect the uptake of design methods in product development companies. These factors are not set within the context of a more general framework. Thus, there is little support available to categorise and structure the literature on these influencing factors. This can result into an inadequate understanding of the subject and can lead to failure in appreciating the relevance of different studies in the literature.

1.2. Scope

This paper provides a literature review on the subject of design methods. In particular, the paper presents a literature review on:

- the purposes of design methods, their different forms (e.g. guidelines, tools, etc.), and their relevance in design practice; and
- the factors influencing the uptake of design methods in product development companies.

These influencing factors have been synthesized in the form of an overall framework. The parallels between the method development process and product development process provided the basis for the creation of this framework.

We believe that the review of different influencing factors and their presentation in an unified framework offer the following advantages: (1) influencing factors presented in different studies are compiled together; (2) the framework integrating these factors provides a structure to enhance our understanding of the subject; and (3) the framework can enhance our ability to design and develop appropriate methods, and to improve their dissemination and uptake in product development companies.

In this paper, we use the term 'design method' as ways of working for improving one or more aspects of the product development process, and these ways of working can be accomplished by using one or more forms such as procedures, guidelines, tools, etc.

2. Design methods: purposes and forms

2.1. Design methods

There are several definitions of design methods. Cross (2000) defines a design method as "any identifiable way of working" aimed at improving the product development process. Thus, design methods can be "any procedures, techniques, aids or 'tools' for designing".

Blessing and Chakrabarti (2009) use the term 'support' to represent possible means for improving the product development process. A 'support' can include "strategies, methodologies, procedures, methods, techniques, software tools, guidelines, information sources, etc., addressing one or more aspects of design".

Some studies have differentiated between methods and tools. For example, Hubka (1980) defines methods as ''Methods are systems of methodological rules that determine classes of possible procedures and actions that are likely to lead on a planned path to the accomplishment of a desired aim''. Araujo (2001) explains the term 'tool' as follows: ''A design tool is an implement that you employ to facilitate the use of a method or an aid to the use of a method''.

The above definitions of design methods have the following two main components: (1) purpose of a design method, for example, improving one or more aspects of the design process; and (2) means to achieve this purpose, for example, procedures, techniques, tools, guidelines, etc. This suggests that design methods can be manifested in different forms such as strategies, guidelines, tools, etc..

2.2. Purposes of design methods

Design methods have different purposes. According to Cross (2007), design methods are important in the assessment of design problems, and also in the development of design solutions. In product development companies, there is a pressing need to reduce the lead-time necessary to design a new product. Design methods help to ensure that the lead-time is kept to a minimum by avoiding the mistakes and delays (Cross, 2000). Design methods have different purposes depending on their applicability to different stages of the design process. At a broader level, design methods have the following two main purposes (Cross, 2000).

Formalization: Formalization helps to avoid the occurrence of oversights and errors that can occur with informal methods. Formalization systematically helps to understand the design problem and to search for appropriate solutions. It "encourages and enables you to think beyond the first solution that comes into your head". Companies generally feel insecure about the efficiency of their intuitive design procedures, especially in the early stages of design where the level of uncertainty and consequences of decisions are high (Gidel et al. 2005). Formalization helps to alleviate insecurity associated with intuitive design procedures.

Externalization: Externalization helps to "get your thoughts and thinking processes out of your head and into the charts and diagrams that commonly feature in design methods". Externalization plays an important role in solving complex problems. It facilitates team work, for example, members of the team

can know other team-members' activities and outcomes of those activities. This thereby allows the team to communicate and plan efficiently. Consequently, this helps to alleviate cognitive load.

2.3. Forms of design methods

Our definition of design methods is broad, and therefore it includes all possible ways for improving design tasks. Blessing and Chakrabarti (2009) present some examples of these possible ways. These are the following: *design approach or methodology, design guidelines, and design tools*.

Design approach or methodology is an overall framework for doing design. Common examples are the design methodologies proposed by Pahl and Beitz (2007) and Total Quality Management (TQM) by Clausing (1994).

Design guidelines include rules, principles and heuristics. Some examples of design guidelines are: principles of design embodiment for simplicity, clarity and safety outlined by Pahl and Beitz (2007) and DfX guidelines (e.g. Design for Environment). Design guidelines became popular during the 1940–1950s, for example, a practical guide to the design of grey iron castings (Booker, 2012). These guidelines are still in use today in many manufacturing processes.

Design tools include hardware and software for the embodiment of some design approaches or design guidelines. There are several types of design tools associated with different stages of the design process, different activities within a particular stage, and types of products. Some examples of design tools are: CAD tools, Product Data Management tools, Finite Element tools, Life Cycle Assessment tools, etc.

Cross (2000) categorizes design methods into two broad types, namely *creative methods* and *rational methods*. *Creative methods* (e.g. brainstorming, synectics, etc.) aim at stimulating creative thinking by removing the mental blocks and by increasing the areas of search for solutions. *Rational methods* prescribe a systematic approach to design. The aims of rational methods can be similar to those of creative methods (e.g. widening the search space for potential solutions). Therefore, the rational methods are not "very opposite of creative methods". Rational methods cover different stages of the design process such as clarifying objectives, setting requirements, generating alternatives, evaluating alternatives, and improving details.

3. Design methods and design practice

Design methods are important to: manage complex problems in product development, create innovative products, and maintain the competitiveness of companies. Studies in the 1980s and 1990s found that that the successful manufacturing Japanese companies attributed their success to their attention to design operations and the use of methods in these operations (Womack et al. 1990).

Several studies emphasise the positive effects of design methods. For example, the use of design methods helped companies in achieving benefits such as (Booker, 2012): (1) 84% reduction in failure costs at Motorola due to the use of Design for Six Sigma; (2) 80% quality-improvements through the use of Taguchi's Robust Design; and (3) 70% of all failure modes identified by the use of Failure Modes and Effects Analysis (FMEA).

While design methods have the potential to improve the product development process, their dissemination and use in companies is limited and lower than one might expect. The effectiveness and impact of several research studies in the area of design methods is often limited. Yeh et al. (2010) identified that many design methods (e.g. FMEA, supplier involvement) had a significant impact on product development processes. However their usage rate is low.

Nijssen and Frambach (2000) analysed major groups of publications regarding the use of design methods in companies. These major groups correspond to: initial stages of the design process; design process as a whole; and particular design methods (e.g. Quality Function Deployment - QFD). The overall conclusion of the study was that design methods are not used by the majority of potential users. Müller et al. (2007) carried out a survey in the companies from Germany in order to identify the use of design methods regarding reliability and safety. They found that only a few companies use these methods in their design processes.

Similar trends have been reported regarding the Design for Sustainability (DfS) methods. While the use of DfS methods is essential to create sustainable products, their use in companies is limited. For

example, Shi et al.'s (2008) comprehensive literature review plus industry-surveys and Ameta's (2009) analysis of DfS trends confirmed that the use of DfS methods is highly limited in companies.
The use of design methods in practice differs from country to country (Fujita and Matsuo 2005, Barczak et al. 2009). Janhager et al.'s (2002) research in the Swedish companies found that a few general design methods such as requirements specification, design review and brainstorming are regularly used. However, the use of specific methods such as Life Cycle Analysis and QFD is lower than expected. Their research also found that the Swedish companies in general believe that a better formulated product development process would facilitate the planning and allocation of tasks in product development.
As mentioned above, the use of effective design methods enhances the performance of product development companies. However, their uptake in companies is limited and lower than expected. An in-depth understanding of the reasons for the poor uptake and use of design methods in companies is not available. This limits our ability to support companies in improving the uptake and use of design methods.

4. Influencing factors

There is a variety of factors that influence the development of design methods. Also, a large number of factors determine the implementation and use of design methods in companies. An in-depth understanding of these factors and application of this understanding in the development of design methods play an important role in the successful dissemination and uptake of design methods in companies. This was also highlighted in the recent Engineering and Physical Sciences Research Council Workshop titled 'Engineering Visions in Design', held in the UK (Gillespie, 2010).

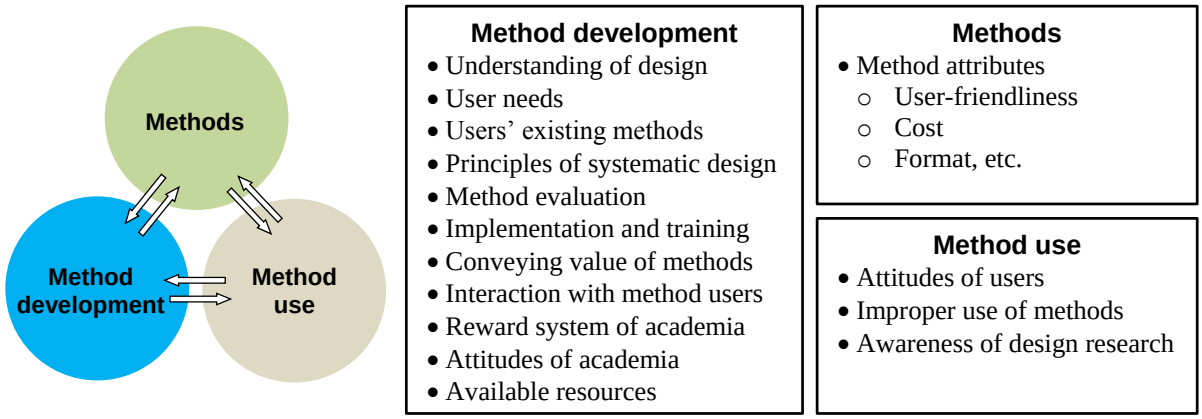

Figure 1. A framework of factors influencing the uptake of design methods in companies

Figure 1 shows the framework of factors that can influence the dissemination and uptake of methods in companies. This framework is based on the factors that we have identified in the reviewed literature. There are three major categories in this framework, namely *method development*, *method use*, and *methods*. We used these categories because there are parallels between method development process and product development process. The categories method development, method use, and methods have similarities with product development, product use, and products, respectively. Methods are outcomes of a method development process, and these outcomes are used by companies (i.e. method users).
As shown in Figure 1, there is a number of factors under the categories 'method development' (e.g. user needs, users' existing methods, method evaluation, etc.) and 'method use' (e.g. attitudes of users, improper use of methods, etc.). The major category 'methods' has one factor, namely method attributes. There can be an overlap between different factors shown in Figure 1. In addition, these factors can influence each other. For example, insufficient understanding of user needs can lead to methods with undesirable attributes. The framework is intended to represent different factors influencing the uptake of methods in companies. These factors are elaborated in the sections that follow.

4.1. Method development

Developers of design methods (e.g. academia) need to follow a rigorous research methodology to develop and evaluate design methods. The factors under the category 'method development' (see Figure 1) are elaborated in the following sections.

4.1.1. Understanding of design

While Individual research projects may not aim at developing support to improve design practice, one of the dominant aims of design research is to improve design practice (Blessing and Chakrabarti, 2009). This dominant aim can promote researchers to develop design methods that are not based on the sound understanding of design. Consequently, a large number of design methods were not based on the solid understanding of design, and were not used by practitioners. Design methods are likely to be more efficient and effective if they are based on better understanding of design. Therefore, developing design methods by using an in-depth understanding of design, enhances the likelihood of their use in practice.
There is insufficient evidence of extensive use of valid empirical data in developing design methods. These methods are developed using single findings, assumptions, and experience (Blessing and Chakrabarti, 2009). The use of empirical data is useful to gain an understanding of design. Therefore, understanding of design grounded in the empirical data provides a sound foundation for the realization of design methods that are effective and efficient.

4.1.2. User needs

One of the prominent reasons for the poor uptake of design methods in companies is that method developers provide less attention to the actual needs of companies. This concern has been identified in several studies (López-Mesa and Bylund, 2011, Luttropp et al., 2006; O'Hare et al., 2007). For example, O'Hare et al. (2007), regarding eco-innovation methods, has identified that the main reason for the poor uptake of these methods in companies is that method developers do not address the user-needs. A survey in the UK industry has also identified this reason (Upton and Yates 2001). According to this survey, design research "does not match industry's needs: in most cases the results of design research are not directly applicable and research is incorrectly focused".
It is therefore important to understand the actual needs of companies in developing design methods. These needs ought to be incorporated in all stages of the method development (Blessing, 2002). Adaptability and flexibility of design methods to the contextual factors in a company can enhance their application (Müller et al., 2007, Nijssen and Frambach, 2000). This is confirmed by Darlington and Booker (2006), who point to the need to adapt new methods to the company's specific needs, rather than developing generic methods for a wide range of products and users.

4.1.3. Users' existing methods

In addition to understanding the user-needs, information on existing methods used in companies needs to be considered in the method development. Design researchers tend not to relate the developed design method to the current commercially available design methods (Blessing and Chakrabarti, 2009). This can result into a mismatch between the developed methods and the existing methods used by companies, and consequently can result into the poor uptake of developed methods. Furthermore, method development needs to consider requirements regarding integration of the developed method in the existing portfolio of company's methods. In addition, the aspects of communication between different methods need to be taken into account (Lindahl, 2005; Gómez, 2001).
The method development also needs to incorporate requirements regarding how designers select methods in their work. For example, Ernzer and Birkhofer (2002) identified that there is a large number of eco-design methods available, and that this complicates the process of selecting an appropriate method. Designers may not use any of the available methods if they find the method selection process cumbersome and time-consuming. López-Mesa and Bylund, (2011), in their empirical research in a company, found that several factors influence designers' selection of methods such as personal preferences, prior experience of using the method, or recommendation of the method by a respected designer. They also observed that designers preferred methods "that are based on principles that match

engineering thinking…The closeness of engineers' natural thinking patterns to formal methods appears to be a key factor in their acceptance".
In addition to the above factors of method integration and method selection, method developers ought to use the understanding of how designers use methods in their work. For example, Lindahl (2006) observed that lack of understanding of how designers use methods can negatively influence the uptake of methods. Designers may not accurately follow every step in the use of methods. They can use the proposed method as a thinking guidance (López-Mesa and Bylund, 2011).

4.1.4. Principles of systematic design

Cantamessa's (2001) analysis of papers, which reported the development of design methods, found that in 47% of these papers motivations behind the method development were not reported. In addition, the method developers did not reveal their view on the underlying design approach used in the method development, and the assumptions were not made explicit. These factors such as motivation behind the method development and assumption made influence the likelihood of method's success.
Methods aim at supporting systematic design process; and method development is in itself a design process. However, method developers appear not to follow the principles of systematic design (Blessing and Chakrabarti, 2009). Aspects of systematic design such as thorough problem definition and generation of variants are not used in the method development. Following systematic design process in method development influences the efficiency and effectiveness of methods.

4.1.5. Method evaluation

Evaluation of design methods is an important factor contributing towards the likelihood of their success. However, evaluation of design methods by academia is inadequate (López-Mesa and Bylund, 2011). Methods are not tested in practice in all their complexity (Reich, 1994). Similar difficulties have been identified by Booker (2012). The author has identified a need to verify methods in practice. Müller et al.'s (2007) survey in companies from Germany found that proving the benefits of methods though their evaluation is crucial in their acceptance in companies. Appropriately modifying methods based on the feedback of designers helps in enhancing their acceptance in practice (O'Hare et al., 2007).
López-Mesa and Bylund's (2011) empirical research found that designers may not follow step by step procedure in using methods, and that they can incorporate some features of methods in their ways of working or thinking. Comparing designers' ways of working or thinking before and after the use of a method can help in method-evaluation. See Blessing and Chakrabarti's (2009) work on Design Research Methodology for the details regarding the evaluation of design methods.

4.1.6. Implementation and training

In addition to the above factors such as understanding needs of companies and evaluation of methods, factors regarding implementation and training also play an important role in the dissemination and uptake of methods in companies. However, implementation and training of design methods by method developers can be inadequate (López-Mesa and Bylund, 2011; Eder 1998; Frost 1999). A low impact on industry of design methods has been attributed to inappropriate implementation and training of methods (Reich, 1994; Ritzén and Lindahl, 2001). In addition, there is a problem in the method development that researchers rarely apply research in practice (Andreasen and Wallace, 2007). Cantamessa's (2001) analysis of the papers from two large conferences in engineering design found that that the issues of method-implementation in industrial settings were considered only in 37% of the 331 papers on methods. See Booker (2012) for details on issues that can arise in the implementation of methods in companies.
One of the reasons behind unsuccessful implementation of methods in companies can be researchers' narrow focus on intrinsic reasons within the design methodology (Reich, 1994). In management domain, an extensive research has been carried out to understand the mechanisms of resistance to change (e.g. Kotter, 1995; Maurer, 1996). Taking into account reasons about why change is difficult to implement can help in enhancing the likelihood of successful method-implementation (Reich, 1994).

4.1.7. Conveying value of methods

The following factors help in enhancing method dissemination and uptake in companies: (1) raising awareness of method-benefits (Andreasen and Wallace, 2007); and (2) conveying the proper value of developed methods to companies (Booker, 2012; Andreasen and Wallace, 2007).

4.1.8. Interaction with method users

An effective and efficient interaction between industry and researchers was suggested by the US National Science Foundation in order to disseminate research results in companies (Shah and Hazelrigg, 1996). This type of interaction is useful for researchers to understand the needs of companies and to transfer research results and design methods to companies. Booker (2012) has suggested developing "consortia of companies and academic institutions with a common aim" in the development of design methods for fulfilling needs of companies. Such consortia can also help in evaluating and implementing design methods in practice.

4.1.9. Reward system of academia

The reward system of academia can influence the method dissemination in companies. In general, the reward system in academic contexts does not motivate researchers to implement research results and methods in practice (Andreasen and Wallace, 2007). Blessing and Chakrabarti (2009) suggest that changing the academic reward system can potentially motivate researchers to work closely with companies and to disseminate and implement the findings of their research in practice.

4.1.10. Attitudes of academia

Lack of mutual understanding between industry and academia can negatively influence method dissemination and uptake in companies. Academia may view design practice through a leans that can discourage development of appropriate methods. For example, Blessing and Chakrabarti (2009) found that researchers can have an attitude of not studying the existing situation in design practice if they aim at automating a particular design task. This type of attitude can result into methods that do not match the context in which the method has to be implemented and used.

4.1.11. Available resources

Academia may lack resources to develop, evaluate and implement methods in practice. For example, researchers lack help to develop demonstrators or prototypes that are at sufficient detail to evaluate the concept of intended method (Blessing and Chakrabarti, 2009).

4.2. Methods

Under the category 'methods', there is one factor, namely '*method attributes*'. A variety of method attributes can influence their acceptability in companies. Some design methods can inhibit creativity, and can be less important than experience (López -Mesa and Bylund, 2011). Their benefits can be unclear. They can be "too systematic to be useful in the rather messy and often hurried world of the design office" (Cross, 2007). In addition, the following attributes influence method acceptance: user-friendliness, monetary cost, flexibility, and popularity (Thia et al., 2005). Designers prefer methods that are easy and quick to learn/re-learn, and that take into account their language preferences and knowledge-level (Hayes, 2004).

The following attributes negatively influence method acceptance (Booker, 2008; Reich, 1994): inappropriate complexity level, conflicts between methods, poor compatibility with the company processes, excessively conceptual for designers, requires resources (e.g. information) that are not available in practice, and using vocabulary and taxonomy not commonly used in companies. Similarity of methods with existing methods used in a company facilitates their adoption (Reich, 2008).

Furthermore, detachment of designers from design methods is a barrier in the acceptance of methods. For example, some methods can be excessively dependent on processing data or can be highly tedious to use with a large number of input parameters and weighting factors (López-Mesa and Bylund, 2011).

Format of methods also influences their use in companies. For example, web-based and lower cost versions of methods help to enhance their dissemination and application in SMEs (Hayes, 2004). Web-based versions of popular design methods have been developed, for example Design for Manufacturing (DfM) (Huang and Mak, 1998) and QFD (Huang and Mak, 2002). Lindahl (2006) and Tanco et al. (2009) found that in this digital world, dominated by ICTs, designers prefer computer-based design methods because they are easy to integrate with existing methods, allow easier documentation, and can help in design reuse.

4.3. Method use

There are three factors under the category 'method use': attitudes of users, improper use of methods, awareness of design research.

4.3.1. Attitudes of users

Designers can be mistrustful of design methods, "fearing that they are a straitjacket, or that they stifle creativity" (Cross, 2000). However, this is their misunderstanding. Design methods are intended to improve design process and consequently the end product of the process. Design methods "should be seen as a lifejacket" rather than a "straitjacket" (Cross, 2000).

4.3.2. Improper use of methods

Improper use of methods, for example, using a given design method for an unsuitable problem can negatively influence their benefits (López-Mesa and Bylund, 2011). Inappropriate use of methods can involve using methods too late in the design process, using for inappropriate product, using with incorrect data, etc.

4.3.3. Awareness of design research

Companies' awareness of design research is low (Blessing and Chakrabarti, 2009). Academia and industry ought to work together to tackle this issue, and to implement research results in practice.

5. Summary and conclusions

There is a wide variety of literature related to design methods, their purposes, their different forms, and factors influencing their uptake in companies. The absence of the synthesis of this literature has resulted into a number of ideas that have remained fragmented. In this paper, we synthesised this literature, and in particular, developed a framework of factors than can influence the uptake of design methods in product development companies.

The main components of a design method are: purpose (e.g. improving one or more aspects of the product development process) and means (e.g. procedures, techniques, tools, guidelines, etc.). While the use of design methods in product development is crucial to enhance the performance of product development companies, their uptake in companies is lower than expected. An in-depth understanding of the reasons for this poor uptake is important to develop appropriate design methods and to disseminate these methods in companies.

Based on the reviewed literature, we developed a framework of factors that can influence the uptake of methods in companies. In the framework, the factors have been categorised into the three major categories, namely, method development, method use, and methods. There can be an overlap between different factors, and these factors can influence each other. We believe that the developed framework provides a structure to enhance our understanding of the subject. The framework can enhance our ability to design and develop appropriate methods, and to improve their uptake in product development companies. Further work can include categorizing the above influencing factors into the categories, namely 'people', 'product', and processes'. It would be interesting to check the validity of these factors in an empirical setting. Further work can also include checking completeness and exclusiveness of these factors.

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