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INTRODUCTORY APPROACH FOR SUSTAINABILITY INTEGRATION IN CONCEPTUAL DESIGN

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1. Introduction

The introduction of sustainability-related requirements into new product development has been a popular topic since the 1990s, and one of the very roots of the topic – scarcity of resources – indicates that market forces will require improved ways of dealing with sustainability for product developing companies. The question remains, however, of the importance of considering sustainability aspects in product design, and if important - how to do it? This paper assumes importance and works to answer the question of how to do it by presenting an approach, currently under development, to include sustainabilty aspects in a generic design process by defining a sustainable design space inpsired by the early steps of a set-based concurrent engineering (SBCE) approach, and then describing how each stage of the generic design process can be aligned in order to arrive at more sustainable products. In a SBCE approach, rather than defining and evaluating design concepts, allowable design "sets" are identified and non-allowable design areas are omitted. The allowable set is determined by requirements and limitations from applicable areas [Sobek et al. 1999].
Current practices of product development in manufacturing companies are predominantly based on cost/profit models [Asiedu and Gu 1998], that aim to achieve high quality at low cost with a result of high profit. Sustainability requirements are commonly perceived as extra costs, due to e.g. generating additional design constraints that must be met or increasing testing and assessment costs. This is due partly to the way that sustainability aspects have been considered, which is often by conducting assessments after significant decisions about a product have already been decided upon. A late design change means higher costs as the degrees of freedom reduce with development time. Awareness of the limitations also from sustainability perspective earlier could instead result in new more innovative solutions. The paradigm of product development towards increasing value (and profit) by reducing costs and increasing benefits is unlikely to change. However, reconsidering how and where sustainability aspects are brought into the product development process is possible to change, to support both reducing costs and increasing benefits. See e.g. [Waage et al. 2007] for discussion; [Schmidt and Butt 2006] for an industrial example.
"To make a difference" the impact of sustainable development needs first to be understood in several dimensions. There are operative, tactical, and strategic aspects with regard to sustainable development that need to be considered when integrating sustainability in produt design. The operative aspect is that people developing products need tools and techniques to impact both the search and evaluation of product concepts within their working environment. The tactical aspect is important since it "controls" the timing of when certain objectives need to be embedded. A clear example is the effectiveness of legislative norms, agreed policies, or simply the timing of a product's introduction (and use) on the market. The strategic aspect is critical, for example, in a development organization that wants to

evolve, expand and change the direction of business towards being (and being perceived as) a leader in providing sustainable solutions.

1.1 Conceptual design

Conceptual design has been widely recognized and studied since the significant impact on nearly every aspect of the product – and its subsequent realization – are determined in this phase, with regard to both life cycle cost [Asiedu and Gu 1998], and presumably also sustainability impacts. It is characterized by many important design decisions, while the data and information is yet limited. The freedom of design is constrained and knowledge of the design problem is increased as progress is made through the development process. Here we use a simplified conceptual design process to explain current limitations and propose methods to address these limitations.

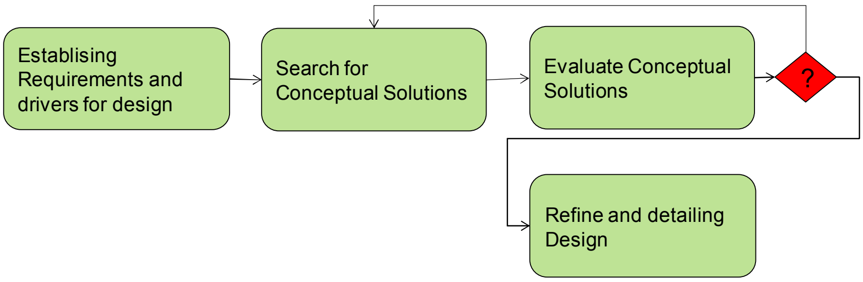

Figure 1. Simplified and generic design cycle

1.1.1 Sustainability in a generic design cycle

With the generic design cycle shown in Figure 1, we can consider how sustainability criteria might today be considered in each of the steps. In the first step – *establishing requirements and drivers for design* – criteria need to be identified that can be used to formulate requirements for the development project. In the second step – *search for conceptual solutions* – the development team needs guidance and support tools to enhance the search for more sustainable solutions. This is partly realized since the criteria previously expressed as requirements are available in this step, yet the criteria alone are not sufficient. In the third step – *evaluate conceptual solutions* – the proposed solutions must be represented so that they can be assessed, i.e. against the sustainability requirements. Comparison against the sustainability criteria are necessary. At this stage, it is unlikely that a concept is well enough defined to allow a full analysis. However, the degree to which the concept is aligned with each of the sustainability criteria may be possible to measure (qualitatively and/or quantitatively). In essence, there is a "sustainability compliance index" per each concept. At the actual decision situation to go or not to go further with the proposed concept (?), there is a need to express the use of a "sustainability compliance index" in a way that can be balanced/judged with any other requirements to be fulfilled. Finally, the concept selected to advance for further refinement and detailing needs to capture and represent the rationale for how the selected solution must be treated for the detailing, since there are several more decisions to be made that relate to sustainability criteria fulfilment. This is in some ways different from some alternative methods and techniques, such as most Design for Environment (DfE) techniques, in which the focus lies on assessing the environmental impact of concepts and solutions, and little or no support is typically found for solution seeking and "what is good enough," i.e. targets are not set or are not operational in the designer's working environment.

1.2 Sustainabilty criteria used today are not sufficient

When sustainability-related criteria exist in product requirements today, they are often developed based on identifying things that are assumed to be desirable or not, along with being easy to assess. An example: minimization of energy is nearly always mentioned in regard to sustainability of products, see e.g. [Herva et al. 2011]. Generally minimizing energy use is good; however, there are forms of energy that can be utilized with no or very low sustainability-related impacts: passive solar, for example. This to say: it is not energy minimization per se that is the goal, but rather the minimization of certain types of energy that are associated with negative sustainability impacts. To address this, the basic principles for global socio-ecological sustainability put forth by [Robèrt et al. 2002] are used in this paper. These principles were arrived at by first assuming to arrive at a complete enough understanding of the global socio-ecological system so as to be able to define success for planning efforts within that system, i.e. a sustained human society, including the ecological system upon which society depends. That definition of success is delivered in the form of first-order principles that are intended to be applicable to any planning effort to arrive at the definition of success by virtue of being sufficient, necessary, concrete, generic, and non-overlapping. These sustainability principles state that in a sustainable society, nature is not subject to systematically increasing… (1)…concentrations of substances from the Earth´s crust, (2)…concentrations of substances produced by society, (3)…degradations by physical means, and, in that society, (4) people are not subject to conditions that systematically undermine their capacity to meet their needs. These principles are designed for "backcasting" (i.e. imagining success in the future and then exploring strategies to reach that success) in contrast with "forecasting" (i.e. analyzing and projecting current or historical trends). We refer to "strategic sustainability" as the combination of these ideas, i.e. backcasting from sustainability principles. These sustainability principles act as system boundaries for sustainable solutions; anything within the boundaries is in essence the set of "sustainable solutions". This approach to sustainbility is essentially the same as the first element (define feasible regions) of the first principle (map the design space) of SBCE set out by [Sobek et al. 1999]. Thus, limiting the range of applicable design solutions in such way is in line with SBCE.

1.3 Strategic sustainabilty in early phases of product innovation: Results from a (previous) descriptive study

To understand the current situation regarding how strategic sustainability aspects are implemented in the early phases of a product innovation process, a descriptive study with a qualitative research approach was conducted at six larger product development companies in Sweden as part of the project "Decision Support for Sustainable Value Chains" (DecSus). This study investigated the current practices for how those companies currently have, and could better implement, a strategic sustainability perspective in the early stages of their product development. The scope of the study and the resources available for data collection included company documentations of the product development process and semi-structured interviews of twenty persons at the different companies with different responsibility areas, i.e. product planning, product development, project management, supplier development and environment, environmental management, advanced engineering, and environmental engineering [Hallstedt et al., in review for journal publication]. Key results from this study include the following.

Interviewees named eight potential types of sources in which sustainability requirements or input for sustainability requirements could be identified: customer requirements, company standards (e.g. material lists, supply assessment requirements), company's environmental targets (for example based on product strategies and/or environmental management system), regulations (e.g. Registration, Evaluation, Authorization and restriction of CHemicals - REACH), life cycle assessments, chemical analysis, customer analysis, European Union (EU) studies.

All the interviewees suggested that sustainability aspects should be included very early in the innovation process, in the "product planning" phase in order to have an affect on the product design. As a result of this study, the authors have argued that if the identification of sustainability aspects were to come earlier, e.g. in the product requirement list, it then would be easier to; i) reduce the negative environmental impacts; ii) avoid additional costs for assessment or late-stage redesign; iii) plan for solutions as flexible platforms towards sustainable solutions; and iv) use sustainability as a driver for product-service innovations [Hallstedt and Thompson 2011]. The importance of defining sustainability criteria and considering these as equally important as traditional requirements of cost and quality from the very beginning for successful implementation are also emphasized in e.g. [Waage 2007].

The study also identified some challenges that should be addressed to avoid suboptimization and to guide decisions towards success for the company in a sustainable society. These included: i) having a full social and ecological sustainability perspective, ii) covering all aspects of the product's life cycle,

and iii) complementing the common "forecasting" approach with a "backcasting" approach (described in previous section).
The results from this descriptive study formulated some guidance for sustainability criteria development that together with theories of basic principles for global socio-ecological sustainability are used to build (in this paper) our first prescriptive approach for integrating sustainability in criteria development. Additional insight was gathered from a two-day workshop involving representatives from Volvo Aero, an airframe manufacturer working within the Volvo Aero value chain, and researchers involved in this research project. The workshop focused on how a backcasting from sustainability principles perspective could support enhanced design requirements.

2. Problem addressed

Two related problems are addressed in this work that are related to bringing sustainability into the conceptual design process. The first problem addressed is that common sustainability criteria are not robust enough to provide a complete picture of sustainability, while sustainability principles identified by Robèrt et al. [Robèrt et al. 2002] are seldom directly applicable for use in requirements specification for a new product. The second is that in an operative design situation, there is little or no time and data available to undertake the work to integrate sustainability. This was not explicitly identified in the previous study, but becomes evident as we try to conceptualize solutions to the first problem. Therefore this work is a first step to arrive at an approach for how to both develop and put into use sustainability criteria in conceptual design. The first problem is addressed by utilizing a set of previously-published sustainability constraints that match precisely with the early steps in set-based concurrent engineering, but to our knowledge have not previously been used in this context. The second problem is addressed through a proposal for how to align sustainability criteria throughout each of the steps of the generic design cycle.

3. Developing sustainability criteria and aligning with conceptual design

This section describes a 5-step approach for how the sustainability criteria are introduced and considered throughout the design cycle. The five steps are based on a modification to the simplified conceptual design model in Figure 1: a step is added to define the "applicable" design space (box 2 in Figure 2). This alteration is a step towards adopting "Set Based" principles as described by [Sobek et al. 1999]. The subsequent search and evaluation activities serve to limit the design space while making conceptual solutions more robust and detailed until the conceptual design phase is completed. This is explained in Step 2.

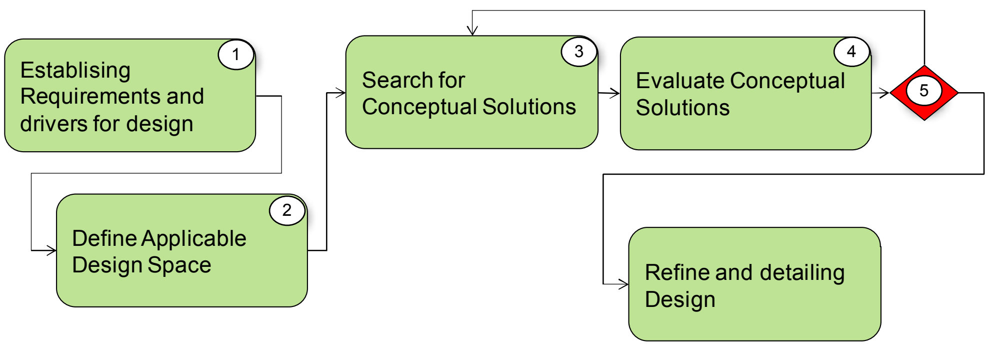

Figure 2. A strategic conceptual design cycle; numbers refer to steps explained below

Step 1: Establish sustainability-based design requirements

The results from the descriptive study and theories of basic principles for global socio-ecological sustainability formulated some guidance for sustainability criteria development that together build the base for the suggested first prescriptive approach for sustainability criteria development. This process needs to: i) be simple enough to collect data and thereby possible to update regularly at the company; ii) be based on company requirements with the goal to link some sustainability criteria to technical product requirements; iii) include a full product life cycle (from resource extraction to disposal phase) and include a full socio-ecological perspective; and iv) be based on both forecasting (trend analysis) and backcasting (goal-oriented planning).

Step 1.1: Collect existing sustainability-related criteria

This step is a divergent step to identify all criteria that could possibly be used. These can come from a variety of sources, such as i) product requirements: sustainability-related criteria already exist e.g. in technical specifications for a product or previous environmental assessments of related products; ii) company requirements & goals, e.g. corporate documents and environmental policies; iii) industry requirements and goals, e.g. within the aerospace industry, the Advisory Council for Aeronautics Research in Europe (ACARE) publishes targets for e.g. future CO_2 emissions; and iv) existing regulations at national and international levels, e.g. REACH.

Step 1.2: Review all product life cycle stages through sustainability principles

Since the criteria in Step 1 are typically coming from a forecasting approach based on known current problems, this step introduces a backcasting approach. Create a map of the product life cycle stages. Use this map to review each life cycle stage with an eye to each of the sustainability principles. (See related concepts from e.g. [Byggeth and Broman 2000]. Where a potential contribution to a violation of a sustainability principle is found, a new criterion can be developed and added to the list.

Step 1.3: Reduce the criteria list based on meta-criteria and relationship modelling

The goal of this step is to arrive at a manageable list of criteria that cover major sustainability aspects of the concept to be evaluated. In this step the criteria list will be shortened with the goal of balancing comprehensiveness (i.e. not being unnecessarily simplified in a reductionistic way) with the ease of use demonstrated in the Ford of Europe case where no new data requirements were made to accommodate the sustainability criteria [Schmidt and Butt 2006].
Criteria are then grouped and classified into product life cycle phases (e.g. material sourcing, production, distribution, use, end-of-life). Each criteria also has a time perspective (i.e. short term and long term) to reflect urgent requirements versus expected requirements in future. Furthermore, address similar or conflicting goals, e.g. if an industry goal is to reduce CO_2 emissions by 30% but product requirements are only sufficient to reduce CO_2 emissions by 10%.
To further shorten the criteria list, it is then scrutinized by a set of meta-criteria. It is important that these meta-criteria allow for a comprehensive socio-ecological sustainability perspective, while also ensuring that the criteria will be usable in the operational working environment. Meta-criteria suggested here are based on previous research by e.g. [Schmidt and Butt 2006] and the PROSUITE project [Dreyer et al. 2010]:

1. Applicability: Criteria must be applicable to different concepts;
2. Logic and simplicity: Criteria need an unambiguous measurement rule and measurement units;
3. Feasibility / data availability: Criteria must draw on information that is possible to obtain;
4. Clarity: Each criteria has to measure a measurable entity;
5. Relevance: Criteria must represent central aspects of the dimensions; and
6. Coverage: All main aspects of sustainability have to be covered, preferably without overlap.

Step 1.4: Set requirements for each criteria

After a final set of criteria are identified, the type of each criterion is determined, e.g. go/no-go, targets, or direct comparisons between concepts. Then targets or a basis for comparison for each criterion are developed. The aim is to develop a set of sustainability targets that can be re-used with only minimal modification for future development projects.

Step 2: Expand the conceptual design process to include definition of allowable design space

Before the search for solution starts, sustainability criteria and associated requirements are used together with the other domains of requirements and restraints. The domain representing sustainability criteria may aid by i) illuminating previously unexplored design space, and/or ii) further constraining the applicable design space to reduce the space that needs to be explored. Such a mapping of domains in a design space is principally illustrated in Figure 3. This figure indicates areas (Design Domains) where we should search for solutions from different aspects. The figure shows that there is no unified area where all domains are united – initially it is not possible to find any design solution (concept) satisfying all views.

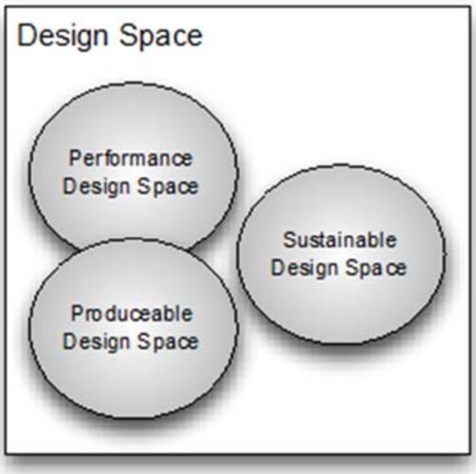

Figure 3. Principal map of design space within three domains

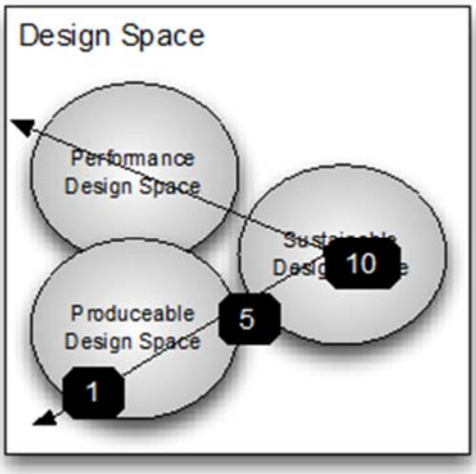

Figure 4. Compliance with sustainable criteria for design space elaboration

It is likely that the preferred, or even allowable, design spaces are not compliant so the designer's first task is to carefully understand the limitations and restraints of the given design pre-conditions. The designer can use the design space mapping as a way to understand limitations and opportunities in advance of actually identifying plausible concepts. Questions guiding the forthcoming design work can be formulated, such as "What would be necessary to merge these three design domains even more?" "What would be the consequence of violating one, or several, design domains?" "Can we modify the restraints and assumptions for the design domains to become more sustainable compliant?" Then we introduce a Sustainability Compliance Index (SCI) to guide the search for solution areas direction. The SCI is currently suggested to be defined as a scale from 1 (minimal alignment) to 10 (complete alignment). This scale is in line with similar scale systems already established for grading maturity, such as TRL (Technology Readiness Levels). In the example, a tentative solution within the unified area between Performance and Produceability, may reach SCI=4 (only). The requirement may be "at least 5" as derived from sustainability criteria. See Figure 4.

Step 3: Making Sustainability Criteria Assessment available in the design environment

As we progress into the actual search, identification and definition of conceptual solutions we start creating product information. Typically this is done using various design definition tools, such as CAD tools. It is highly desirable to bring the knowledge about sustainable requirements and criteria as close to the designers work environment as possible. Some requirements derived from sustainability principles in step 1 can be directly associated to the product model being defined, for example sustainability compliance of alternate materials. Such information can be made available through coloring the CAD model as materials are selected.

Secondly, guidelines and check lists for sustainability driven design can be made available directly via the designers interface with the product model being defined in the CAD tool. See Figure 5. Functionality of the CAD system even allows certain requirements and rules to be executed immediately as the designer builds and modifies the conceptual design.

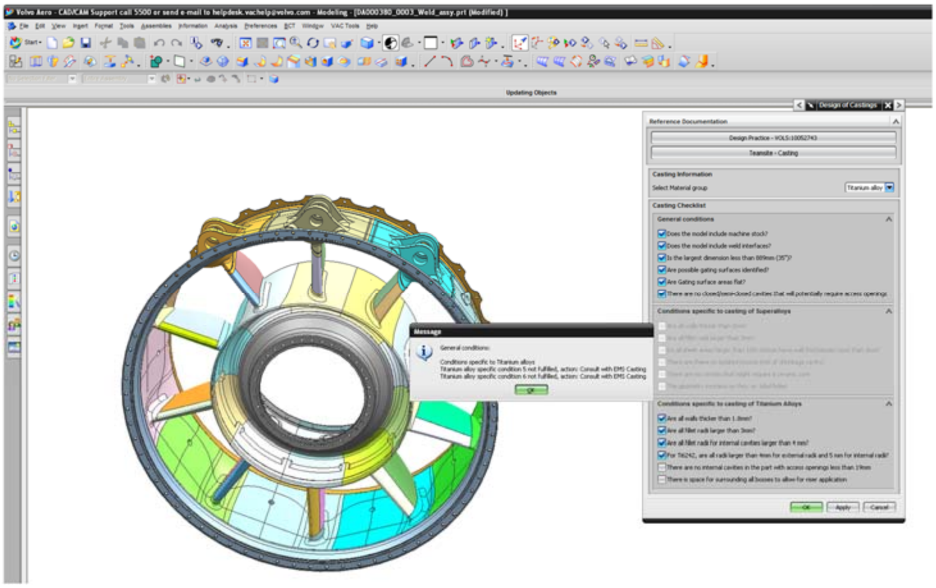

Figure 5. Illustration of making sustainability criteria assessment in a CAD model

Step 4: Ensure accessibility of data required to evaluate against sustainability criteria

When a set of conceptual designs have been defined, it is important that these can be evaluated against all applicable requirements. Data are necessary to make these evaluations, i.e. data that connect the decision to be taken with the sustainability criteria, e.g. material and energy flows relating to a selected material or process, upsteam supplier implications with regard to social sustainability, etc. There are two things to consider here. First, since sustainability criteria may require extensive amount- and quality- of data, the availability of data for the concepts is critical. Second, even if the necessary data exists, it may exist in many different sources. Practically, such data needs to be made available in the designer's context.

Illustrated by an example: a concept may use material A, which in turn can be manufactured in alternative ways. The material flow may not be known at first. It may, or may not, be recycled and reused. It may need to be treated in production in many ways that have not yet have been defined, etc. Consequently, criteria for sustainable evaluation within conceptual evaluation need to use data that already exist at that time, or can easily be derived. The evaluation criteria are therefore referred to as design criteria.

Step 5: Integrate sustainability criteria into the decision gate

The design and evaluation of conceptual solutions is a maturation process where the concepts as well as the evaluation methods are being refined and made more robust and detailed as the development process proceeds.

Since most companies use gated processes as a monitoring, control and communication mechanism during product development, the sustainability criteria, and acceptable level of the sustainability compliance index, can be implemented as gate criteria.

4. Application

A pilot test to identify a relevant list of sustainability criteria to be used in the very early phases of the product innovation process was conducted at the company Volvo Aero to get an indication of the applicability of the approach. Step 1.1 resulted in a long list of over 150 criteria based on eight different sources such as company requirements, ACARE, the environmental management system, and environmental impact assessments from previous development projects. Step 1.2, ensuring the full life cycle and socio-ecological perspectives, identified some additional criteria, frequently covering a more long-term time perspective. See illustration of the process in Figure 6.

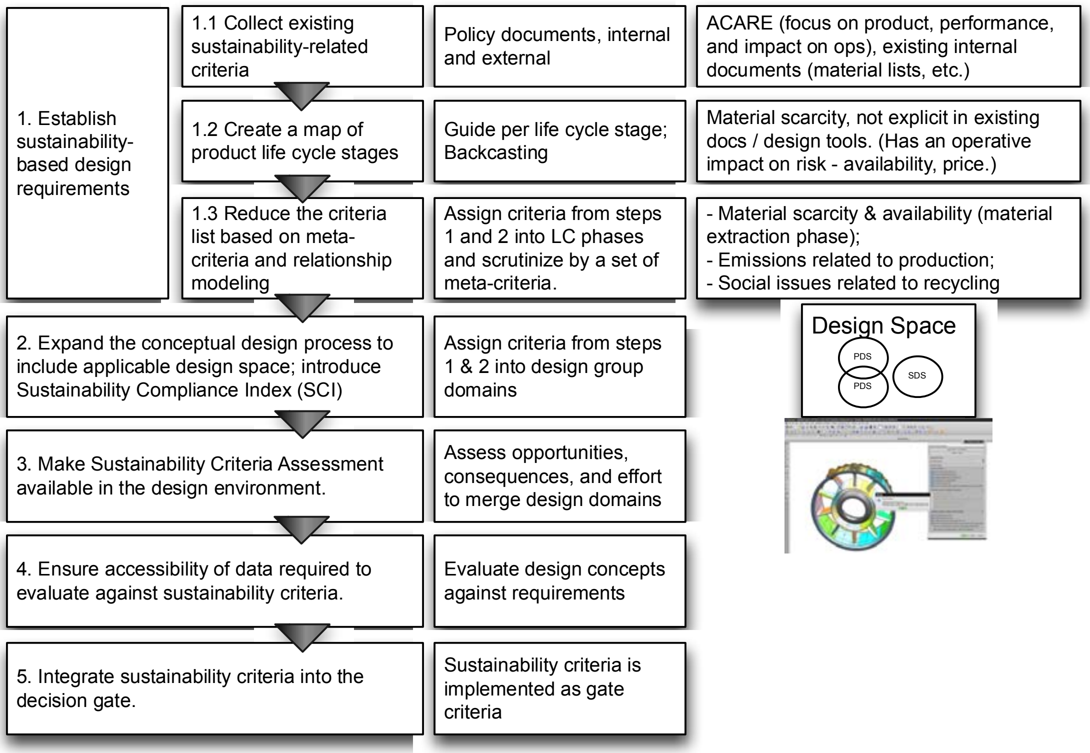

Figure 6. Introductory approach for sustainability integration in conceptual design

The criteria were classified and grouped according to step 1.3. The full set of criteria need to be identified to be reduced according to the meta-criteria decided in the third step. However, in this simplified example the full set of criteria has not yet been identified. Despite being in process, the example shows how the criteria for tactical and strategic dimensions could support and guide decisions at the operational level so that solutions under development can act as flexible platforms in-line with the strategic direction toward more sustainable solutions.

5. Discussion

Products are often analyzed for some sustainability aspects in later phases of product design where changes may be quite costly to introduce. This research aims at filling these two gaps: bringing in a full global socio-ecological sustainability perspective, and doing so early and throughout the conceptual design process. Our ambition is to develop a decision support process that will guide the product developers in their daily work during development, evaluation and validation of concepts, technologies and decisions for future products and services. The results from a descriptive study formulated some guidance for sustainability criteria development that together with theories of basic principles for global socio-ecological sustainability build our first prescriptive approach for developing sustainability criteria and integrating them into a conceptual design process.

Initially we mention the need to consider three dimensions: operative; tactical; and strategic dimension, when integrating sustainability aspects in product design. The proposed approach does this at the strategic level by using basic principles that define the boundary conditions for a sustainable society, which is used to define the sustainability design space "set" (Step 1). Consideration of tactical aspects is included in Step 2 of the approach with regard to which level of the strategic sustainability design set would be integrated into the selective design solution of the design space measured through a Sustainability Compliance Index. Operative aspects for the designer then come in Steps 3-5 in order for sustainability aspects to be brought into the designer's desktop working environment (Step 3), appropriate data is available (Step 4), and decisions utilize the integrated and data-supported sustainability considerations (Step 5).

5.1 Observations

Establishing both comprehensive and operational sustainability-based criteria is imporant: a comprehensive and operational set of sustainability criteria can be derived with input from existing design requirements (Step 1.1) and complemented by both considering the product's full life cycle and utilizing a "backcasting from principles" perspective (Step 1.2). It is important that these criteria comply with a well-considered set of meta-criteria to ensure robustness (Step 1.3).

Sustainability-based criteria can be set independent of a design project: the overarching and multifaceted nature of sustainability suggest that the derivation of sustainability criteria can, and probably should, happen independent of and prior to the design process of a product. "Can" because at least the majority of sustainability criteria are not specific to the product itself, but rather to the relationship between any product and its surroundings (e.g. with regard to material use, emissions, etc.). "Should" because collecting sustainability requirements from the variety of sources from which they originate and aligning those requirements (next point) takes time to coordinate.

Criteria alignment through design cycle: it is critical that the criteria are aligned throughout the conceptual design cycle (not only integrated into the design requirements). By expanding our thinking from "get sustainability into design requirements" to "align sustainability criteria throughout the design cycle" we think there will be a much higher likelihood of influencing the sustainability aspects of the resulting products. Because having data and methods available to support processes requires time to be aligned with these criteria, we suggest that pre-defined criteria and requirements be made ready for implementation:

- Very early when design studies are being defined—this is a critical step to introduce the sustainability requirements and criteria as domains, both to introduce design opportunities and limitations as early as possible;
- By integrating with the designer's environment, making known data and methods easily accessible by the design engineer; and
- As gate criteria, with acceptance levels, in the company's development process.

Defining design space: Influenced by the concept of set-based concurrent engineering [Sobek 1999], efforts to integrate sustainability criteria into concept design processes would benefit from some modifications to the general design cycle introduced in Figure 1. Specifically, this means introducing sustainability as a design domain to be considered along with other design domains (e.g. produceability and performance) from the outset of the project. This would ensure that sustainability requirements are considered from the beginning, addressing the common challenge that sustainability aspects are considered after design decisions have already been taken. We have suggested the introduction of a sustainability compliance index as a means to introduce which direction to elaborate at this stage. Such an index can further be used for decision making.

Supporting designers with regard to the sustainability domain: there is a need to provide guiding tools for how to search for sustainable solutions that complement the sustainability criteria so that designers know how to work with those criteria (Step 3). At a minimum this requires having appropriate data accessible, and likely implies a need for additional support tools.

Implications of introducing "Sustainable Design Space": we think it is possible that introducing a sustainable design space as a domain, and a sustainability compliance index, may actually open up design spaces that have previously been disregarded because they were not at the intersection of existing (e.g. produceable and functional) domains. By introducing a third (sustainability) domain, this may encourage exploration of intersections between this and one of the other domains.

5.2 Further research

This paper has primarily focused on establishing sustainability-based design requirements (step one) and including ideas for remaining steps. In further work, we will: i) continue to refine steps 2-5, and ii) test, validate, and continue to refine step one. The suggested approach needs to be verified in a concept design case to investigate if the sustainability criteria together with the suggested changes to the conceptual design process can guide decisions towards a more sustainable and long-term profitable solution for the company. This is planned for the next research phase.

6. Conclusion

This paper has proposed a 5-step approach for integrating sustainability into the conceptual design process that addresses two problems: 1) robustness of a "sustainable design space" in the same manner as the early steps in a set-based concurrent engineering approach, and 2) alignment of sustainability considerations throughout a generic design cycle. Initial work has been done to complete the first step in a design project to develop a set of robust sustainability criteria that ensure a full product life cycle perspective and a comprehensive view on social and ecological sustainability. Suggested next steps are presented that emphasize the need for alignment through all stages of the conceptual design process with an emphasis on defining applicable design space, searching for conceptual solutions, evaluating conceptual solutions, and deciding with regard to those conceptual solutions. In further work we will continue to develop and refine these additional steps more in detail and also test and verify the first step.

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References

Asiedu, Y., Gu, P., "Product life cycle cost analysis: state of the art review", International Journal of Production Research, Vol.36, No.4, 1998, Pp.883-908.

Byggeth, S, Broman, G., "Environmental aspects in product development: an investigation among small and medium-sized enterprises", Proceedings of SPIE: Environmentally Conscious Manufacturing, Surendra M. Gupta, Boston, Massachusetts, USA, Vol.4193, 2001, Pp.261-271.

Dreyer, M., et al., "Literature Review on Social Indicators and Integrated Model of Indicator Selection", Report No.227078. Report prepared within the EC 7th framework project, Development and application of a standardized methodology for the PROspective SUstaInability assessment of Teechnologies (PROSUITE), 2010.

Hallstedt, S. I., Thompson, A. W., "Sustainability-Driven Product Development - Some Challenges and Opportunities for the Aero Industry", International Society for Airbreathing Engines (ISABE), Gothenburg, Sweden, 2011.

Hallstedt, S. I., Thompson, A. W., Lindahl, P., "Key Elements for Implementing a Strategic Sustainability Perspective in the Product Innovation Process", in review for journal publication.

Herva, M., Franco, A., Carrasco, E. F., Roca, E., "Review of corporate environmental indicators," Journal of Cleaner Production, 2011, Vol.19, No.15, Pp.1687-1699.

Robèrt, K.-H., Schmidt-Bleek, B., Aloisi de Larderel, J., Basile, G., Jansen, J. L., Kuehr, R., Price Thomas, P., Suzuki, M., Hawken, P., Wackernagel, M., "Strategic sustainable development - selection, design and synergies of applied tools," Journal of Cleaner Production, Vol.10, No.3, 2002, Pp.197-214.

Schmidt, W.-P., Butt, F., "Life Cycle Tools within Ford of Europe's Product Sustainability Index: Case Study Ford S-MAX & Ford Galaxy", International Journal of Life Cycle Assessment, Vol.11, No.5, 2006, Pp. 315-322.

Sobek II, D. K., Ward, A. C., Liker, J. K., "Toyota's Principles of Set-Based Concurrent Engineering", Sloan Management Review, Winter, 1999, Pp.67-83.

Waage, S. A., "Re-considering product design: a practical "road-map" for integration of sustainability issues", Journal of Cleaner Production, Vol.15, No.7, 2007, Pp.638-649.

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