Integrating LCA into PDM for Ecodesign

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Abstract—Product Data Management (PDM) systems for Computer Aided Design (CAD) file management are widely established in design processes. This management system is indispensable for design collaboration or when design task distribution is present. It is thus surprising that engineering design curricula has not paid much attention in the education of PDM systems. This is also the case for eduction of ecodesign and environmental evaluation of products. With the rise of sustainability as a strategic aspect in companies, environmental concerns are becoming a key issue in design. This paper discusses the establishment of a PDM platform to be used among technical and vocational schools in Austria. The PDM system facilitates design collaboration among these schools. Further, it will be discussed how the PDM system has been prepared in order to facilitate environmental evaluation of parts, components and sub-assemblies of a product. By integrating a Business Intelligence solution, environmental Life Cycle Assessment and communication of results is enabled.

Keywords—CAD, Engineering Design, Design Education, Product Life Cycle, Sustainability

I. INTRODUCTION

THE use of Product Data Management Systems (PDM) in industry is becoming an integrative part of the design process, in particular in the design of complex products [1], [2]. Looking at various job postings for engineering designers, knowledge about PDM systems shows to be a more and more demanded qualification asset. It is thus surprising that in Austria, this aspect of the engineering design process is almost not existent in the curricula of technical and vocational schools or even universities. The focus lies on the handling of one or several CAD systems rather than the management of CAD data along the design process [3]. As a consequence of this educational system, almost no design collaborations between students are taking place during their education. In other words, the design education is favoring the raise of individual designers rather than designers who are able to collaborate and work in teams.

Technical and vocational schools in Austria have an important role in the education of technically skilled employees. Engineering design is part of the curricula of many technical disciplines taught in these schools. Although the curricula are homogeneous for the different schools and almost the same content is taught, there is barely any interaction or interdisciplinary collaboration in design projects between the schools.

To advance collaborative design projects among these schools, Vienna University of Technology has started to establish and maintain a PDM platform by cooperating with several national technical an vocational schools. Since most of the collaborating schools are using ProE Wildfire from the company PTC as their preferred CAD system for engineering design education, the PDM platform solution from PTC, named Windchill, is used within the project [4]. One of the cooperating schools is using Autodesk Inventor as their preferred CAD system. The interaction between ProE and Windchill works smoothly, as the two systems were developed by the same company. Nonetheless, various other CAD systems can be used with Windchill too, but may show shortcuts in some functionalities.

Windchill provides a raw platform for data management which then has to be adapted to the specific needs and requirements of its particular users. In the first step of the project, the usability of the platform was adapted to the needs of the schools. In a second step, the PDM platform was successively integrated into the design process. A particular aim in this step was to allow students to focus on the environmental aspects of their design and to reduce the environmental impacts of their design over its entire life cycle. Life Cycle Inventory Data (LCI) was integrated into the PDM system to allow environmental Life Cycle Assessment through PDM.

This paper discusses how the PDM platform has been prepared in order to share information among the technical and vocational schools. In particular it is discussed how the Windchill platform has been manipulated to allow basic environmental LCA of product parts and assemblies. An open source reporting tool, named Pentaho, has been integrated into the PDM system for presentation of results. A case study of a cordless drilldriver that was jointly designed in the high schools will be introduced to demonstrate the functionalities of the PDM platform and the experiences gained through its use.

II. STATE OF THE ART

The appearance of CAD systems posed a new era in engineering design. It facilitated the creation of digital geometric models of a product. To handle those digital files, PDM systems appeared during 1980s which originally focused on solving the problems of CAD file management by providing a data vaulting facility. By then, PDM systems were limited to the engineering aspects of a product.

Today, the concept of PDM is enhanced and PDM systems are an integrative part of Product Lifecycle Management (PLM) systems. The term PLM emerged in the late 1990's.

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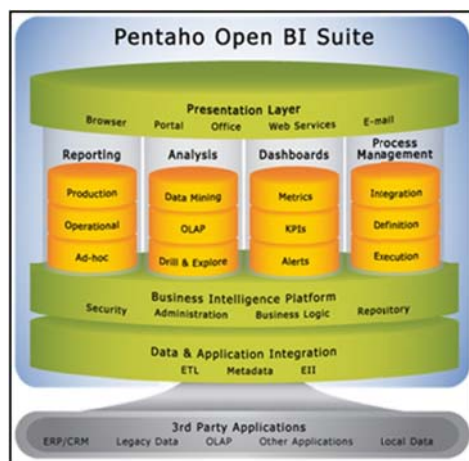Vol:5, No:9, 2011

Fig. 1   Pentaho architecture [8]

It is a development and management strategy focusing on all aspects related to product development [5]. PLM systems constitute a consistent set of business solutions which support collaborative creation, management, dissemination and use of product life cycle definition information across the extended enterprise, integrating people, processes, business systems, and information [6].

Windchill is a web-based system and facilitates enterprise-wide access. It supports geographically dispersed teams while managing critical processes such update-/configuration- management and release to manufacturing [4]. In particular, Windchill has some other features that pose a strategic advantage for the project conducted. Without a doubt, its seamless interaction with ProE for site-and cross-company cooperation in data collection and compilation of product information, was seen as an asset.

To extract, visualize and communicate particular information and analysis results, a reporting application needs to be integrated.

Such reporting tools are known as *Business Intelligence (BI) and reporting* tools. In the early 1990's the term "Business Intelligence" appeared. *Intelligence* refers to understanding, insight, intelligence and search [7]. BI systems usually have three main purposes:

1) Provide data
2) Analyze data and
3) Present data

In the scope of this project, an open source BI system from Pentaho [8] has been used. Pentaho provides all necessary features which are relevant for this project, i.e. complete package for reporting that runs under different operating systems. An other benefit is the existing community that supports the user.

The architecture of the Pentaho BI Suite is shown in Fig. 1.

Pentaho is a client-server architecture and consists of several modules; each module consists of individual components. The heart of the architecture of Pentaho BI Suite is the Pentaho BI platform, which is responsible for coordinating the various modules. It provides the complete infrastructure to be able

to integrate a BI solution. Server components (engines) are responsible for coupling the modules to the BI platform. The modules of the Pentaho BI Suite can also be used separately without being connected to the Pentaho BI platform. This is due to the open architecture of Pentaho BI Suite.

The reporting module consists of three components: Pentaho Reporting Engine, Report Designer and Report Wizard. The most important component of this module is the Report Designer, which facilitates the creation of reports. Thus, Pentaho is used to analyze data, proceed with environmental assessment and visualize the assessment results.

With the rise of sustainability as a strategic aspect in companies, environmental concerns are becoming a key issue in design [9]. Reducing the environmental impacts of a product over its entire life cycle have been given different names such as ecodesign, green design, Life Cycle Design (LCD) or Design for Sustainability (DfS) amongst others [10], [11], [12].

The public is becoming more and more aware of the concept of sustainability. Issues like energy consumption or CO_2 emissions have gotten introduced in public culture, and designers, product developers and manufacturers cannot neglect their influence in the purchase decision.

To ensure that engineering designers are focusing on the most relevant aspects of their product, environmental information is necessary. It is therefore common practice to start any ecodesign process with some sort of environmental assessment. Life Cycle Assessment (LCA) is one of the most widespread methods for this type of assessments [13], [14], and even in cases where it is not fully applied, its principles are generally considered [15], [16], [17]. Many design methods were "environmentalized" and some other new ones were generated [18], [19], [20]. Gómez-Navarro et al. [21] speak about more than 60 categories of methods, many of them with several tool implementations. Some barriers such as data requirements, difficulty and time-consumption withhold LCA from being common practice in the design process [22]. To address these barriers, many efforts have been carried out to simplify the process. Different databases, such as those provided by Ecoinvent [23], shortens the time needed to get to a preliminary result. Some tools combine environmental databases with quick assessment tools, such as the assessment tool developed by Goedkoop et al.[24] or the tool Greenfly Online [25]. Ostad-Ahmad-Ghorabi et al. [26] parametrize the product to extrapolate results for similar products. Sousa and Wallace [27] and Sousa et al. [28] aim at creating groups, for which a neural network can be trained to give LCA results.

Luttropp and Lagerstedt distinguish between tools which can be used when product specification is being developed and tools, which are applicable after the product specification phase [29]. It shows that the early design stages have the greatest potential for environmental improvement of a product. Many authors have proposed tools and methods that bring the environmental assessment to this point of the design process [30], [31]. To avoid excessive use of multiple tools and to avoid increase in workload for engineering designers, some efforts have been undertaken to integrate environmental assessment into CAD Systems. Both worlds, engineering

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design and CAD systems on the one hand, and LCA and LCA software on the other hand, have strong relationships - especially when Ecodesign is to be implemented - but they are not necessarily connected. Poyner and Simon [32] proposes a tool that presents the designer with a set of ecodesign strategies from an expert system and aids in the management of the improvement proposals, including an effort to export information to LCA software. Roche [33] developed a CAD-integrated assistant that delivers ecodesign advice. In both cases the link to LCA is external. Ostad-Ahmad-Ghorabi et al. [34] introduce an approach by which LCA could be directly integrated into CAD systems.

Some efforts have also been undertaken by industry, such as Dassault Systems for its CAD System Solidworks, where a module named *SustainabilityXpress* [35] is part of the standard installation. It allows an environmental evaluation of the part or assembly drawn in the CAD system. SustainabilityXpress gives direct feedback to the engineering designer about the environmental performance of the concept being developed.

A major drawback of all the proposed approaches for CAD integration is that they strictly depend on the CAD system used. In other words, results generated in one CAD system can not be shared and further processed on some other CAD system. This requires the entire team, including the supply chain, to work with the same CAD system.

Obviously, this drawback poses a serious constraint in the conducted project where different schools with different CAD systems were supposed to collaborate. It also poses a constraint for industry, should the supply chain of a accompany running a different CAD system than the company itself. An effective way out of this constraint is to integrate environmental analysis on PDM level rather than on CAD level. On PDM level, CAD data, independently of which CAD system has been used, is stored. This data can be retrieved and further analyzed. In the next sections the method and approach used to manipulate those data will be introduced.

III. METHOD AND TOOLS

In order to be able to assess CAD parts and assemblies from an environmental point of view, in a first step, a database containing product life cycle impact category indicator results was integrated into Windchill. The database used is Ecoinvent [23]. The PDM system architecture is shown in Fig. 2. The impact indicators chosen for the assessment are those for global warming expressed in $g - CO_2 - eq$ (gram CO_2 equivalents) and Cumulative Energy Demand (CED) expressed in MJ. There are many categories that express environmental impact. Experiences from previous projects of the Institute for Engineering Design of Vienna University of Technology (VUT) with youth aged between 15 to 18 indicate that global warming and energy demand are the most tangible categories for these ages. This is also due excessive awareness raising campaigns of media for these two impact categories.

In a second step, the data structure in the PDM system was extended to contain additional meta-data for the stored CAD files. Extended meta-data contain a set of parameters through which the complete LCA inventory can be modeled.
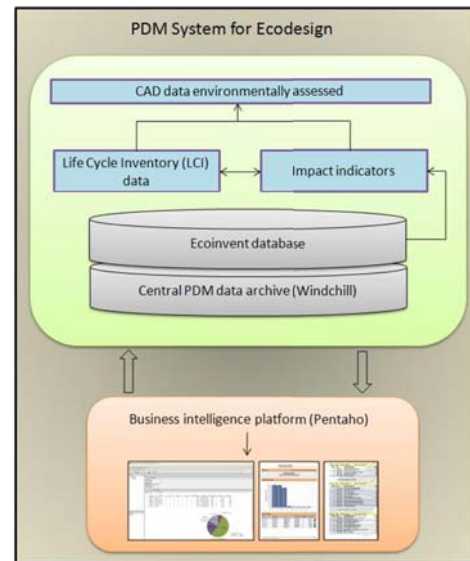

Fig. 2   PDM system for Ecodesign

The approach followed to define those set of parameters were similar as to the approach defined by Ostad-Ahmad-Ghorabi and Collado-Ruiz [36], but for general products rather than specific ones. The idea is to set up a generic *parametric model* valid for different product designs to describe the LCA results out of a reduced set of parameters that are known in the early design stages. To be able to assess the products environmentally, following life cycle information for each designed part has to be known:

- Materials stage: weight of the materials used.
- Manufacture stage: manufacturing processes and their quantities, auxiliary materials and their quantities, transports during manufacturing including transport mode and distance, wastes and their quantities and overhead energies .
- Distribution stage: packaging used, transport modes and distances.
- Use stage: lubricants and their quantities. Energy use of the product and additional components can only be allocated to assemblies, not to a single part.
- End of life stage: end of life treatment scenarios.

Some of the parameters above can already be defined in a CAD system. For example, the material of a given part can be specified. A CAD system is then able to calculate the mass of the part out of its geometrical data and material specifications. These data can be transferred to the PDM system.

Another approach is to define all parameters in the PDM system rather than in the CAD system. Parameters can be transferred from the PDM system to the CAD system and vice versus. This approach works smoothly for different CAD systems, as first experiences with Windchill indicate. Some parameters however, can not be defined in a CAD system and have to be specified manually, e.g. transport during manufacturing.

Once parameters were defined and the environmental database was integrated, the aim is to use the chosen Pentaho

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BI tool to access all CAD data as well as meta-data and use them for further analysis. This third step appeared to be a difficult to handle step.

Pentaho Report Designer needs appropriate queries to in order choose the desired data. Further, the Report Designer has to be told how to analyze the data. To configure the queries, it has to be clear were in the PDM system the required data is to be found. Unfortunately the database structure of Windchill proved to be a black box, and the Entity Relationship (ER) model was not visible. In other words, it was not clear where the required CAD data and related meta-data where stored and how they were linked. Proper documentation was lacking.

To understand the ER model of Windchill, reverse engineering was applied. Reverse engineering of a relational database refers to the process of developing an ER model out of table and data structures of a database. Various logical circuits and scripts were developed and inquiries were send into the black box. With the help of these scripts and by conducting intensive trial and error, successively all relations were identified and the required CAD data including meta-data were sourced. Also the hierarchical structure of the files were determined, i.e. which product sub-assemblies/ parts belong to a certain assembly.

The result of the reverse engineering approach was an ER model of the relevant portion of the database structure, which also allows an outsider to understand the contents of the data and reconstruct the model if necessary. The new model was then enhanced to contain environmental data and LCI data.

The original model contained approximately 730 different tables, containing almost an unaccountable amount of data. Out of this amount, some 15 tables were sourced which contained those CAD data and meta-data relevant for the environmental assessment of the parts and assemblies. Interdependencies of these 15 tables with other tables were thoroughly documented. It proved that by taking data listed in those 15 tables, an LCA can be carried out.

IV. Results

With the help of the new ER model, a final script was programmed. The script is able to access specific data once the user starts to generate queries for reporting purposes. The script retrieves data from the 15 sourced tables, reads out all necessary environmental parameters for environmental evaluation and processes with the algorithms to conduct an LCA. The environmental database, the query for environmental parameters and the reporting tool were integrated into the Windchill PDM system and has been provided to the collaborating technical schools in Austria. The PDM system further allows the storage and exchange of CAD data within and among different schools.

By integrating a database containing Life Cycle Inventory data and impact category results, environmental assessment of product parts and assemblies has been facilitated. Each design decision taken through the design process can be easily evaluated as to its environmental impact and if necessary, be optimized. Different design concepts can be compared in regard to their environmental performance, since each concept can be analyzed with the help of the BI tool and results can

be stored in the PDM system. Parts and components as well as a whole product assembly can be evaluated, independently of whether the same or different CAD systems has been used to draw parts and components.

V. Case study

A cordless drilldriver was taken as a case study to test the performance of the provided PDM system. The screw driver was grouped into four main components:

1) Housing
2) Drill chuck
3) Gear and
4) Power unit

Each component was designed by one of the collaborating high schools. The aim was to develop a new, environmental friendly screw driver. Within the project, the requirements list for each component was defined, a functional analysis performed and a concept was developed. In parallel, it was aimed to find a concept with the least possible environmental impact.

Except the power unit which was drawn by using Autodesk Inventor, all other components were drawn in ProE. Each school formed a team of several students (designers) to proceed with the development of their component. Windchill was used for both, the internal management of design data and for exchange between the different schools. Only the final concept was made public for the other schools.

The different components stored in Windchill were then assembled to form a complete screwdriver. The students were supposed to define each environmental parameter queried through Windchill and generate an environmental report. Fig. 3 shows a screenshot of this report for the example of the gear component and the its life cycle stage materials. All parts and components of the gear and their material composition are listed. Mass of each component in kg and environmental impact in MJ are calculated by Pentaho Report Designer by using the developed queries. A graphical representation of the environmental impact of each part is also given.

Such reports can be generated for each single part, for each subassembly as well as for a product assembly for each particular life cycle stage (materials, manufacture, distribution, use and end-of-life)

The final report can be generated by starting the Pentaho server and query a particular report. The queries were those generated by reverse engineering.

VI. Conclusion and Outlook

Experience with students in technical schools, aged between 15 and 19, proves that issues such as sustainability are a serious concern to them. However, it is difficult for the students to relate the concept of sustainability to the topics of their curricula, to what they learn and how their acting as engineering designers contributes to environmental impact.

By providing a basic insight in ecodesign to the students, the demand for a tool that allows for sustainable product development was posed. The integration of LCA into PDM system had a twofold advantage: education in the use of PDM systems and education in the field of ecodesign was provided.

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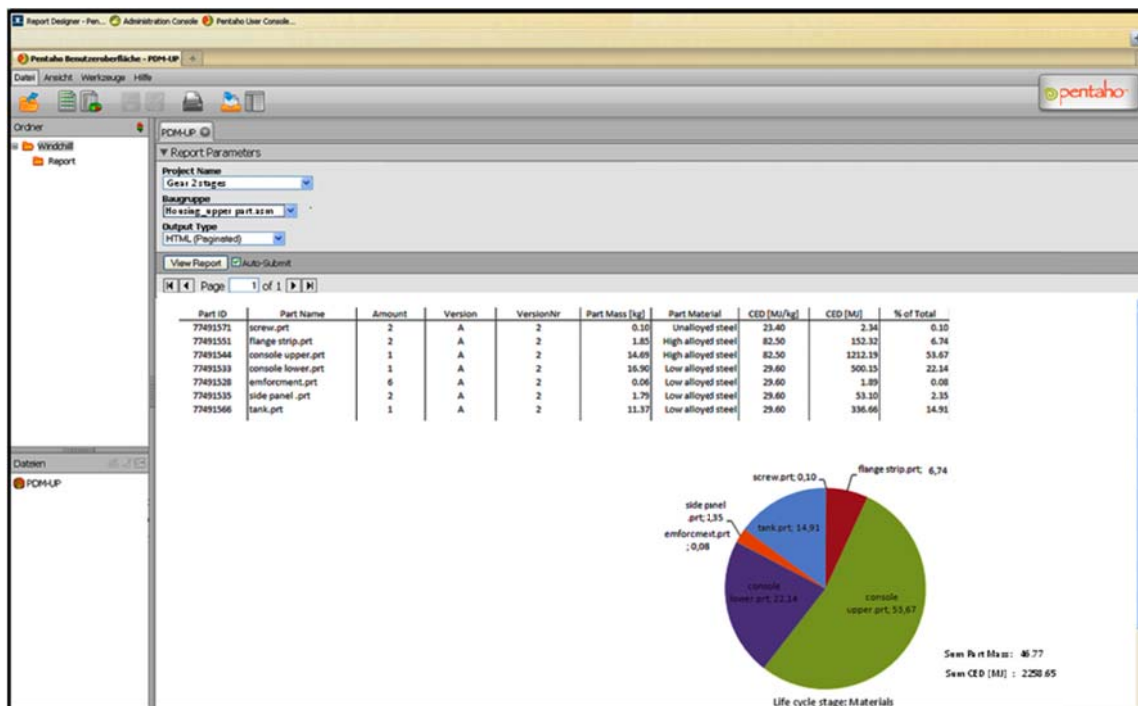Vol:5, No:9, 2011

Fig. 3   Report screenshot

In the next steps within the project, the usability of the provided system will be elaborated in more detail and will be adapted to the specific requirements of the potential users, hence students.

For future work, several improvements of the system will be carried out. The most important step is to take some effort to optimize the handling and use of data. Semantic networks can be established which can make use of a common ontology for knowledge management. Ontologies describe a knowledge domain by making use of standardized terminologies, relations and rules. With ontologies, the complex data structure of the database can be managed more efficiently. It also helps to optimize search queries by making use of semantic networks.

An other path to be taken in future is striving from a solely PDM system to a PLM system. This becomes in particular an interesting approach when more high schools are going to collaborate in design projects and when design tasks are widely distributed.

In the current version of the platform, manual data input is necessary. In particular, the definition and quantification of some environmental parameters may pose some difficulties for an unexperienced user. The integration of some sort of assistant that can help in the choice of appropriate data is highly desired. Currently, the verification of data input by an ecodesign expert is indispensable.

Finally, the project has potential to be extended for design collaboration among international technical high schools or an implementation in technical universities.

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