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Procedia CIRP 48 (2016) 437 – 442
www.elsevier.com/locate/procedia

23rd CIRP Conference on Life Cycle Engineering

Information management platform for the application of sustainable product development methods

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Abstract

A multitude of information is required to address sustainability aspects in product design decisions. However, information required for applying methods in the field of sustainable product development often overlaps. Moreover, specific improvement measures can primarily be identified if method results can be traced back to data origin. This paper presents a concept and implementation of an information platform which is integrated into a PLM system and integrates an ontology based knowledge model and a semantic wiki. The information platform shall avoid double work, improve documentation of information and assist in understanding the data basis of method results. This paper discusses requirements and solution elements and presents findings from applying the methods Lifecycle Design Strategies (LiDS) Wheel and the Product Sustainability Index.

Peer-review under responsibility of the scientific committee of the 23rd CIRP Conference on Life Cycle Engineering

Keywords: Sustainable product development, information management, ontology, IT- tool

1. Introduction

Product development determines essential characteristics and properties of a product and sets boundary conditions for subsequent lifecycle phases such as manufacturing and product use [1]. During the last decades many methods were developed to identify or assess sustainability relevant properties. Applying different methods with often similar concepts but different concept naming implies a high risk of double work and a lacking comparability.

In the project Collaborative Research Center (CRC) 1026 “Sustainable Manufacturing” 50 methods were analyzed which address sustainable product development. Several potentials were identified on how to support information management for those methods to avoid double work and improve their comparability. This paper presents identified potentials and proposes a solution architecture. This solution architecture has been implemented and tested based on the methods LiDS (Lifecylce Design Strategies) Wheel [2] and PSI (Product Sustainability Index) [3].

2. State of the art

A major share of published articles on sustainable product development sets a focus on the question how sustainability can be embedded into design processes of producing companies. Various means for supporting decision making of actors involved in the design process were developed (cf. [4]). Several authors proposed criteria for method classification, e.g. design stage appropriateness [5] or the type of given recommendation [6]. According to Baumann et al. corresponding design methods can be classified into checklists/guidelines, rating/ ranking tools, software/expert systems, methodologies as well as in analytic and organizational tools [7]. Checklists provide qualitative generic support for design synthesis but often lack of specitivity for supporting product dependent design decisions. Rating & ranking tools, e.g. LiDS-Wheel, enable simple comparisons between decision alternatives on a semi-quantitative basis, whereas analytical tools focus on quantitative assessment of

Peer-review under responsibility of the scientific committee of the 23rd CIRP Conference on Life Cycle Engineering
doi:10.1016/j.procir.2016.04.091

environmental/sustainability impact. Life Cycle Assessment, as an example for a mature and commonly used analytic method [8], is already supported by several software tools, e.g. GaBI or SimaPro and first approaches for integrating LCA into the engineering workspace (e.g. Solidworks Sustainability Pro) are available. Expert systems like the G.EN.ESI software platform & methodology support the interplay between design methods (in particular Checklists, Life Cycle Assessment, Life Cycle Costing, Social Life Cycle Assessment), specific models of lifecycle phases (e.g. disassembly) and PLM/CAD [9]. The approach GREENESYS [10] focuses on selection of design methods and tools based on the project context.

Leibrecht et al. developed an information platform which connects CAD, an assessment tool and a lifecycle modeler to assess the sustainability of product variants based on an LCA [11]. Since they pursue a quantitative approach the solution is primarily designed for embodiment design and detailed design (cf. VDI 2221).

3. Designing the information platform

3.1 Requirements and solution elements

In the course of a previous study 50 methods for sustainable product development (SPD) were analysed and classified [12]. Target of the study was to enable design engineers to select and combine existing SPD methods in order to prove sustainability related milestone targets in a development project. A case study was conducted which focused on the redesign of a turbocharger. Within the course of the development project the approach for combining different SPD methods was tested by applying nine design methods in requirements definition, conceptual and embodiment design.

The diversity of applied approaches was experienced as beneficial since it enabled a multilateral view on the product which cannot be achieved by one single perspective. An insight which was gathered in the course of the case study was a significant overlap of information which different methods require. Especially information considering the product lifecycle (e.g. lifetime or energy consumption of the product) needed to be specified for several methods. The main effort for applying a method is the search for information.

Often information sets required by methods are further not sufficiently specified, e.g. by factors which should be considered when assessing reusability of a product.

The analyzed rating & ranking methods deliver requirements on a product which can be considered from a sustainability perspective and provide a means to assess product properties in an early stage of product development. The requirements are associated to product properties (e.g. weight). Adoption costs of product characteristics increase during the course of a product development project. Requirements should thus be verified as early as possible. However, if only solution concepts or basic product characteristics such as a technology are defined, assessing product properties is related to a high effort and a high uncertainty. Rating & ranking tools use a semi- quantitative scale to estimate product properties. This implies, the magnitude is normalized to a scale, e.g. from 1 to 10. The normalization allows method users to combine sustainability indicators where quantitative values are available and indicators which can be only vaguely estimated.

Supporting the application of different rating & ranking methods was considered as most promising as those methods propose the highest flexibility especially in early phases of product development. The aim of the research was to design, implement and test a solution for an information platform which supports different rating and ranking methods. The solution is aimed at facilitating the application of different methods to get a more holistic view on the product and to reduce application time especially for information search. Table 1 displays the requirements which were derived from the case study [cf. 12]. They are arranged to the categories information management, specification of method concepts, specification of calculation and visualization.

Table 1 Requirements and solution elements

	Identified potential	Requirements	Solution concepts
A	• Different naming of method concepts or undefined links between concepts • Information must be inserted several times for different method	• Links between different concepts can be identified • Previously inserted values can be reused	• Information model to link concepts (ontology) • A database to store values for method concepts
B	• The meaning and calculation of method concepts is sometimes not specific • General method concepts must be adapted to product specific context	• Explanation of method concepts is provided on demand • Individual explanation can be inserted	• Semantic wiki which allows users to read and insert explanations and best practices
C	• Often factors are provided to rate an indicator but not how to calculate a value for the method concept based on these factors • Values must be calculated manually again once one factor is changed. • The combination of quantitative and semi-quantitative assessment provides high flexibility	• Provide a default calculation • Store the applied calculation parametrically to reduce effort if a value or criterion is changed	• User interface to insert information and define further criteria and the calculation of method concepts • Store default calculation in information base
D	• Only some methods propose visualization in a diagram.	• Allow method results to be visualized in a diagram	• User interface which offers different diagrams

A- Information management B- Specification of method concepts C- Specification of Calculation D- Visualization

3.2 Solution architecture and implementation

According to the solution elements identified in the previous section, the information platform consists of an user interface, an ontology, a database and a semantic wiki. The user interfaces allows method users to display and insert information required to apply the method and visualize results. An ontology captures information concepts which are required for method application and their relations. The semantic wiki explains information which is required and captures best practices, and the database stores values for specific method applications.

Similarities among methods, especially concerning the structure, was analysed to determine a model supporting method application and linking different method concepts. A method concept is referred to as being either an information (concept) which is required for method application or a structuring concept. The analyzed methods differed especially according to their structure to gather data, combine data and visualize results. The methods are mostly structured in a two dimensional array usually clustered according to the lifecycle phases as rows or columns (ERPA [13], MECO [14], PSI [3]) and according to further impact categories such as the triple bottom line based on society, economy and environment (PSI) or materials choice, energy use, solid residues liquid residues and gaseous residues (ERPA). Some of the methods (e.g. LiDS Wheel [2]) were only structured in one- dimension according to specific categories such as 'reduction of material'. The methods use a specific structure to organize the information which the user must gather und to identify hotspots associated to an impact category. Partially this structure is also used to visualize method results.

Each method is thus assigned with at least one impact structure. A method with one dimension is linked to only one impact structure. Methods which use a matrix are linked to two impact structures (e.g. lifecycle structure and triple bottom line). The impact structure is in return linked to impact categories, e.g. 'Lifecycle Structure' contains the impact categories premanufacturing, manufacturing, use and end- of-life. Each impact category is further linked to specific indicators (e.g. 'premanufacturing' to 'material emission'). Each indicator can be also associated to further impact categories (e.g. 'material emission' to 'environment'). Indicators are determined by further factors (e.g. 'material emission' by 'CO2 emission in material extraction' and 'amount of hazardous substances to the environment'). The factors must be combined based on a formula to determine a value for the indicator. This formula is either based on physical relations or on heuristics. Ideally factors can be directly linked to a value in a data storage (e.g. CO2 emission /kg or weight). Figure 1 displays the different concepts.

To identify similar concepts the relations between different concepts must be captured and serialized. Ontologies are often

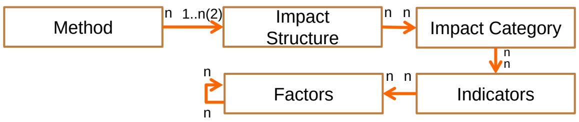

Figure 1 Meta model for structuring information concepts

used as a data and serialization format, if managing and traversing relations is emphasized. The meta concept (extract in figure 1) and specific indicators were stored in the ontology format owl (ontology web language).

The owl format distinguishes between class concepts which can be seen as meta- concepts and individuals which are specific instances of one or more classes. There is the option of modelling all method concepts on class level or modelling sufficiently specific concepts on individual level. The first option allows to easily instantiate a concept, e.g. weight of a specific pedelec frame based on the class concept 'weight'. The second option avoids creating long relation names, e.g. to specify indicators related to the impact category 'Manufacturing' would require a term such as 'Manufacturing_has_associated_indicator'. Creating all relations on class level requires multiple relations. Modelling indicators on individual level only requires one 'has_associated_indicator' relation which can be used for all methods. This increases understandability and maintainability of the ontology. Since values for a product will not be stored in the ontology itself, specific methods, indicators and factors are stored on individual level. Figure 2 displays the java code used to iteratively extract method concepts based on the Jena framework. The relations are extracted as 'Statements' (triples which contain subject, predicate, object), e.g. {'Initial_life_time', 'has_Factor', Modular_product_ structure). The code extracts in this case all relations which have 'Initial_life_time' as subject and extracts all objects. The order of impact categories associated to one structure is stored in the ontology as a string.

```
//NS = http://www.semanticweb.org/pfoeanne/ontologies/2016/0/MethodOntology#"
//verify if relation named "has_Impact_Structure" exists for the method (ontmethod)
if (ontmethod.hasProperty(prop=model.getOntProperty(NS+"has_Impact_Structure"))){
 StmtIterator structiter= ontmethod.listProperties(prop);
 //iterate over all property values to get all related structures
 while (structiter.hasNext()){
    struc=new Structure((structure=structiter.next()).getResource().getLocalName());
    method.addStructure(struc);                          //assign structure to method
    ontStruc= model.getOntResource(NS + struc.getName());
    //get all associated impact categories to the structure
    prop=model.getOntProperty(NS+"has_Associated_Impact_Category");
    //Impact categories, indicators and factors are associated likewise
 }}
```

Figure 2 Code snippet for extracting indicators from ontology

In previous work a software tool was developed to select suitable methods depending on the purpose of application. This software tool was integrated into the product data management (PDM) software Siemens Teamcenter. The access to the information platform was also integrated into this plugin. This allows selected methods and data stored within this PDM system to be directly accessed.

The case study revealed, the process of determining indicators was often not well described especially for product-specific indicators. A semantic wiki was conceived to provide general descriptions for indicators and provide space for describing company specific best practices and knowledge. Two feasible options were identified. The ontology which was created can be used as a basis and comments and descriptions for a concept can be stored as annotations. This way, only one information basis is used. On the other hand existing open source software for a semantic wiki can be used such as Semantic MediaWiki (http://semantic-mediawiki.org/). This way, a tested software is used which already includes server functionalities and web access.

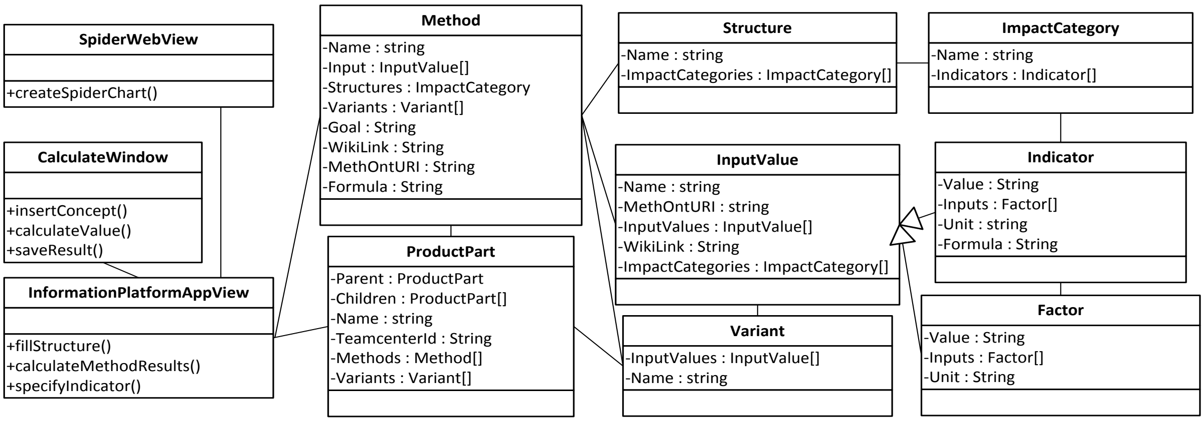

Figure 3 Class Diagram

The semantic wiki was implemented based on the Semantic MediaWiki to avoid the risk of failures and programming effort. The concepts described within the semantic MediaWiki are linked to concepts of the ontology by storing the respective wiki URL as 'WikiLink'.

Figure 3 displays the UML class concept for the information platform. A method (instance) is assigned to a product part. Available product parts are derived from Teamcenter by extracting a respective product structure. The user selects a product part which shall be analysed and assigns a suitable method. Rating & ranking methods are primarily used to compare different variants. The user can thus specify different variants for the product part. For each variant an equivalent set of input values (indicators and factors) is instantiated based on indicators and factors specified for the method. The input values are derived from the ontology. The class InputValue was defined as an abstract class to offer the possibility to add further information relevant classes.

The InformationPlatformAppView allocates indicators to their correct cell determined by their impact categories and displays indicators in a table with one or more columns. Figure 4 depicts the user interface to manage information required by a respective method. The user can click on the cell 'link' next to an indicator, such as 'Material emission' and a new user interface is opened (CalculateWindow). Default factors (previously derived from the ontology) are displayed. The user can add new factors which seem more suitable for his/her context. Documents can be linked. In a dedicated field the user specifies how the factors are combined. The entire rating is normalized to the scale of 10. The combination must thus still have a maximum value of 10. The value is then displayed within the table.

The method results are visualized in a spiderweb diagram as proposed e.g. by LiDS Wheel and PSI. The results are visualized according to the structure of the method (cf. section 4). If the structure is a matrix, several spiderweb diagrams are created according to one impact structure (e.g. according to social, economic and environmental impact).

4 Application to ProdSI and LiDS Wheel

In the course of the collaborative research project CRC 1026 a peledec was developed. During the development, a drive concept was selected. Three different alternatives were generated. The application case was used to test the concept and implementation of the information platform. The methods LiDS Wheel and PSI were selected. LiDS Wheel is a widely recognized method and PSI proposes a flexible framework allowing a comprehensive set of indicators to be integrated.

LiDS wheel is a simple method to assess the progress of a

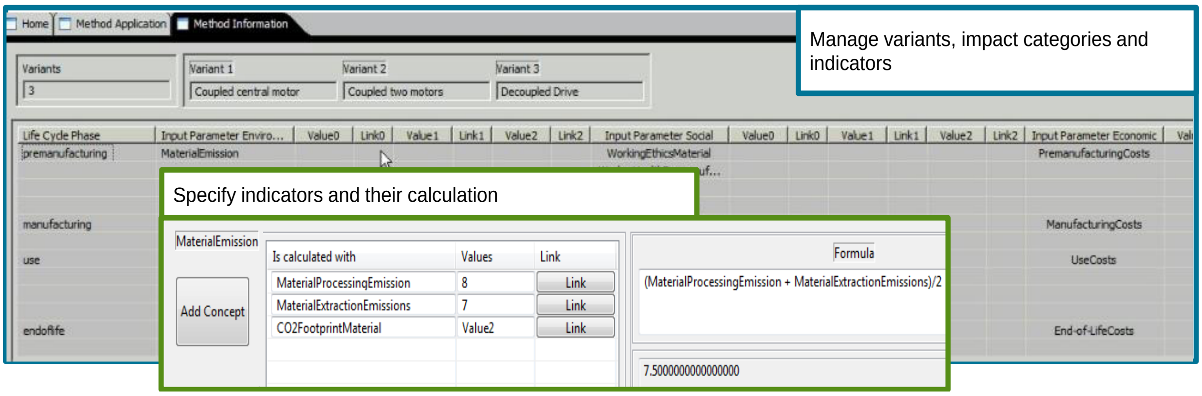

Figure 4 User Interface

company made towards developing sustainable products based on eight strategies e.g. 'optimization of production techniques'. The strategies were considered as impact categories. The criteria associated to a strategy were considered as indicators.

The product sustainability index proposes a framework to assess the sustainability of a product or product part. In previous publications, the framework was considering influencing factors allocated to the lifecycle stages premanufacturing, manufacturing, use and post-use and to the triple bottom line economy, environment and society. The index was abbreviated PSI [3]. In a subsequent publication the index was abbreviated ProdSI and five different levels for influencing factors were introduced- sub- index, cluster, sub-cluster and individual metric [15]. The lifecycle stages were not explicitly considered. Both frameworks are similar. However, PSI was designed to assess product design and ProdSI to assess a manufactured product [15]. The separation of indicators according to the lifecycle stages is assumed to be beneficial to identify improvement potentials which are e.g. directly linked to manufacturing. The first version PSI was consequently chosen to select the drive concept.

PSI allows indicators to be selected according to a specific context, e.g. product. Some adaptions have been made to the indicators proposed in [3]. PSI used product pricing in the use phase as a social impact. Product pricing has also impact on the economic dimension. It was thus renamed in 'Affordability' to only consider the social dimension of product pricing. The renaming was documented in the ontology as an annotation and within the semantic wiki. The economic dimension of product pricing was not reflected in the PSI matrix. The indicator 'market value' was thus introduced to include factors such as ROI.

Functionality is in PSI assigned to environment. However, functionality is directly linked to customer value and was thus assigned to the social dimension. As a compensation, initial lifetime, derived from LiDS Wheel, was considered as indicator which is also related to functionality. The costs were aggregated to one indicator per lifecycle phase and the specific costs were described as factors. The indicator cradle to cradle was defined to combine remanufacturability, recyclability, landfill contribution, and incineration.

This avoids having an indicator for each where each indicator must be rated separately and not the ability to recirculate components and substances itself.

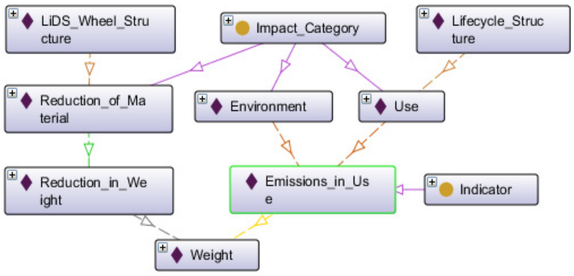

Figure 5 Extract from ontology for PSI and LiDS Wheel

An example were LiDS Wheel and PSI could be linked is displayed in figure 5. The weight is a central information which is relevant for determining the factor 'reduction of weight' of LiDS Wheel. At the same time weight is determining the CO2 emission in the use phase. Several further links could be identified. The indicator 'end- of- life system' by LiDS Wheel is almost equal to indicators of the matrix cell determined by post- use and environment by PSI. Clean energy source by LiDS Wheel is linked to emissions in use by PSI. The modular product structure indicator of LiDS Wheel is directly linked to the upgradeability proposed by PSI. The indicator can be determined, e.g. by number of modules and percentage of separable connections.

The analysis identified 9 method concept pairs which could be directly mapped whereof 5 were used in the application case. 4 method concepts, whereof 3 were used, were identified in LiDS Wheel which can be additionally integrated into the structure of PSI. Data required to determine indicators was derived from different IT-systems and databases. The Granta Eco Audit Tool was used to determine the CO_2 emission for a component. The weight was derived from a CAD model or, if not available, by researching the weight of similar components. The CO_2 emission was aggregated for all components and normalized on a linear basis to a scale from 1 to 10. The Gini coefficient (Database Worldbank) was used to determine work ethics. Toxnet was used to identify toxic substances materials. Different metrics were used to determine e.g. disassembly friendliness.

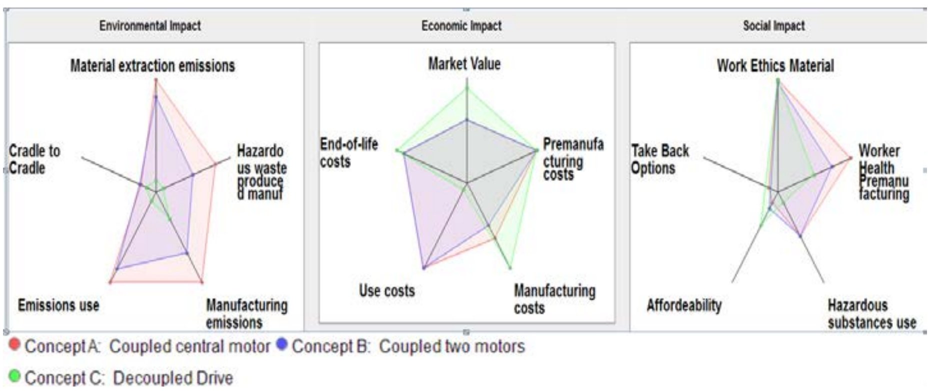

Figure 6 Spiderweb View: PSI results

Other indicators such as ‘willingness to pay‘ as a factor for market value were subjectively rated. Results for PSI are displayed in figure 6. The application case showed that the different views provided a better understanding of the impact. PSI provided a better and more holistic understanding of the effects of different variants on the lifecycle phases and triple bottom line while LiDS Wheel provides better understanding of improvement potentials due to their strategy orientation and partially more product oriented indicators like ‘reduction in weight’.

5 Discussion and outlook

Based on the proposed ontology several method concepts could be linked within one method to facilitate the identification of relevant indicators and factors and to facilitate the automatic calculation and visualization. The application case revealed that method concepts can be also linked among different methods. This will especially support the application of methods at different points of time or by different users but can also make methods whose indicators are not fixed such as PSI more holistic. The different views offered through the methods were experienced as beneficial. The use of the ontology also lead to a clearer understanding how reference data such as weight of a similar component or a CO2 emission/kg are integrated into the overall assessment. However, further browsing and analysis functions are necessary to identify critical factors/product properties.

The application case considered three fixed variants. A generic parametric formula was thus not yet required. Generic parametric formulas, though, are for most indicators difficult to determine and require further research.

The information platform assists in specifying indicators and factors for a company’s own products and in formalizing best practices in an ontology and in the semantic wiki. In future research, once the ontology is filled with several methods and its concepts and the semantic wiki provides a sufficient amount of descriptions, the information platform including the semantic wiki will be further tested.

The entire ontology knowledge could have also been stored directly within the plug- in. However, an ontology can be also accessed and maintained by software such as Protégé by non-IT personnel. It allows a higher separation of method knowledge and the application itself.

Linking values from data storages (PDM, environmental database etc.) can increase transparency and provide up-to-date data. Right now only documents can be linked.

The information platform was designed to support one design engineer to select sustainable variants and to identify improvement potentials. The platform must still be extended to allow further users (e.g. sustainability experts) to insert information.

Considering components on assembly level is only supported by adding concepts for components as factors in the calculation window and specifying how this data is integrated into the calculation on product (assembly) level. Especially for visualizing impacts and its sources, the information platform should allow to specify components in assemblies and conduct a visually separated assessment of components.

6 Conclusion

The concept and implementation of the information platform provides a suitable basis to facilitate the application of rating & ranking methods and to combine information from different methods. However, to fully exploit the potential, the combination of different product parts, distributed access for different persons and improved support to identify potentially relevant information and data must be implemented.

Acknowledgements

This research has been funded by the Deutsche Forschungsgesellschaft based on the Collaborative Research Center 1026- sustainable manufacturing.

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