Integration of Environmental Assessment Functions in Design and Product Development Tools

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ABSTRACT

This paper presents a computer-based environmental tool that will make it possible for product designers to integrate environmental assessments into their work. The environmental tool described in this paper is a concept for integrated environmental assessment functions in design and product development tools. The concept presents a way of reducing modelling time by making simplified assessments. The concept, and finally the environmental tool, is based upon companies' demands and wishes regarding how a tool for making environmental assessments during the product development process might be useful for them. The intended user is the company product designer.

Keywords: environmental impact assessment, product development, support tools.

1. INTRODUCTION

Environmental aspects must be integrated into the product development process, and at an early stage – when it has the biggest impact on the product [5]. This also [7] means that it is important to measure or estimate environmental impact as early in the design process as possible, since much of the environmental impact of a product is determined during the early stages of design. This is why the product designer is a key function when it comes to making environmental assessments.

An accepted method for making environmental assessments is life-cycle assessment (LCA) – which is a common tool in the industry nowadays, although often said to be too complex and time-consuming. LCA is normally used by experts, and the results are seldom utilised in everyday product development work. There are also many other approaches to assisting the designer, i.e. qualitative environmental assessment tools, Design for Environment (DfE) guidelines, and different kinds of databases. These kinds of tools are very important for raising the product designer's awareness, but they also have limitations [4].

In order to help product designers to create more environmentally friendly products, a project was initiated by Trätek (the Swedish Institute for Wood Technology Research), together with IFP Research (the Swedish research institute for composites, fibres and textiles, plastics and rubbers), and KTH (the Royal Institute of Technology in Sweden). The purpose of the project, which is still running, was to develop a life-cycle based environmental tool for product designers. The environmental tool is based on CAD, PDM and LCA support tools, and is intended to give the product designer an indication of the reason for and magnitude of environmental impact. The objective of the tool is to make product designers aware of how choice of material influences the environment, and how they – in their product-design work – might create more environmentally friendly products. For example, if a designer is comparing two different product concepts, the tool helps the designer easily –from an environmental perspective – to find weaknesses, and take a decision on which concept to prefer.

This paper describes just parts of the project. It includes a description of the product development and environmental work of five selected companies, which all participated in the project. The companies' demands and wishes provided the starting-point for developing a tool for the product designer. These requirements, the developed tool, and the process for developing such a tool are all encompassed by the paper.

1.1 The product development process

The product development process or design process is complex, and several authors have developed more or less equivalent models to describe or guide it [1,8,13,14,18].

Product development can be described as a process, which translates an idea into a product and brings it to the market. It is an interdisciplinary activity involving different functions within an organisation. Despite this, *market, design* and *manufacture* are almost always crucial to a project of this kind [18].

Most manufacturing companies have some form of structured product development model that accords with the definition above and the phases described below (see Fig. 1.) A well-defined development process is useful in the following respects: *quality assurance* of resulting products, *co-ordination* of the people involved, *planning* for anchoring the time schedule, *management* for identifying possible problem areas, and identifying *improvement* areas through documentation [18]. This paper provides a product development model that describes the different phases, separated by checkpoints.

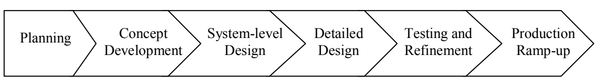


Fig. 1. The product development process and its phases, derived from a variety of models.

1.2 Support tools

Support tools are important ingredients in product development. Support tools are typically defined as an artefact, in the form of a software program or written set of guideline that supports a specific aspect of product development work [2]. In this paper, a support tool refers solely to a software program.

1.2.1 Computer Aided Design (CAD)

Computer Aided Design means that design and drawing work is handled with the help of an interactive graphic computer system. A geometric model of the product, i.e. a description of the product's geometric form in the computer, is created within the CAD system.

There are different ways of representing a product's geometry, but – for this project – only a solid modelling system was used. A *solid model* is the most complex type of geometric model, which provides a complete geometric description of the product. It describes the details' edges, corners and surfaces, and also the inside and outside constituents of the model. The extensive geometric information creates an enormous number of possibilities in CAD-related work. Virtually all large CAD systems have drawing and document management add-ons, but sometimes these are not sufficient to satisfy the need for managing the data created by the process.

1.2.2 Product Data Management (PDM)

A PDM system offers technology to satisfy the need for managing data related to the product development life-cycle. The need has become obvious as sophisticated and automated design tools (e.g. CAD systems) have become available, and as the amount of data accumulated about the designed artefact has increased dramatically [2].

A data management system basically stores data about data, which – in most cases – are stored files. The concept is usually referred to as "metadata". Typical metadata for a file may be the name of the file and where it is located, the type of information in the file, and other useful information – such as who created it, and when and where it was created [17].

Basic functions of a PDM system are [2]:

- *Design Release Management,* the process of controlling design data with check-in/check-out, release level maintenance, access security, and review and approval management.
- *Product Structure Management,* the ability to define, create, modify and display multiple versions of product structure.
- *Change Management,* the ability to define and manage data over the life-cycle.
- *Classification*, the ability to classify parts by their structure, function or processes for future manufacturing.
- *Systems Management,* the use of project-oriented scheduling techniques with work breakdown structures that should be able to manage any facet of systems design.
- *Impact Analysis,* the ability to detect the effects of a design change on the overall product life-cycle.

1.2.3 Life-Cycle Assessment (LCA)

Life-cycle assessment is a method of assessing environmental impact through a product's life – from raw material acquisition, through production and use, to disposal. LCA is a form of systems analysis for quantifying industrial processes and products by enumerating flows of energy and materials [15]. A life-cycle assessment has the following inter-related components: *goal definition, inventory, classification, evaluation, and improvement analysis* [15]. There are a number of different impact assessment methods based on different philosophies, e.g. the EPS system, the Swiss Ecopoints model, and Eco-Indicator 95 [4].

1.2.3.1 The EPS system

EPS is a system that adopts a holistic approach to the assessment of the environmental impact of products. It supports the valuation (classification and evaluation) phase in a LCA. It is developed on the basis of quantifying environmental indices for the consumption of natural resources, effects of emissions, materials and processes. The values obtained provide a product-relative measure of environmental impact during the entire life-cycle [16].

2. PROJECT DESIGN

The companies participating in the project were selected on ground of their intention to implement more systematic and active environmental work. Such environmental work was to be concentrated on product development, although the companies had earlier worked on routines for environmental control and improvements to production. In total, five companies from the furniture and joinery industries participated.

The project was divided into three phases, the first two of which are covered by this paper. The phases are illustrated in Fig. 2. and are further described below.

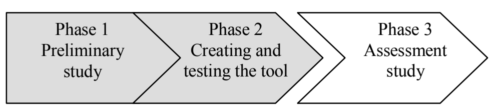


Fig. 2. The three phases of the project.

At the first phase, the preliminary study, the purpose was to find out how the companies develop their products, how they handle environmental aspects, what need they have for an environmental tool during the product development process, and what requirements they place on any such tool. The research method at this phase was empirical, and based on semi-structured interviews. A semi-structured approach was preferred, since it would support investigation of an unknown but specific area. The study was based on two different interview guides – the one for product designers, the other for accompanying functions. Both interview guides encompassed the following areas:

- Product development process in practice.
- Environmental work in practice.
- Need for support tools.
- Tool requirements.

Some interviews were conducted in groups, but others – especially with product designers – were performed individually. The interviewees were selected in conjunction with the contact person of each company. The functions represented by the interviewees at Phase One are shown in Tab. 1.

Company	Functions (number of interviewees)
A	Purchase (1), Market (1), Environment (1), Development* (3)
B	Production (1), Market (1), Development* (2)
C	Financial (1), Purchase (1), Environment (1), Development* (3)
D	Environment / quality (2), Purchase (1), Market (1), Development* (3)
E	Environment (1), Purchase (1), Finance (1) Development* (6)

**Development means in:* *Company A: Responsible development supervisors and product designers.*
Company B: Development manager and product designers.
Company C: Development manager and product designers.
Company D: Development manager, product designers and project leaders.
Company E: Project leaders (product developers), product development technician and product development communicator.

Tab. 1. Companies and functions participating in the study.

The companies that took part in the project varied in size; and, accordingly, their product development departments were organised in different ways. The number of product designers indicated how large the product development organisation of the different companies was (Tab. 2.). In all companies, the industrial designer (or architect) played an important role in product development work, sometimes on a contract basis. Although most company functions were involved in product development, the design department remained responsible. The other functions involved in product development were located in manufacturing, purchase, market and financial departments.

Following the interviews, there was a meeting with all the companies with the aim of verifying whether company needs for and requirements on the tool were correctly understood.

The second phase was to create and test the environmental tool. Trätek and IFP Research developed the tool in co-operation with a company that creates company-specific solutions for PDM systems (Maxiom Partners). The first version was based on findings from the interviews and the meeting. One or more product designers in each company then tested it for a period of three months. Then, the product designers were invited to respond to a questionnaire to determine how they had experienced the environmental tool. The items in the questionnaire were related to the wishes and demands that were identified during the interviews. After the product designers had responded to the questionnaire, they were interviewed over the telephone in order to check that they had understood the issues involved. During the interview, they could also give a more specific explanation for what had to be improved in the tool. Later, a second version of the tool was developed, and again the companies were asked to test it. During development of the tool, a three-day course of training in *environment-friendly product development* was provided to all the companies.

3. RESULTS

3.1 Company in-house product development

It is usual for both direct and informal co-operation to take place in small companies. But, development in large companies is carried out in projects with formally bounded functions. Almost all the companies that took part in the study adhered to a formal model of work, i.e. one that was conducted according to a definite structure – with activities and checkpoints defined.

Company	A	B	C	D	E
Number of Employees	130	250	600	1400	>*
Number of Designers	<5	<5	5-10	40	20
CAD tools	ProEngineer	→ Inventor	SolidWorks	SolidWorks	SolidWorks
Data Manage-ment System	Intralink	" Folders"	"Folders"→ Conisio	" Folders " Material database	Own system

*The number of employees is not given, as we were just involved with one department in the company. It is a big company and the unit that involved product development has 700-800 employees.
→ The arrow means that the implementation of the tool was going on at the same time as the interviews.

Tab. 2. Size of companies and use of computer-based support tools.

3.1.1 Support tools

The focus was not only on how CAD systems were used, but also on how the data created were handled during the product development process. At the time of the interviews, four companies already worked with 3D-CAD systems, while the fifth company was just about to introduce such a system (choice of CAD system, see Tab. 2.). The general feeling among product designers and other interviewees was that the full potential of their CAD tool was not utilised. They only used the system for producing drawings, and for visualising the product. Product designers were aware of the capacity of the tool, but they did not have time to use it as intended by the developers. In the future they hoped to find the time to use it more effectively. Only a few companies had a proper data management system. Normally, the companies had computer-based folders. When exploring the problems of data management, the companies saw a need to manage data in a uniform manner within the company. One company had just introduced a PDM system, and two others were planning to launch such a system.

3.2 Environmental work

The environmental area was very important for both management and employees in all the companies investigated. Earlier, legislation was the main driving force [5], but today there are also other forces of great importance. The drivers of environmental activities in the companies varied from company to company (Tab. 3.), but none of the participants referred to legislation.

Company A	Individual devotion, the company has an environmental profile, market forces
Company B	Customers' demands, a wish to follow development in society, corporate culture
Company C	Market forces, commitment among employees
Company D	Corporate culture, strong and driving characters, market forces
Company E	Market forces, corporate culture, long-term management

Tab. 3. Driving forces for environmental work.

In all the companies, both customer demands and the market forces were mentioned as driving forces, which is natural in profit organisations. It is interesting that individual commitment and corporate culture were said to be important drivers. In Company A one of the owners was actively pursuing the issue, whereas the corporate culture of companies D and E went back to the ideology of their founders, i.e. to conserve resources. Long-term management and consumption of resources had to do with the fact that some of the interviewees of Company E indicated that the risk of strongly increased costs for resources was a strong driving force.

All companies had some kind of formal environmental activities (Tab. 4.), and an employee or some employees were responsible for environmental work.

Company	A	B	C	D	E
Org. of env. matters	Quality and env.: 2 persons	Production manager responsible	Env.: 1 person	Quality and env.: 2-4 persons*	1 person with env. response-bility**
Env. Declara-tion	Yes	No	Yes	Yes	No ***
Certifica-tion	ISO 14 001	None	ISO 14 001	ISO 14 001, EMAS	None
Eco-labelling of products	None	Svanen (Swedish)	Svanen (Swedish)	French marking	None

* 2 persons full-time, 2 persons part-time
** 1 person at studied department
*** Had a system of their own for declaring the products' contents; their relation to environmental influences is under development.

Tab. 4. Organisation of environmental issues and environment-oriented activities.

3.3 Company needs

With regard to environmental assessments, three concrete needs could be identified from the interviews:

- To be able to make environmental assessments immediately during the design work itself.

- To be able to provide an environmental assessment that supported choices between materials and between manufacturing processes.
- To be able to express oneself with certainty on environmental matters.

These needs were strongly related to the fact that the companies perceived a need to be able to attest a choice from an environmental point of view during the development of a product. Environmental matters were, however, not considered to be as important as other issues – such as costs or lead-time. But, if environmental issues did not have too much of a negative impact on costs or lead-time, they were regarded as important in product development work. The designers perceived environmental issues as becoming more and more important, and felt that they had opportunities to affect them.

Yet another need, as well as the three mentioned above, was that of an environmental tool for the product developer or product designer. This was also a basic project idea, and therefore also an obviously identifiable need. It is also interesting because it represents a conclusion to other needs, namely that the product designer needs a support tool to be able to make environmental assessments during development work without having to be an environmental expert. It was not a requirement on the part of the product designers to integrate the tool into in and PDM, but they could see the advantages of doing so. The advantages they could identify in this respect were that they did not have to learn to use, or use, any further tool. They could also avoid duplication of work by using existing product documentation.

Some of the companies could also see a need for being able to make environmental assessments at two different phases of their product development work; at the beginning of the product development process, an overall assessment at a general level was preferred – by contrast with a more detailed assessment at the end of the process.

3.4 Life Cycle Assessment

The environmental tool described in this paper should be seen as a concept for making environmental impact assessments during the product development process. The concept constitutes a way of reducing modelling time by allowing for simplified assessment. The concept, and finally the environmental tool, is based upon companies' demands and wishes regarding how a tool for making environmental impact assessments during the product development process might be useful. The intended user is the product designer.

3.4.1 Requirement specifications

During the interviews and meetings, the demands and wishes of the product designers regarding the support tool were discussed. The following requirement specifications describe the characteristics of the support tool (with no specific distinctions made between demands or wishes):

- The tool should contain an environmental index, i.e. there should be a basis of comparison without the need for any specific environment- related knowledge.
- The tool should have a life-cycle perspective, i.e. the assessments should be related to the product's entire life-cycle.
- The tool should be reliable, i.e. one should be able to have confidence in any result that demands traceability.
- The tool should be perceived as easy to learn, understand and use (it should even be self-instructional).
- The tool should be simple to update, i.e. it should be easy to change parameters and to make new analyses. It should also be easy to update data about materials and processes.
- The tool should provide a comprehensive view on a product's environmental impact, i.e. it should regard an entire system of parts or products.
- The tool should indicate problems, i.e. give support in finding weak points.
- The tool should have a CAD connection, i.e. it should be capable of becoming an integral part of any existing system.

3.4.2 Structure

The concept of structure is concerned with how to make environmental impact assessment functions integral parts of design and product development tools. The systems that are used for realising the concept are the PDM system, SmarTeam, and the solid modelling system, SolidWorks. These systems were chosen because they are used in the furniture industry (and also among the companies taking part in the project). The materials database was in MS Excel.

The PDM system was used as an archive for all documentation and information about the products. The environmental tool is integrated into the PDM system. How all the involved systems are linked together is described in Fig. 3.

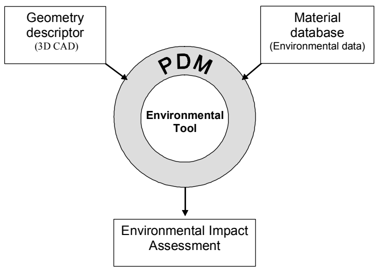


Fig. 3. The concept for making environmental impact assessments during the product development process.

3.4.2.1. The materials database

As mentioned above, the database was in MS Excel. For each set of materials, it includes life-cycle inventory data, indicator results for different impact categories (Tab. 5.), and weighted data. The life-cycle data encompass resources, energy use, emissions etc., and represent – to an environment expert – the most objective and informative way of presenting environmental performance [6]. To make the results more comprehensible and easier to overview for a product designer, a characterisation model is used that includes impact categories derived from CML 1992 – except for climate change, where the IPCC model is employed. Also a weighting model with one single value is used for summarizing the results specifically for the product designer – in this project, Eco-Indicator 95. Several other models are also available and can be used if they are consistent with the goals and scope of product development. The methodology used is based on international standards of life-cycle assessment [9]–[12].

Greenhouse effect	Ozone layer
Ecotoxicity	Human toxity
Eutrophication	Acidification
Summer smog	

Tab. 5. List of impact categories.

Trätek and IFP Research jointly supplied the materials database with environmental data related to materials and coatings (e.g. HDPE, chipboard, 15 years with energy recovery, cotton or solid borne alkyd paint). The database also contains information on materials and coatings density. This is of importance for knowing the weight of the parts, which is related to the quantity of each substance.

To be able to use the tool properly in the future, the companies must themselves supply the database with relevant data related to their own products. The materials database should only contain accepted (not banned) material. We suggest that, within the company, the environment manager, not the product designer, should be responsible for supporting the database.

The system boundary is largely determined by the data included in the materials database. But, the user may individually decide and alter the system boundaries through adaptation of the environmental data.

3.4.2.2. The geometry (product) descriptor

In his or her daily work, the product designer builds geometric models of the products he or she creates. As well as for the reasons mentioned earlier, SolidWorks is used because the PDM system supports exchange of its file format. Almost all geometric models (parts) are assembled into a finished product (assembly). All parts in the assembly affect the environment to a greater or lesser extent – depending on volume, solid materials, coatings, and coating areas. In a solid modelling system, areas and volumes are known, which is needed when making an environmental impact assessment of a product. The model does not need to be complete or fully defined before the environmental tool can be used. Depending on when the product designer starts to use the CAD system, the environmental tool can be used during the entire product development process. During this project, the environmental tool was used only when the product was completed, but – for the future – it is intended that the tool should be used during the entire process, even at the very beginning of product development (Fig. 4.).

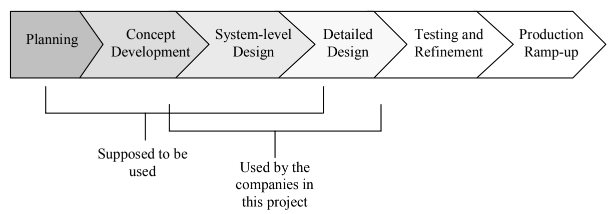


Fig. 4. Steps in using the environmental tool in the product development process.

3.4.2.3. Environmental impact assessment

All relevant information for making an environmental impact assessment is imported into the PDM system. Volumes and areas are imported from the CAD system, and – through an importing tool – each material's density, life-cycle inventory data and all impact categories related to each material are taken from MS Excel.

The result can be shown in three different ways:

- As a weighed result with a single environmental index.
- As an indicator result for each impact category.
- As an environmental profile.

The result can be shown for the whole assembly or for selected parts. The quantity of each part is connected with the assembly. This implies that for an assembly including one part and two copies of it, the result value will be three times higher that for the part alone.

3.4.3 Work procedure

This section will describe opportunities to let the product designer make environmental assessments as an integral part of his or her daily work. Fig. 5. below illustrates the work procedure, which is also described in detail in the text below.

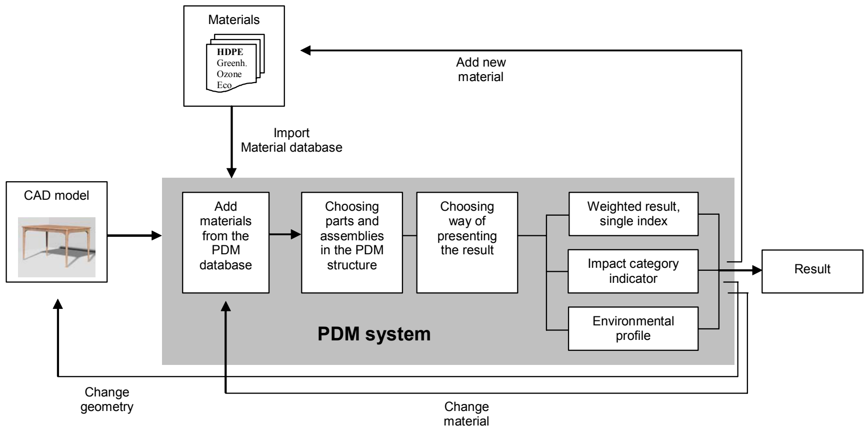
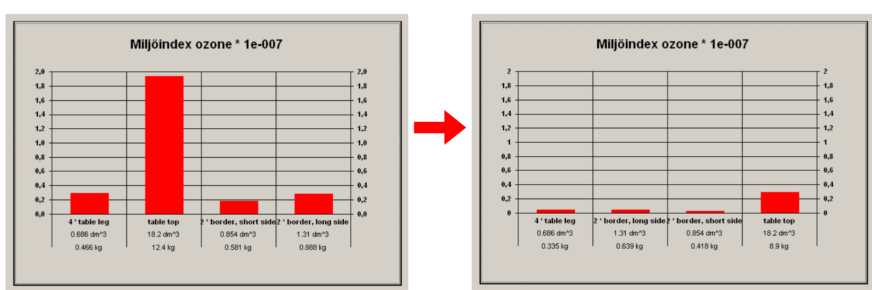


Fig. 5. Work procedure for making environmental assessments.

For demonstrating the possibility of making environmental assessments during the product development process, a *table* is used as an example of a product. The object of this demonstration is to select material – solid wood or chipboard with laminate. In this example the impact category *Ozone layer* is chosen. The first step is to create a geometric model of *the table* in the CAD system (Fig. 5.). The *table* is created as an assembly including four parts, one tabletop, two short borders, two long borders, and four table legs. At the same time as the model is saved into the PDM system, the materials related to each part are chosen – either chipboard or laminate in this case. Then the assembly (the *table*) is selected from the document tree in the PDM system. The kind of environmental assessment that should be used can be selected from the menu, in this example the *Impact category indicator*. The impact category *Ozone layer* can now be chosen from a list. The result is shown in Fig. 6., Picture A. By updating the parts in the PDM system, the materials can be changed. The result after changing the material to solid wood is shown in Fig. 6., Picture B. Both of these diagrams can be viewed at the same time.



Picture A

Picture B

Fig. 6. The results from the environmental impact assessment.
Picture A shows the material chipboard and laminate and picture B shows the solid wood.

This example shows a possible way of using the environmental tool, but there are still many more ways in which the tool could be used for indicating problems and making them visible for product designers. The product designer does not need to be an environmental expert to be able to use the tool.

3.4.4 Limitations

There are many limitations to the approach described above that could be mentioned. One of the most serious ones is that the environmental tool can only handle materials, not processes. It is obvious that processes have to be included in the future.

Another limitation is that the environmental tool cannot yet treat any other file format than SolidWorks, which is why not all of the companies taking part in this project could use the tool in their daily product development. SmarTeam can handle other file formats, but only SolidWorks is treated in this project. Using, for example, STEP or specific solutions for each CAD system could solve the problem, but such a solution was not treated in this project.

4. DISCUSSION AND CONCLUSIONS

In this project, product development in practice has been in focus. All the companies had ambitions to increase their environmental work, and could also see the advantages of integrating environmental assessment functions into their design and product development tools. The driving forces for all the companies were almost the same based on market considerations, policies and corporate culture.

CAD was used in the companies to roughly the same extent, although the degree of implementation varied from company to company. All the companies, however, had the potential for more varied and deeper use of their CAD system, and the same applied to managing the documentation (data) that is created during product development. As regards managing the data, a perceived need for improvement was expressed.

The environmental tool was developed from demands and wishes defined by the participating companies. At the beginning of the project, demands were quite abstract and at an elevated level, e.g. “easy to use” or “be able to rely on the result”. During the development period, the demands became more and more concrete, and easier to relate to parts of or requirements on the environmental tool.

Development of the tool has been successful. When its limitations have been reduced, the tool could become very useful in product development work. Even today the following advantages (or functions) can be identified:

- The tool is self-instructional and easy to navigate. It follows the structure of the PDM system, which makes it very easy to use. The tool also fits in well with product designers’ normal routines for work already performed in their CAD and PDM systems.
- The tool makes it possible for product designers clearly to visualise the environmental influences related to different choices of material.
- It is possible to see several results at the same time with different choices of materials. The scale of the diagram is updated during any new assessment to assure comparability.
- It is possible to change the characterisation and weighting model.
- It is possible to change how the result is presented in the diagram, e.g. whether it should be presented by part or by material, and so on.
- The environmental tool could be used without having a connection with CAD if the volume and area data are defined in the PDM system. This is useful if materials alone are to be compared.

Although the tool has advantages, it also has disadvantages. Some of these are mentioned in the Limitations section, and have to be treated in the future. The tool also places high demands on data collection related to materials, but this is unavoidable. This is an important issue that has to be taken under consideration. It will be a major impediment for individual users to overcome and should therefore probably be addressed by the companies in the furniture and joinery industry in co-operation. We suggest that the industry, as part of their procurement demand relevant environmental data from their sub-suppliers of products, components or materials. This would make the environmental tool easier to introduce and use. It is understood that even the establishment of a joint standpoint in this matter is easier said than done, but without it, only the major companies will have the necessary competence and strength to use and maintain the proposed tool properly. An additional challenge is to enable data sharing and exchange among users and between different systems.

It is also very important that the environmental data are correct and always updated. If they are not, the environmental impact assessment will be unusable. This also affects the extent to which the product designer can trust the result. Accordingly, it is of importance that a person with environmental and company-specific knowledge supplies the materials database with information.

5. ACKNOWLEDGEMENTS

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