Chapter 8

Adapting a Design Approach: A Case Study in a Small Space Company

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8.1 Introduction

Many design problems often do not match the boundaries of a single discipline. As a consequence, designers from different disciplines have to collaborate. In contrast to that, it is observed that much of the developed support, such as design methodologies, is rather mono-disciplinary focussing for example on mechanical engineering, software development, or service design.

The development of design methodologies is accompanied by an on-going debate concerning their applicability in practice. While many authors highlight the usefulness of design methodologies for training of novices, it is recurrently reported that design methodologies are only seldom applied in design practice (Franke, 1985; Jorden *et al.*, 1985; Franke *et al.*, 2002; Jänsch, 2007). An argument usually produced concerns the abstract character of design methodologies (Eckert and Clarkson, 2005; Brook, 2010). As they are intended to be applicable in different branches within a specific domain, they propose only abstract process models, thus no exact representation of the design processes in each specific branch (Eckert and Clarkson, 2005; Wynn and Clarkson, 2005).

Currently there are two main axes for further development of design methodologies: the rising interdisciplinarity in design practice which is not sufficiently addressed in the rather mono-disciplinary design methodologies (Gericke and Blessing, 2011) and the adaptation of design methodologies to different contexts (*e.g.* to a specific branch, company, or product), which is recommended by many authors but lacks a systematic support (Maffin, 1998; Bender and Blessing, 2004; Meißner *et al.*, 2005).

This paper addresses the adaptation of a branch-specific design approach to different contexts. The term design approach is used in this paper in order to refer to a specific approach for the design of a system, for example described in design methodologies (Pahl *et al.*, 2007; Ulrich and Eppinger, 2007), standards (*e.g.* BSI, 2008; ECSS, 2008), guidelines (VDI, 2004), or company specific design processes.

The paper reports a case study in the space industry. The study is based on a document analysis and of expert interviews. This descriptive study compares the design processes of four projects, which show some major differences in context requiring a project-specific adaptation of a branch-specific design approach.

8.2 Adaptation of Design Methodologies

The claim of many design methodologies to provide a support which is applicable to a wide range of different contexts, resulted in a dilemma. In order to cover a wide range of different contexts the process models proposed in the methodologies, thus the whole design approach became rather abstract. The high level of abstraction resulted in the perception of being of limited use because abstract approaches usually provide less context-specific support. Providing a more detailed process model offering appropriate support for a specific context seems also to be no solution to that dilemma as this would limit the usefulness to a specific context, thus being in conflict with the goal to be widely applicable.

An approach suggested by different authors (Maffin, 1998; Meißner *et al.*, 2005) is to start with an abstract, context-independent approach and adapt it to a specific context. Lawson (1997) points out that the ability to manage this adaptation is one of the most important skills of designers. Obviously many designers do this regularly in a successful manner as they have to align their project plans with a mandatory design approach. Even though, no systematic support is offered to adapt design methodologies, thus the outcome of adaptation is dependent on interpretation of a design methodology and skills of the particular designer.

It is assumed that a systematic support for adaptation of design methodologies will contribute to an enhanced impact of design methodologies.

Meißner *et al.* (2005) highlight the influence of the context on the product development process. Based on a literature study they identified factors which are considered to describe the product development context such as market needs, company size, and design task complexity and grouped them into seven categories (see Figure 8.1).

Context factors are distinguished with regard to the level of abstraction of the design process. Meißner *et al.* (2005) postulate that abstract process descriptions (*e.g.* company specific reference processes), project plans, and specific situations within a project are all affected by their context. However, the context factors might not have to be the same for the long-, mid-, and short-term context (see Figure 8.2). Based on this distinction of the product development context Meißner *et al.* (2005) propose to adapt design approaches in multiple steps, beginning at a high level of abstraction considering the long-term context succeeded by further adaptation steps of more detailed process descriptions. Unfortunately no detailed recommendations or support for adaptation are provided.

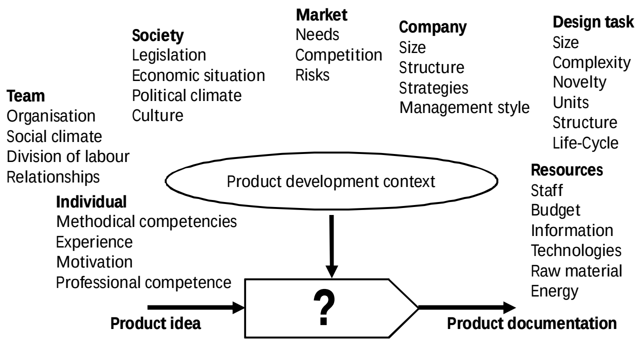

Figure 8.1. Product development context (Meißner *et al.*, 2005)

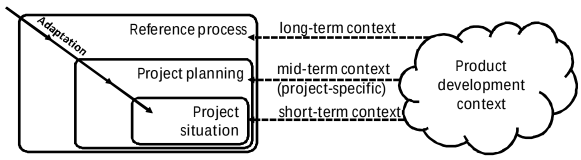

Figure 8.2. Different levels of context factors (Meißner *et al.*, 2005)

From the authors' perspective important issues which hinder currently the development of a support for adaptation of design approaches are: a comprehensive understanding of what context means, an empirically based selection of those context-factors which are relevant for adaptation, and an understanding of the rationale of process adaptation in practice. Therefore, this paper is guided by the following overall research questions:

- How do companies solve the challenge to adapt a generic design approach to a specific context?
- What are the main influencing factors for the adaptation?

8.3 The Case Study

The research presented in this paper is based on a case study of a small space company in Luxembourg (30 employees including 24 engineers). The company which is a subsidiary of a larger German group develops space applications (space related services), and space equipment (small satellites, subsystems of larger satellites). The analysed company has no defined departments and a flat hierarchy with the Managing Director on top. The projects are mastered by teams with members selected from a pool of different engineers specialised in certain disciplines. The position of the project manager introduces a project-specific hierarchy and is also performed by an engineer.

The study is based on a document analysis and expert interviews. The document analysis considered descriptions of the company's design approach and documentations of four completed projects. The expert interviews were used to verify the results of the document analysis and to analyse current practice of design approach adaptation and the identification of major influencing factors for the adaptation.

The interviewed experts have been involved in several projects prior to the interviews and acted as systems engineer, quality assurance and product assurance manager, and project manager. One of the authors was part of the engineering team of the four projects which provides a deep understanding of the internal processes, the developed systems, and validity and relevance of the gathered information.

8.3.1 Product Development Practice in the Studied Company

Current development practice in space equipment development is strongly determined by space agencies *e.g.* National Aeronautics and Space Administration (NASA) and European Space Agency (ESA). As this paper reports a case study of a space company in Luxembourg, standards provided by the European Cooperation for Space Standardization (ECSS) which define the design practices of ESA and their subcontractors are of major importance.

Design practices of the analysed company are documented in a company-specific handbook that covers all product life cycle phases in which the company is involved or responsible for and detailed process instructions for specific activities.

The company's handbook and the process instructions are based on the ECSS system. The company's handbook and the process instructions are written in German what limits their usefulness in a multi-lingual team, which uses English as working language. This leads to the situation that the team uses mainly the ECSS system (written in English) as guidance for their product development activities.

The ECSS system provides standards, handbooks and technical memoranda addressing project management, engineering, and product assurance (ECSS, 2008).

For each of these areas a set of disciplines are defined for which a considerable set of documents is provided. These documents offer process guidelines, descriptions of methods, a documentation guideline, factors and numbers for requirements definition, engineering and calculation.

8.3.2 Design Projects

The four projects which have been analysed as part of this case study: EAGLE1, EAGLE2, ORCA2, and COLIBRI (see Table 8.1) are part of a larger program of the company. All four projects were managed by a team of less than ten members. This multi-national team involves specialists from different engineering disciplines such as radio-frequency engineers, thermo-mechanical engineers, and software engineers.

EAGLE1 and 2 are company investments. EAGLE2 is an advanced version of the EAGLE1 spacecraft with the same operating baseline as an attached payload. Attached payload describes the fact that the spacecraft is mechanically connected to the last stage of a launcher but operating independently (Fleeter, 1999). The main drawback of an attached payload is the unpredictable attitude of the last launcher stage in orbit which imposes limits on power generation and thermal control. ORCA2 is a space project comprising two identical satellites which are leased to a commercial customer. EAGLE1 and 2 and ORCA2 are microspace missions (Fleeter, 1999). COLIBRI is an experimental payload operating in human spaceflight. Human spaceflight imposes the highest requirements on safety and risk. The payload is connected to another spacecraft, here the International Space Station (ISS).

Table 8.1. Characteristics of analysed projects

Characteristics	**EAGLE 1**	**EAGLE 2**	**ORCA 2**	**COLIBRI**
Type of mission	microspace	microspace	microspace	human spaceflight
Relation with other spacecraft	mechanically connected	mechanically connected	separate	electronically and mechanically connected
System complexity	low	low	moderate	high
Customer	company investment	company investment	commercial	institutional
Cost	lowest	lowest	low	moderate
Schedule pressure	moderate	high	highest	moderate
Allowed program risk	highest	highest	moderate	lowest

8.4 Findings

The case study focuses on the adaptation of a branch specific design approach. This differs slightly from adapting a generic branch independent design approach. The most important difference is: compared with a generic branch independent design approach (*e.g.* described by many design methodologies) a branch specific design approach (here the ECSS system) is already augmented by additional support for example standards, guidelines, methods, recommendations and modelling approaches. A further difference is that the underlying process model is more detailed and has already been adapted to the context of a specific branch (here space equipment). However, the claim of the ECSS system to be applicable to every type of space equipment makes the case study relevant for analysing adaptation approaches in general as it is expected (Meißner *et al.*, 2005) that adaptation of generic branch independent design approaches towards project specific design approaches should be done in multiple steps considering different subsets of context factors for each level.

This section reports two different approaches for adapting the ECSS system to the project specific contexts. The first approach is proposed by the ECSS and is applied when compliance with the ECSS system is mandatory. The second approach was developed by the company and is applied when compliance is not mandatory.

8.4.1 ECSS System Tailoring Process

> *"The ECSS system provides a comprehensive set of coherent standards covering the requirements for the procurement of a generic space product. This system can be adapted to a wide range of project types. The process of adapting the requirements to the project specificities is called tailoring."*
>
> (ECSS, 2008)

An advantage of the ECSS system is the consistency of the design approach and compatibility of interfaces. Compliance with the ECSS system is mandatory if the customer explicitly requires compliance, which is usually the case if the customer is a national or international space agency.

ECSS proposes a 7-step process for tailoring the ECSS system. The overall goal of this tailoring process is to establish the applicability of all relevant ECSS standards and their requirements. The process starts with an analysis of the projects characteristics. Main characteristics proposed by ECSS to be considered during the tailoring process are *e.g.* ECSS (2008): objective of the mission, product type, expected cost to completion, schedule drivers, maturity of design or technology, product complexity, organisational or contractual complexity, supplier maturity.

After an analysis of the project characteristics (step 1) and risks (step 2) which might be associated with them (for the product and the development project), the complete set of ECSS standards has to be screened for applicability (step 3). If a standard is identified as applicable all standards to which this standard refers become also applicable. During the next steps all requirements documented in the applicable standards have to be analysed regarding their applicability (step 4), completed by additional requirements if necessary (step 5), harmonised (step 6), and finally documented (step 7) (ECSS, 2008).

The tailoring (*i.e.* to let out selected activities) of the initial design approach goes along with augmenting (*i.e.* adding for example. specific activities, support, standards).

The ECSS tailoring process has some disadvantages if compliance with the ECSS system is not mandatory. The main limitation is that the overall goal of the ECSS system is to keep the risk at lowest possible level - at all cost. However, this is not always an appropriate design maxim, especially when the company has to operate in a highly competitive market sector and occurring risks have no consequences for other systems or human beings. Therefore, for such type of projects the company had to develop a new tailoring approach.

8.4.2 The Company's Own Approach

The new adaptation approach was developed in the company based on a project classification scheme which was introduced by the Quality Assurance and Product Assurance (QAPA) manager and supplemented by recommendations for adaptation based on experiences from the four projects EAGLE1 and 2, ORCA2 and COLIBRI.

8.4.2.1 Experiences from Past Projects

The COLIBRI project allowed no adaptation others than the tailoring process proposed by ECSS, but the EAGLE1 and 2 and ORCA2 projects required a further adaptation in order to make them feasible.

The EAGLE1 and 2 projects were affected by the risk of being mechanically connected to the last stage of a launcher. This connection imposes the risk that the satellite is oriented in an unfavourable attitude towards the sun which could cause thermal and power generation issues. This risk, which cannot be mitigated, leads to the premise to keep the cost as low as possible.

The ORCA2 project had an enormous schedule pressure which required a reduction of the systems complexity at constant cost and risk. In negotiation with the customer it was decided that the company applies a certain level of standards in order to show that customer's requirements are met, to secure team decisions, and to be able to sufficiently track decisions in case of anomalies once the spacecraft is in orbit.

While the customer of EAGLE1 and 2 is the company itself, COLIBRI's customer was a public institution and ORCA2's a commercial company. The two different customers of EAGLE1 and COLIBRI can be seen as origin of the three main contradictions which have been identified by the team members of the analysed projects and had to be considered in the adapted design approaches:

- QAPA approach especially configuration and documentation management,
- Team responsibilities,
- Coordination and communication.

Configuration and documentation management was seen as the major issue conflicting with time pressure and low resources. EAGLE1, being an own investment of the company had the strict goal of being a low cost project in a very short timeframe. Documentation was secondary priority after "getting the thing running up there". Contrary, COLIBRI was a project involving human spaceflight with a public institution as customer. Documentation of the process played a major role in the project. These two diametrical requirements on the documentation management caused the main contradiction.

The second contradiction identified by the team was unclear team responsibilities, *i.e.* defining and communicating who is responsible for what in the space project.

The third contradiction requested a better coordination and communication inside the team and with externals, *e.g.* keeping the team members up to date on the current status of the project, the system and the subsystems in order to identify and solve interface issues.

8.4.2.2 Project Classification Scheme

The QAPA manager of the company proposed a classification scheme which eases the whole adaptation process. The classification scheme is based on a project classification scheme described in a US Department of Defense (DoD) handbook (DoD, 1986). The DoD scheme describes four project classes: class A (high priority, minimum risk), class B (risk with cost compromises), class C (economically reflyable or repeatable), class D (minimum acquisition cost). For each project class specifications of selected characteristics like prestige, complexity, product life span, cost, and schedule pressure are given in order to provide guidance for categorisation.

The DoD classification scheme was adapted by the QAPA manager in order to improve the fit of the descriptions of each class with the types of projects usually executed in the company (due to confidentiality of the results the adapted scheme is not shown here). The project classification scheme allowed a retrospective classification of the analysed projects and a mapping of the lessons learned from these projects with the different project classes (COLIBRI - class A, ORCA2 - class B/C, EAGLE1 and 2 - class D). The project classification scheme in combination with the lessons learned data, which are now transferred into recommendations, offers guidance for adapting the product development approach for future projects.

8.4.2.3 Adaptation as a Collaborative Effort and Learning Process

During the execution of the projects the team reported continuously about issues with the design approach and the associated documentation process. The reported issues were discussed and reflected during a series of team sessions and by additional e-mail correspondence. The whole process was moderated by the QAPA manager and the lessons learned were documented.

Finally, the outcomes of this learning process resulted in the formulation of recommendations which could be related to the different project classes. The classification scheme and the recommendations build the support for the adaptation of future projects in order to provide some guidance and to avoid having the same issues again. More details on the analysis of the learning process itself can be found in Moser *et al.* (2011).

8.4.2.4 Consequences of Adaptation

For projects classified as class A, compliance with the ECSS system is mandatory, thus no adaptation other than the ECSS tailoring will be done. The design approach applied for projects of classes B, C, and D is still based on the ECSS system but will be adapted for each class based on the company internal recommendations together with the customer, thus simplified in different areas, for example: coordination principles, product simulation and test procedures, monitoring and reporting procedures, configuration and documentation management, and other.

Examples of possible consequences for Class B, C, and D projects are:

- emphasis on a trust-based sub-contractor relation rather than on formal reviews and assessments;
- different model and test philosophy;
- qualitative estimation of the risk because of the use of Commercial Off The Shelf (COTS) components and mitigation of the risk by de-rating and radiation protection according to ECSS system;
- documentation management (*e.g.* product description, test procedures, test reports) and reporting are simplified.

Projects of classes C and D show further differences. Change proposals are handled rather informal and in direct contact with customers. Projects of classes A and B will be executed as formal Stage-Gate processes, because payment by customers is dependent on gate-reviews. The gates and milestones are similar for projects belonging to the same class but differ for projects of different classes.

Even though, the coordination and documentation is simplified, the team agreed that regular internal progress meetings, regular progress reports and communication with customer and sub-contractors, and formal Gate-Reviews by the customer and the company's sub-contractors are necessary to ensure successful project completion.

8.4.2.5 Retrospective - A Reflection on the Developed Approach

After analysing the projects and the company's adaptation approach the main findings were presented to the QAPA manager. Subsequently he was interviewed in order to gather information about first experiences in applying the new adaptation approach on a project. The QAPA manager agreed with the statement that the DoD handbook 343 can be seen as a proper matching filter that includes the entire rationale parameters for having projects of different standards.

The ECSS system as a set of standards describing how to work in general but also in detail may be binding depending on the customer but also supports the design in providing agreed best practices to which one can refer in describing the way of working.

Further findings which are based on the conducted interviews and observations of one of the co-authors (acting as systems engineer in the company) are that the adaptation process is supported by the corporate management, contributing to the acceptance and utilisation of the approach. An important aspect which also contributed to the acceptance and usability of the approach is the development of the new approach as a collaborative learning process.

8.5 Discussion

8.5.1 Approaches for Adaptation

The company's design approach is based on the ECSS system which needs adaptation in order to be applicable for a specific project.

It was found that the company applies different adaptation approaches. One approach is proposed by ECSS and one was developed by the company. The main factor for the selection of the adaptation approach is compliance with the ECSS system. The ECSS approach for adaptation is used when compliance with the ECSS system is mandatory. The company's approach will be used when compliance is not mandatory.

Both approaches support a tailoring of the ECSS system, which means they focus mainly on a selection of those elements of the ECSS system which are relevant for a specific project. The criteria for assessing the relevance of elements of the design approach differ dependent on the class to which a project belongs.

In order to support and simplify adaptation the company developed a classification scheme representing typical projects. The development of an adaptation approach which is dependent on the classification of projects corresponds with findings from literature (*e.g.* Maffin, 1998; Meißner *et al.*, 2005) which highlight that adaptation needs to be context sensitive. The classification scheme is sort of a clustering of projects by using a selected set of relevant context factors.

As demonstrated in the case study, the development of a classification scheme and the formulation of recommendations and guidelines for the selection of suitable practices, methods for each project class can be done as a collaborative effort. This goes along with a learning process, which might enhance the acceptance and applicability of the developed support and guidelines.

8.5.2 Influencing Factors

Cost, allowed program risk, schedule pressure and product's complexity were observed to be the main factors that influence the degree of adaptation, respectively tailoring from a class A project "understand everything" to a class D project "go to the essentials". The different ratios, of which the cost/risk is the most prominent one, are negotiated with the customer.

In qualification, it should be stated that, the identified factors are derived from a case study in one company which operates in a specific context. Therefore, a generalisation is not possible, even though it can be expected that these factors are relevant for many companies operating in a competitive environment.

8.5.3 Adapting Design Approaches

Adaptation seems to be different for different levels of abstraction of a design approach. The adaptation of a generic design approach to a specific context requires different activities: augmenting and tailoring (see Figure 8.3).

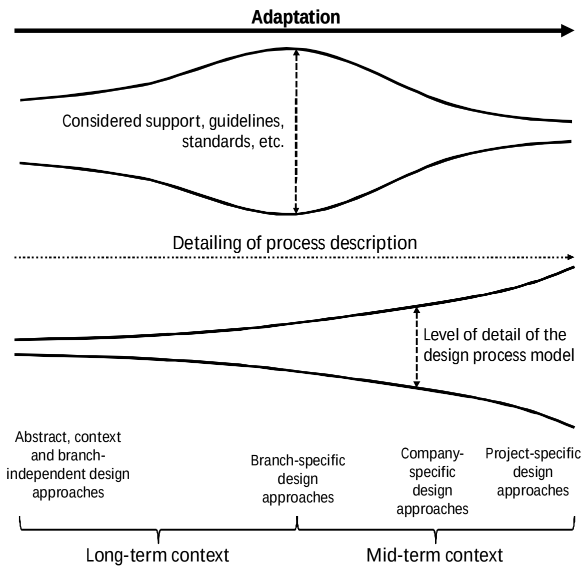

Figure 8.3. Adaptation of design approaches

The adaptation of generic and branch independent design approaches requires augmenting, *i.e.* the addition of process steps, design practices, guidelines, and other support. The adaptation of a branch specific or company specific approach to the context of a specific project can be seen as a tailoring. Tailoring means that only few additional elements will be considered and the adaptation is mainly a simplification of a comprehensive set of standards, guidelines and pre-selected support. Even though augmenting is more prominent for the adaptation on a high level of abstraction, and tailoring is more prominent when the design approach becomes context specific, both activities are conducted during the complete adaptation process.

Augmenting and tailoring of a design approach can be interpreted as divergence and convergence. Divergence and convergence during exploration and selection of suitable and necessary elements of a design approach seem also to differ with regard to the influencing factors which drive the process. Convergence seems to be mainly influenced by considerations of cost/effort, benefit, remaining risks, restrictions by standards, technical feasibility, and customer specifications. The rationale of divergence seems to be much more complex.

8.6 Conclusions

This paper contributes to design practice by describing an approach for tailoring of a branch specific design approach. The company's approach which is based on a classification of similar projects with regard to cost, allowed risks, schedule pressure and product's complexity eases the adaptation as established practices, suitable processes, and further recommendations are pre-selected, *i.e.* lessons learned are directly linked to project classes. This approach can be implemented by other companies after reformulation of the project classification scheme and collecting relevant experiences and lessons learned from their designers.

Furthermore, this paper contributes to the body of knowledge of design research by providing insights into adaptation of generic design approaches. The case study leads to a breakdown of adaptation into augmenting and tailoring.

Augmenting describes the activity to adapt a design approach to a specific context by adding *e.g.* specific support, standards, and design guidelines. Tailoring describes the activity to adapt a design approach to a specific context by selecting relevant elements. Adaptation can therefore be best described as the interaction between augmenting and tailoring of the provided support and an accompanying detailing of the design process description.

This more detailed representation of the adaptation of design approaches suggests that different types of support are required for different levels of abstraction of the design approach. The rationale for the divergent augmenting process seems to be a different one than for the rather convergent tailoring process.

The analysis of the categorisation scheme and the particular consequences for adaptation in the company allow drawing conclusions about the rationale of design process adaptation in practice, thus contributes to the debate on the applicability of design methodologies and generic design process models and provides some ideas for the support of a context dependent adaptation thereof. However, the identified factors (cost, risk, schedule pressure, product complexity) which guided the adaptation in the case study describe only the rationale of a tailoring process.

In order to understand the rationale of adaptation in general further studies are required, which also address the rationale of augmenting.

8.7 Acknowledgements

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