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**Application and evaluation of eco-design methods for SMEs**

***Aplicación y evaluación de métodos de diseño ecológico para PYME***

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**Abstract:**

Various methods and tools (referred to below as techniques for simplicity) have been developed for the development of sustainable products. For small and medium-sized enterprises (SMEs), this diversity poses a challenge. What leads to difficulties for SMEs and start-ups to select and apply appropriate techniques, which makes it in the sequel difficult for them to align their innovation activities with environmental requirements [1], [2].

This contribution focuses on techniques for product development with a low application threshold. The techniques were selected according to predefined criteria of integrability in SMEs and promotion of the development of a sustainable product [3, 4]. These techniques were integrated into the product development process (PDP) concept of Integrated Design Engineering (IDE [5]) to evaluate them in regard of their moment of use, practicability, and manageability. Therefore, six case studies were conducted to test the techniques and integrate the results into a PDP model. The aim of this work is to help SMEs and start-ups to become more competitive in product development by proposing techniques and describing them, thus contributing to long-term sustainability through the development of sustainable product development processes.

This can lead to the possibility to align both the design and manufacture of products with ecological requirements, which makes a significant contribution to the development of an integrated and networked product development process and is thus an important step towards solving current environmental problems [6].

***Abstract:*** (The abstract must be structured and must not exceed 250 words in length.).

spanisch

**Keyswords:** *PRODUCT DEVELOPMENT; ECO-DESIGN METHODS; SME; SUSTAINABILITY; SME SUSTAINABILITY*

***Palabras Claves:*** *DESARROLLO DE PRODUCTOS; ECO-DESIGN MÉTODOS; MÉTODOS DE ECODISEÑO; PRODUCT DEVELOPMENT PYME SOSTENIBILIDAD*

# Introduction

Small and medium-sized enterprises (SMEs) facing the challenge of aligning their product development (PD) with the Sustainable Development Goals (SDGs) [7, 8]. Goal 12 of the SDGs – to reduce energy consumption and CO2 emissions through sustainable industrial and consumer products [9, 10] - is only possible to achieve if the design and development of consumer and industrial products as well as the processes and process models behind them are oriented towards environmental considerations and aligned with corporate goals and opportunities.

In such a context, the diversity of available techniques is an obstacle especially for SMEs, whose resources are limited and whose lack of knowledge makes the choice of technique difficult. Furthermore, SME-specific framework conditions such as reduced capacities, lack of innovation or sustainability competence, and incomplete product life cycle data need to be taken into account.

A selection of techniques tailored to SMEs is made by a set of criteria defined in a former paper which has been categorized into three categories; integrability, applicability, and sustainability [4, 11]. Narrowing down the variety of techniques can avoid overburdening the non-specialized user [12]. Techniques are selected primarily on the basis of their popularity rather than on an analysis of the company's needs and their applicability and compatibility [13, 14]. Furthermore, integration hurdles has been identified in previews work [4].

To support SMEs while selecting and applying techniques, techniques are selected in the study phase on the basis of the previously elaborated criteria and integrated into the phases of the IDE process model (cf. [15]). This is followed by the development of a technique catalog, which underpins the techniques with a brief description as well as application notes and examples. This catalog and the refined process model are tested in a total of three waves of case studies and optimized based on the results. One wave of case studies comprises two case studies on real tasks for a product development, in cooperation with a company. On the basis of the information collected after the completion of the product development, a survey of the developers and a survey of the cooperating companies are used to determine the criteria fulfillment of the procedure concept and the preselected techniques, and the procedure model and the technique catalog are then optimized.

Thus, current state-of-the-art techniques can be selected for integration into the product development process of SMEs and integrated into the process concept of the IDE to test their practicability and manageability. This work focuses on the last two waves of case studies.

In addition, the current process concept will be adapted in the future based on the findings and results of two further waves of case studies, with the aim of making it easier for SMEs to develop sustainable products in a competitive environment.

So, the main focus of this work is on the context-sensitive integration of sustainability techniques into the IDE process to make the development of sustainable products more accessible to small and medium enterprises. In doing so, applicable sustainable and integrative techniques are integrated into the holistic IDE approach to test and evaluate the selection criteria, the selected techniques and their position in the PDP.

# 2. Current situation

An important conclusion from the previous paper is that specific application objectives can be assigned to the phases to assist in the selection of techniques. Since the first wave of case studies, new alignment techniques have been introduced in the technique catalogue, such as the 10 Golden Rules (cf. [16, 17, 17]) and the Design for Sustainability strategies (D4S Strategies) [18].

Furthermore, it was identified in the previous case studies that technique integration is more often diminished in the timing of the techniques' application. Therefore, in the waves presented in this paper, technique specialists of the project team will be appointed in each team to guide the applicability and integration of the techniques. Consequently, the team leadership and also the technique specialists of the respective team will be involved earlier in the conceptual procedure. In addition, the technique catalog has been expanded to provide a more informed knowledge base. Aspects such as phase assignment and #hashtags were also implemented in this living document to simplify assignability for new users. The phase concept has been updated based on the results of the first wave of case studies, and the locations and main applications of the techniques have been adapted.

Further information’s about the first waves of case studies are available in ICoRD [19].

# 3. Prototypical evaluation of case studies

The implementation of the second case study wave was based on the findings of the first case study wave and subsequently the third on the first two. The findings were cumulatively collected in a technique catalogue where the techniques and their purpose were described and step by step findings and knowledge gaps were added. This was made available to the participants at the beginning of each case study to enable a selection, team and context specific. As already known from the first case study wave, both waves contain two different product development tasks, each of which was carried out in cooperation with an industrial partner. This serves the further evaluation and qualification of the process model and the techniques and their location in the process model.

# 3.1 Second wave of case studies

**Case study C**

As shown in Table 1, the Ten Golden Rules and the Sustainability SWOT [20] (sSWOT) are applied at the beginning of the project to get an overview of the topic of sustainable product development, to align the project and to sensitize the team. These techniques significantly influence the vision model of the case study and form a solid basis for the further course of the product development.

In the conceptualization phase, the use of a technique with a focus on sustainability is avoided. As this may represent supposedly unused potential during the concept development. Moreover, many of the techniques are not suitable for concept evaluation. Instead, the assessment is carried out using VDI 2225 [21], which does not fundamentally consider sustainability aspects.

The Quality Function Deployment for Environment [20, 22] (QFDE) is used in this case study to compare the final concept with two references and to evaluate the success of the case study in detailing phase and realization phase. The application of the QFDE in the detailing phase is considered unusually late, as the intermediate results can hardly influence the product development at this stage. The results are mainly used for application in the later phases.

Table 1. Application phases of the sustainability techniques within case study C

| **Phase** | **Applied sustainability techniques** |
| --- | --- |
| Initialization phase | 10 Golden Rules, sSWOT |
| Conceptualization phase | - |
| Detailing phase | QFDE I & II |
| Realization phase | QFDE III & IV |

**Case study D**

In case study D, the Ten Golden Rules and the sSWOT were applied to clarify the initial situation and to align the project. The application is the same as in case study C.

In Table 2, it is noticeable that no techniques with a sustainability focus were applied in the conceptualization and detailing phase, although there are techniques that are suitable for evaluating and comparing the concepts and provide a high added value in terms of sustainability. This is partly due to the multidimensional nature of the project, which, in addition to the development of a new product, also had to investigate possible energy suppliers for the application.

The life cycle analysis (LCA) was carried out to determine the carbon footprint and to assess the achievement of sustainability goals. This was a "light LCA" that took into account factors such as material use, transport, resource extraction and production processes.

Table 2. Application phases of the sustainability techniques within case study C

|  |  |
| --- | --- |
| **Phase** | **Applied sustainability techniques** |
| Initialization phase | 10 Golden Rules, sSWOT |
| Conceptualization phase | - |
| Detailing phase | - |
| Realization phase | LCA |

# 3.2 Second wave of case studies

**Case study E**

In the initialization phase, the technique of the 10 Golden Rules was also successfully applied and later formed an important orientation aid in the project. As can be seen in Table 3, in contrast to the technique catalog, a utility analysis was used in the conceptualization phase to narrow down ideas and concepts from the idea factory, while the QFDE was only carried out in the detailing and realization phase.

Within the framework of the 4-question utility analysis, which is based on the Philips Fast Five technique [23], a sustainability technology was for the first time adapted by the developers to their needs beyond the normal dimensions.

Table 3. Application phases of the sustainability techniques within case study C

|  |  |
| --- | --- |
| **Phase** | **Applied sustainability techniques** |
| Initialization phase | 10 Golden Rules |
| Conceptualization phase | 4-Questions Utility Analysis |
| Detailing phase | QFDE I |
| Realization phase | QFDE II & III & IV |

**Case study F**

The LiDS Wheel [24], [25],[18], [26] was applied for the first time in a case study and modified in this case by using the ten Golden Rules in a modified form (reduced to 8) as evaluation criteria. The aim of the application was a clear evaluation of different burning media, which are already aligned with the project goals through the use of the Golden Rules.

For a comprehensive analysis, the sSWOT was carried out in the realization phase, as can be seen in Table 4. This was done for two preferred concepts in order to assess possible strengths, weaknesses, opportunities and risks with regard to their sustainability.

Table 4. Application phases of the sustainability techniques within case study C

|  |  |
| --- | --- |
| **Phase** | **Applied sustainability techniques** |
| Initialization phase | 10 Golden Rules in combination with the LiDS Wheel |
| Conceptualization phase | 10 Golden Rules in combination with the LiDS Wheel |
| Detailing phase |  |
| Realization phase | sSWOT |

# 4. Findings

The new alignment techniques added to the catalog of techniques are used in all case studies. This is due to the simple and uncomplicated application and the lasting effect through the orientation towards sustainable product development.

Experienced users of the techniques in the second wave case studies focus on known techniques and avoid techniques that are perceived as difficult or elaborate. This is probably due to the low resources within the case studies and the learning inhibition threshold towards techniques not yet used.

Furthermore, it is noticeable that significantly fewer techniques were used overall. This can also be attributed to the experience of the developers. In particular, elaborate techniques were avoided. Alignment techniques, on the other hand, such as the sSWOT or the Ten Golden Rules, were chosen and implemented independently by both case study groups.

In the third wave of case studies, the sustainability potential of the conceptualization and detailing phase was only partially exploited. Here, in both cases, easy-to-use and quick techniques were chosen, which, however, resulted in less meaningful and purely qualitative statements.

It was found that already known techniques and extensively elaborated techniques were most frequently used in the catalog of techniques, and a total of three sustainability techniques were used, indicating a reduction in the variety of techniques as expertise increases.

Overall, fewer techniques were used. Elaborate techniques were avoided, while alignment techniques such as sSWOT and the Ten Golden Rules were chosen and carried out independently by both case study waves.

No sustainability-oriented techniques were applied in the conceptualization phase, although this would have been appropriate for evaluating and narrowing down the concepts. The high amount of work and time involved in this phase may have led to this. However, it is questioned whether the omission of sustainability criteria in this phase is actually beneficial.

# 5. Conclusions and Lessons learned

The developers' focus on already known techniques suggests that the techniques should be described more concisely or even more comprehensively.

This is countered by the already large number of pages in the catalog and the additional work involved in reading the catalog, understanding the techniques and subsequently selecting them. The two points contradict each other, but can be explained by the different levels of difficulty of the technique applications. According to this, simple techniques should be described briefly and succinctly and more difficult techniques should be supported with the necessary examples and information.

It is also evident that the provision of templates is an important element for the easy adaptation of the techniques. This facilitates rapid application and reduces the barrier to using new techniques.

Within the case studies, techniques have been adapted by the developers themselves, beyond what is required by the technique, which shows a high level of understanding of the technique and can be attributed to a good basis of understanding. As a result, the techniques have been adapted to the needs of the users by the users themselves and have been applied significantly more efficiently within the case studies.

The conclusion of the previous paper can be supported by the case studies presented here. The newly added alignment techniques, which were used in particular in the initialization phase, serve to record the initial situation and to align and sensitize the project.

The location of the techniques applied beyond this underpin the application goals of the respective product development phase. In addition, the possible application periods of the techniques can be described in more detail and also assigned to concrete activities within the phases of the process model (cf. Appendix).

# 6. Summary & Outlook

The selection of techniques and their testing is refined by the results of the last two waves of case studies, which showed that some major problems need to be addressed. It was noted that with each successive wave of case studies, the range of techniques used reduced. This is apparently due to the emergence of specialists who preferred already known techniques due to the low capacity within the case studies. The application times of certain techniques also coincided with the same phases and product development activities within them and the increasing size of the technique catalogue. This insight allows techniques to be assigned to application recommendations and located within the process model, making their integration even easier. For example, several techniques can be used to compare concepts or variants of a product. By assigning goals to the individual phases and the techniques that can be used to achieve these goals, a universally applicable yet adaptable process model can be created.

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# Appendix

**Ecodesign checklist**

Originally created by Brezet and van Hemel [24], this method is versatile and can be used both to identify optimization potential in existing products and to aid in detailed product design. The checklist contains questions from a total of six categories that cover and evaluate the entire product life cycle. The list of questions is answered successively, while non-relevant aspects can be identified at the beginning and excluded from the evaluation. An assessment can also be approximated if time or information is limited. In practical applications, the answers in the list have proven to be sufficient for identifying the most serious environmental issues.

**MET matrix**

The MET matrix is used to identify weak points and improvement potentials of products. The matrix records inputs and outputs for the three categories of materials, energy, and toxic substances for each phase of the product life cycle [27]. This is done by either collecting quantitative data or by analyzing qualitative statements using rough estimates. In summary, the MET matrix provides the most comprehensive overview possible of the environmental impacts of the analyzed product [20].

**MECO matrix**

According to Wenzel [28], the MECO matrix provides a simple but comprehensive view of potential problem types throughout the life cycle of a product. The categories of materials, energy, chemicals and others are evaluated. Analogous to the MET matrix, ecological aspects are recorded for each category for each of the product life phases. This makes it possible to compare the ecological impacts of the individual product life phases without having to carry out time-consuming research and calculations beforehand [29].

**Philips Fast Five**

Philips Fast Five [23] are a series of questions whose answers enable a qualitative and quick evaluation of product concepts. Five defined questions are answered with either "yes" or "no". From the number of positive answers, the sustainable potential of an imagined concept can be estimated in comparison to a reference product [30]. Due to the absence of an approach to PD that could be applied to SMEs generally, various PD models were examined that are similar to PD in SMEs. As techniques should be applied contextually and independent of concrete models, the case studies are prototyped using the IDE model. However, the results can be applied to other SME-like approaches.

**Sustainability SWOT (sSWOT) analysis**

Sustainability SWOT Analysis is useful for analyzing a market and its context from a sustainability perspective. The primary requirement is that a life cycle can be modelled. Using a life cycle analysis, the current and future sustainability impacts (ecological, social, economic) are mapped for each stage of the life cycle and accompanied by a qualitative assessment of their significance [20].

**Quality Function Deployment for Environment (QFDE)**

Using QFDE, it is possible to analyze the initial situation and, based on this, elicit the focal points of potential development. In addition, it is possible to compare the original product and the new product. The method is based on the use of similar matrices as in traditional QFD and it consists of four phases. The application of QFDE generally begins with the collection of customer and environmental requirements and the identification of correlations between these requirements and quality attributes. In addition, a functional analysis is conducted to capture correlations between quality attributes and technical attributes, including structure or components, as well as key redesign opportunities from both an environmental and traditional perspective. Lastly, the optimization approaches with the greatest potential for improvement can be selected for further development [20, 22].

Techniques added to the catalog after the first wave of case studies:

**Design for Sustainability Strategies**

There are seven strategies in Design for Sustainability that provide developers with approaches and directions for designing a sustainable product [18]. In addition to the product-related sustainability effects in the course of production, use and recycling, the influence on user behavior is also taken into account in product design and optimization is oriented towards the user. In the beginning, the team discusses the strategies, and any necessary adjustments are made to the project. Based on this, project-specific measures and conclusions can be discussed in order to align the project with these guidelines. Developers are thereby made aware of these guidelines.

**Ten Golden Rules**

The Ten Golden Rules by Luttropp and Lagerstedt [16] contain ten guidelines that help to sensitize the team members and to strategically align the project. First, the team discusses the strategies and project-specific concretizations are formulated in a context-sensitive manner. On this basis, project-specific measures and conclusions can be developed to align the project with the guidelines.

**Idemat app**

Idemat allows users to select sustainable materials and perform a quick life cycle assessment (LCA) based on three scenarios. This is done directly in the app. Various scenarios, materials, and transportation routes as well as product manufacturing processes can be specified based on the project.

**LiDS Wheel**

The LiDS Wheel is used in particular to work out improvement strategies. With the help of a reference product, the individual strategies of the spider web diagram can be used to search for constructional and design possibilities to achieve the desired product improvements. [31]

**Technique combinations**

Several recommendations for appropriate combinations of methods have also been included. This can simplify the application of techniques, especially when techniques build on each other.

**Techniques application time within the case studies**

**Table 4** Application goals of the sustainability techniques of both case studies

| **Phase** | **Activity** | **Technique** |
| --- | --- | --- |
| **Kick-Off** |  |  |
| **Initialization** | Specifying the task | 10/12 Golden Rules |
| Specifying the task | D4S Strategies (Design for sustainability strategies) |
| Specifying the task | Ecodesign checklist (for Redesign tasks) |
| Specifying the task | LiDS Wheel |
| Researching on basic principles, state of the art & science & intellectual property rights | sSWOT |
| Creating the requirements profile | Ecodesign checklist |
| Creating the requirements profile | MET matrix |
| Creating the requirements profile | MECO matrix |
| Creating the requirements profile | QFDE I & II |
| Characterizing the stakeholder requirements | PERSONAE/sPERSONA |
| Deriving a catalog of criteria for the development | *Criteria catalog* |
| Defining the subproblems | *Requirements list* |
| Defining the subproblems | *Vision model* |
| **Conceptualization** | dentifying interrelationships between environmental and stakeholder requirements | QFDE I(I&II) |
| Performing the idea factory | *Bionics/Synectics* |
| Structuring the ideas & performing the morphology | Phillips Fast Five |
| Limiting the solution concepts | QFDE (III&IV) |
| Limiting the solution concepts | Phillips Fast Five |
| Performing the rough visualization of the concepts | - |
| Selecting the preferred concept | Ecodesign checklist |
| Selecting the preferred concept | Phillips Fast Five |
| Selecting the preferred concept | LiDS Wheel |
| Selecting the preferred concept | sSWOT |
| Selecting the preferred concept | MECO matrix |
| Selecting the preferred concept | MET matrix |
| Selecting the preferred concept | QFDE (III&IV) (final selection) |
| **Detailing** | Creating the assembly structure and the CAD models for the preferred concept |  |
| Creating the hand & functional models |  |
| Calculating & simulating the design |  |
| Detailing and visualizing the preferred concept | Idemat App (lightLCA) |
| Evaluating the detailed preferred concept | Ecodesign checklist |
| **Realization** | Optimizing the CAD models for the detailed preferred concept |  |
| Creating the technical drawings for the detailed preferred concept |  |
| Photorealistic rendering of the detailed preferred concept & prototype manufacturing |  |
| Evaluating the latest state of product and business model development | LiDS Wheel |
| Evaluating the latest state of product and business model development | sSWOT |
| Evaluating the latest state of product and business model development | QFDE III & IV |
| Evaluating the latest state of product and business model development | Ecodesign checklist |
| Evaluating the latest state of product and business model development | MECO matrix |
| Evaluating the latest state of product and business model development | MET matrix |