Metadata of the chapter that will be visualized in SpringerLink

Book Title	ICoRD'15 – Research into Design Across Boundaries Volume 2	
Series Title		
Chapter Title	An Interface Between Life Cycle Assessment and Design	
Copyright Year	2015	
Copyright HolderName	Springer India	
Corresponding Author	Family Name	**Uchil**
	Particle	
	Given Name	**Praveen**
	Prefix	
	Suffix	
	Division	Centre for Product Design and Manufacturing
	Organization	Indian Institute of Science
	Address	Bangalore, India
	Email	praveen@cpdm.iisc.ernet.in
Author	Family Name	**Chakrabarti**
	Particle	
	Given Name	**Amaresh**
	Prefix	
	Suffix	
	Division	Centre for Product Design and Manufacturing
	Organization	Indian Institute of Science
	Address	Bangalore, India
	Email	

Abstract	Results from a full Life Cycle Assessment (LCA) of a product contain complex information about its constituent components and materials; subsequent manufacturing processes, emissions, and potential environmental impacts. Understanding such LCA information in detail can help designers make robust decisions related to reducing environmental impacts of the product through appropriate choice of components, materials and processes during Eco-Design. A key resource for LCA information in a Full LCA tool (also called Detailed LCA, and henceforth referred to as LCA tool) is its databases. However, LCA tools have often been criticised for not being useful to designers. Among the various underlying causes, the issues with visual representation of LCA information and usability of LCA tools have gained minimal research attention. In order to address these issues, we adopt an information visualization approach. Information visualization is an interdisciplinary research area focused on computer supported development of visual representations of complex information in order to render it interpretable by humans. In this paper, we discuss the potential of using information visualization techniques as an interface for LCA tools for educating designers about the likely environmental impact of their design decisions. We also discuss potential benefits of using a novel interface developed by us using interactive, multi-view based visualization techniques in understanding context sensitivity of LCA information. The proposed interface is part of an ongoing research effort for developing user friendly interactive visual representations for LCA. Ultimately, the proposed interface is intended to enhance designers' capabilities for developing environmentally benign product life cycles.

Keywords (separated by '-')	Life cycle assessment - Information visualization - Ecodesign - Usability

Layout: T1 Standard Unicode | Book ID: 329970_1_En | Book ISBN: 978-81-322-2228-6
Chapter No.: 22 | Date: 6-12-2014 | Time: 3:53 pm | Page: 251/259

An Interface Between Life Cycle Assessment and Design

Praveen Uchil and Amaresh Chakrabarti

Abstract Results from a full Life Cycle Assessment (LCA) of a product contain complex information about its constituent components and materials; subsequent manufacturing processes, emissions, and potential environmental impacts. Understanding such LCA information in detail can help designers make robust decisions related to reducing environmental impacts of the product through appropriate choice of components, materials and processes during Eco-Design. A key resource for LCA information in a Full LCA tool (also called Detailed LCA, and henceforth referred to as LCA tool) is its databases. However, LCA tools have often been criticised for not being useful to designers. Among the various underlying causes, the issues with visual representation of LCA information and usability of LCA tools have gained minimal research attention. In order to address these issues, we adopt an information visualization approach. Information visualization is an interdisciplinary research area focused on computer supported development of visual representations of complex information in order to render it interpretable by humans. In this paper, we discuss the potential of using information visualization techniques as an interface for LCA tools for educating designers about the likely environmental impact of their design decisions. We also discuss potential benefits of using a novel interface developed by us using interactive, multi-view based visualization techniques in understanding context sensitivity of LCA information. The proposed interface is part of an ongoing research effort for developing user friendly interactive visual representations for LCA. Ultimately, the proposed interface is intended to enhance designers' capabilities for developing environmentally benign product life cycles.

Keywords Life cycle assessment · Information visualization · Ecodesign · Usability

P. Uchil (✉) · A. Chakrabarti
Centre for Product Design and Manufacturing, Indian Institute of Science, Bangalore, India
e-mail: praveen@cpdm.iisc.ernet.in

A. Chakrabarti (ed.), *ICoRD'15 – Research into Design Across Boundaries Volume 2*,
Smart Innovation, Systems and Technologies 35, DOI 10.1007/978-81-322-2229-3_22

Layout: T1 Standard Unicode | Book ID: 329970_1_En | Book ISBN: 978-81-322-2228-6
Chapter No.: 22 | Date: 6-12-2014 Time: 3:53 pm | Page: 252/259

1 Introduction

Life Cycle Assessment (LCA) results of a product contains comprehensive information about the complex interactions between materials and processes and the environment during the entire life cycle of the product. However, use of LCA tools for design has been critiqued for factors such as its outcomes being too complex to interpret, too time consuming to implement, the tools being not easy to use and not in alignment with designers' requirements, etc. [1–3]. Although there have been several efforts to improve adoption of LCA by the design community through various approaches such as integration with CAD systems [4], development of single scores [5] and improvement of LCA interfaces [6], many issues still persist, either due to their complexity or due to the lack of adequate, systematic effort [7]. In this paper, we discuss the feasibility of addressing some of these outstanding issues through the application of techniques adapted from the domains of decision making [8], information visualization [9] and user-centered design [10].

2 Objective and Methodology

The objective of this paper is to highlight information visualization issues in LCA tools and to discuss the potential of using recent techniques from information visualization for addressing some of these issues. Information visualization issues can exist in LCA either due to issues with the content, or with the form of the information representation used.

2.1 Research Questions and Methodology

The following research questions are asked:

1. What is the role of information visualization in LCA-driven decision-making?
   This is addressed by reviewing literature on decision-centered design e.g. [8], and by application of information visualization e.g. [9] and user centered design e.g. [10].
2. What are the design decisions taken during ecodesign? What among them can be supported by LCA?
   This is addressed by reviewing literature on models of designing e.g. [11], and by application of LCA in decision making e.g. [12].
3. What are the visualization issues faced by current LCA tools?
   This is addressed by reviewing literature on requirements of support tools for ecodesign e.g. [1] and analyzing user interfaces and visualization aspects of LCA tools from the perspective information visualization principles [9].

Layout: T1 Standard Unicode | Book ID: 329970_1_En | Book ISBN: 978-81-322-2228-6
Chapter No.: 22 | Date: 6-12-2014 Time: 3:53 pm | Page: 253/259

4. Which information visualization techniques can potentially address the issues identified?
   This is addressed by designing alternative representations using existing techniques of information visualization that have been found suitable in addressing similar issues in other domains.

3 Research Outcomes

3.1 Role of Information Visualization in LCA

A decision is a commitment to use resources; therefore, it deserves serious emphasis [8]. Design as a problem solving activity involves generating and refining information punctuated by decision-making [8]. The activities involved in ecodesign are similar to those in design [4]. We adopt the decision thinking framework for design developed by Ullman [10] as it succinctly represents the relationships between decisions and information (Fig. 1).

A decision is a conclusive piece of information obtained as an outcome of interpretation facilitated by an internal representation. Representation is visual encoding of data in terms of various shapes and relationships. Internal representation is a tacit entity that drives decision making, consisting of prior knowledge and knowledge obtained from external (LCA) representations. Visualization methods can accelerate internal representation by presenting information in an appropriate format or structure or by helping users find, relate and consolidate information, helping them to form an appropriate internal representation [12]. Interaction is a dynamic means through which a decision maker alters the LCA representations to obtain insight into the LCA information. LCA information refers

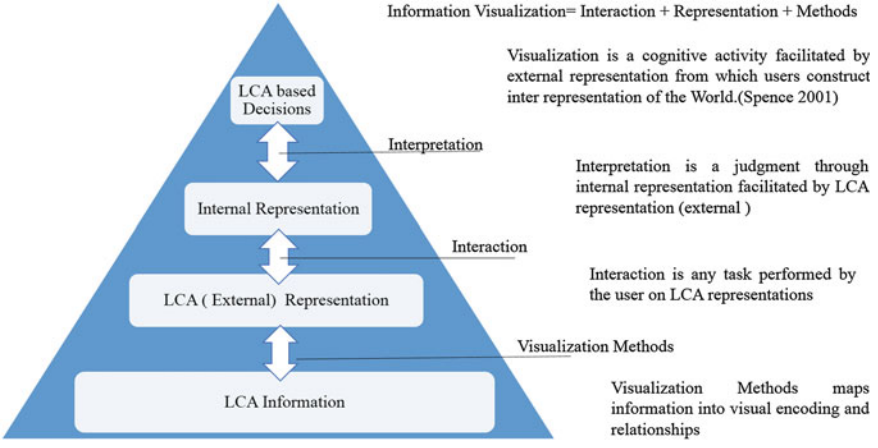

Fig. 1 The value of information visualization

Layout: T1 Standard Unicode | Book ID: 329970_1_En | Book ISBN: 978-81-322-2228-6
Chapter No.: 22 | Date: 6-12-2014 | Time: 3:53 pm | Page: 254/259

not only to the computed outcomes of life cycle impact assessment models, but to all information required to make sense and assess credibility of the outcomes [7]. The outcome of the research discussed above is an extension to the information visualization framework proposed in our earlier paper [7].

3.2 A Decision Centred View of Ecodesign for Structuring Information Space

Table 1 shows a generalized decision framework according to the integrated model of designing proposed by Srinivasan and Chakrabarti [11], which can be used to represent the decisions driven by LCA. For example, decisions on evaluating product alternatives can be represented using "evaluate" decision, and decisions on identifying environmental target can be represented under "Generate" decision, in Table 1. The list of LCA applications in decision-making is adopted from Gloria et al. [12]. The decision typology compiled in Table 1 can be useful for developing decision-specific interfaces, since the typology provides a basis for grouping the methods and identifying the tasks necessary to represent information as per the information requirement of a decision.

3.3 Review of Information Visualization Approaches for LCA

Through a review of literature [13–17], we identify that although many authors argue for using an information visualization approach in LCA, none of them benchmark the performance of the proposed approaches against current visualization in LCA tools, nor do they explore the most suitable visualization techniques for a given LCA decision. Addressing each of these gaps is a formidable challenge, because there are no formalized methods or criteria to identify the visualization issues, nor is there a concrete basis for prescribing the most suitable visualization for a given task. Moreover, lack of any concrete theory for visualization [18] and lack of objective evaluation methods pose further challenges for assessing the value of novel, alternative, information visualizations against existing ones.

Table 1 A decision typology for LCA

General decision category	GEMS frame work	LCA based application example
Analysis	Evaluate	Product/process/materials alternatives
Synthesis	Select	Energy materials emission audits
		Eco labelling (marketing) information
		ISO standards, Legislatory requirements
	Generate/modify	Environmental targets
		Product/process alternatives

Layout: T1 Standard Unicode | Book ID: 329970_1_En | Book ISBN: 978-81-322-2228-6
Chapter No.: 22 | Date: 6-12-2014 Time: 3:53 pm | Page: 255/259

3.4 Issues in a Current LCA Visualization

Put simply, a visualization issue is an example of bad design. A visualization issue in a decision support system may arise due to non-adherence to the principles of information visualization. In this section, we highlight various information visualization issues using a hypothetical example of LCA of a coffee machine design adapted from an example project used in a commercial LCA software tool. The most frequent application of LCA, as identified by a survey of LCA practice pertains to the decision of evaluating design alternatives [19]. We assume LCA information of an existing coffee machine is available for the designer. The objective of the designer involved in redesign of the coffee machine is to evaluate whether Plastic (Poly-propene) makes a better alternative for the housing of a coffee machine.

Figure 2 presents a 2D stacked bar chart representation as an outcome of an analysis for supporting the decision task comparative evaluation of product alternative. In order to understand the issues in this representation, it is necessary to consider the perspective of task sequence involved in generating the above representation in current LCA tools, and how accurately the representation reflects the truthfulness of the impact captured by the LCA results. On these lines of thought, we discuss visualization issues against the following requirements of information visualization.

(a) Accuracy and Insight: Results of LCA are context-specific [18]. Therefore, an accurate LCA representation should provide insight into the context-specific nature of the outcomes of the LCA. Currently, context-specific dimensions, such as functional unit, system boundary etc., are not explicitly represented in Fig. 2 representation. The above results, which considered only manufacturing phase in the life cycle analysis, may lead the designer to conclude Plastic as a

Fig. 2 A sample of LCA representation in a commercial LCA tool

Layout: T1 Standard Unicode | Book ID: 329970_1_En | Book ISBN: 978-81-322-2228-6
Chapter No.: 22 | Date: 6-12-2014 Time: 3:53 pm | Page: 256/259

worse alternative to Aluminium—the current constituent in the coffee machine. However, when the same analysis is repeated by changing the system boundary (e.g. including the material extraction processes in this case) reveals opposite results as shown in the top left chart in the Fig. 3. Relying on the representations without understanding the contextual parameters (in this case the exclusion of material extraction phase) could lead to incorrect decisions.

(b) Ease of Use: A commonly used heuristic for ease of use is the number of operations required to accomplish a task [20]. Generating the above representation requires the user to perform the following tasks in the current LCA software: Open the project > Product stages > Coffee machine > Assembly > Analyze > Calculate > Single Score > Bar Chart. The large number of operations as listed here indicates a poor ease of use.

(c) Performance: Performance in decision making can be assessed as the inverse of the amount of time taken for arriving at a decision. Performance is dependent on ease of use and adequacy of information. As the user has to search for the methodological dimensions within the current tool, this is likely to be time consuming.

3.5 An Alternative Visualization

In order to address some of the above mentioned issues, we propose an alternative visualization (Fig. 3) that uses a multi-view representation technique to display higher dimensional data. A multi-view representation technique uses two or more distinct representations to display a piece of information [21]. A multi-view

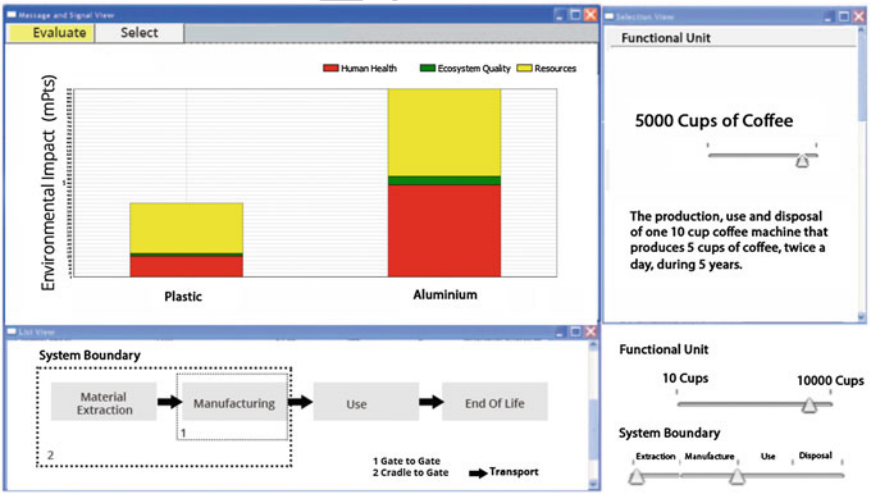

Fig. 3 An example of a multi-view visualization technique

Layout: T1 Standard Unicode | Book ID: 329970_1_En | Book ISBN: 978-81-322-2228-6
Chapter No.: 22 | Date: 6-12-2014 | Time: 3:53 pm | Page: 257/259

representational technique is used in scenarios where interpreting information involves navigating complex data sets and identifying the relationships among various data fields required for decision making [22]. To facilitate interaction among such complex data sets within a multi-view approach, we propose integration of dynamic sliders on the interface.

The proposed representation is likely to be more effective than the current representation in the following aspects:

(a) Accuracy and Insight: The multi-view representation should enable linking of contextual data to LCA results through provision of dynamic sliders and distinct views for methodological dimensions. Thus, users can gain insight into the context-specificity of the information, by visualizing the effect of changing methodological parameters (using dynamic sliders) on LCA results. For instance, in the coffee machine, multiple representations of the same model can facilitate the user to perform 'what-if' analysis by quickly and interactively changing the system boundary from 'gate to gate' to 'cradle to gate', as indicated in the bottom view in Fig. 3. Users can interpret the results of Plastic being better than Aluminium for the Housing of the Coffee machine is contextual, and that often there is no single absolute answer to evaluation of design alternatives. Thus by making context-specificity explicit, the above representation more accurately represents the LCA model, and facilitates the user to gain insight into the dynamic nature of the LCA.

(b) Performance: North and Shneiderman [23] observes that multiple views offer improved user performance and identification of unforeseen relationships. The proposed interface reduces search for information and task sequence for a user to elicit the methodological dimensions by representing required dimensions (For instance: Functional unit and system boundary) explicitly using multiple representations.

(c) Ease of Use: The task sequence for generating the above representation in proposed prototype is the following: Open LCA results > Evaluate (Highlighted in Yellow Marker in Fig. 3). Any further interaction, if required can be made using dynamic sliders. Thus a smaller number of operations is required, indicating improved ease of use.

3.6 Discussion

The proposed representation shows a tentative, alternative visualization framework for evaluating product alternatives using LCA. Further studies are required to identify the most suitable representation for each given task. The proposed representation needs to be experimentally validated for the benefits it claims over existing tools. In our earlier paper [7], we had discussed the limitations of 2D bar charts in terms of representational attributes such as dimensionality, uncertainty and interactivity. This paper discusses the limitations of the visualizations from a

Layout: T1 Standard Unicode | Book ID: 329970_1_En | Book ISBN: 978-81-322-2228-6
Chapter No.: 22 | Date: 6-12-2014 Time: 3:53 pm | Page: 258/259

relatively more tangible (i.e. empirically assessable) set of attributes such as ease of use, performance, perceived insight and accuracy, thus providing a more convincing approach for demonstrating the value of information visualization in LCA.

4 Conclusions

This paper discusses as to how interpretation of LCA information is hindered by the way LCA information is visualized. We highlighted some of the limitations of current LCA representations, and proposed application of higher dimensional techniques, such as multi-view and dynamic sliders, for improving this situation. The proposed visualization is intended to improve the adoption of LCA information in design by reducing the time taken to arrive at decisions, as well as by improving the credibility over the decisions through providing insight into the LCA information. Future work includes empirically evaluating the effectiveness of the proposed visualization against current LCA representations.

References

1. Kota, S., Chakrabarti, A.: Understanding the needs of designers for developing environmentally friendly products. In: International Conference on Research into Design (ICoRD '09) (2009)
2. Millet, D., Bistagnino, L., Lanzavecchia, C., Camous, R., Poldma, T.: Does the potential of the use of LCA match the design team needs? J. Clean. Prod. **15**(4), 335–346 (2007)
3. Bhander, G.S., Hauschild, M., McAloone, T.: Implementing life cycle assessment in product development. Environ. Prog. **22**(4), 255–267 (2003)
4. Kota, S.: An interactive support for developing environment friendly product life cycles. PhD thesis (2009)
5. Goedkoop, M., et al.: The Eco-indicator 98 explained. Int. J. Life Cycle Assess. **3**(6), 352–360 (1998)
6. Rio, M., Reyes, T., Roucoules, L.: A framework for ecodesign: an interface. Int. J. Eng. 121–126 (2011)
7. Uchil, P., Chakrabarti, A.: Communicating life cycle assessment results to design decision makers: need for an information visualization approach. In: DS 75-5 Proceedings of the 19th International Conference on Engineering Design (ICED13) (2013)
8. Ullman, D.G.: Toward the ideal mechanical engineering design support system. Res. Eng. Des. **13**(2), 55–64 (2002)
9. Card, S.K., Mackinlay, J.D., Shneiderman, B. (eds.): Readings in Information Visualization: Using Vision to Think. Morgan Kaufmann, Los Altos (1999)
10. Norman, D.A.: The Design of Everyday Things. Basic Books, London (2002)
11. Srinivasan,V., Chakrabarti, A.: An integrated model of designing. J. Comput. Inf. Sci. Eng. **10**(3), 031013 (2010) AQ4
12. Börner, K., Chen, C., Boyack, K.W.: Visualizing knowledge domains. Annu. Rev. Inf. Sci. Technol. **37**(1), 179–255 (2003)
13. Otto, H.E., Mueller, K.G., Kimura, F.: Efficient information visualization in LCA. Int. J. Life Cycle Assess. **8**(4), 183–189 (2003)

Layout: T1 Standard Unicode | Book ID: 329970_1_En | Book ISBN: 978-81-322-2228-6
Chapter No.: 22 | Date: 6-12-2014 Time: 3:53 pm | Page: 259/259

14. Otto, H.E., Mueller, K.G., Kimura, F.: Efficient information visualization in LCA: approach and examples. Int. J. Life Cycle Assess. **8**(5), 259–265 (2003)
15. Otto, H.E., Mueller, K.G., Kimura, F.: Efficient information visualization in LCA: application and practice. Int. J. Life Cycle Assess. **9**(1), 2–12 (2004)
16. Otto, H.E., Mueller, K.G., Kimura, F.: Interactive visualization for the comparative analysis of life cycles in complex product design. In: ds 31 Proceedings of ICED 03, the 14th International Conference on Engineering Design, Stockholm (2003)
17. Ragnerstam, E.: Enhanced interactivity in charts: visualization of life cycle assessment results. Skolan för datavetenskap och kommunikation, Kungliga Tekniska högskolan, Stockholm (2010)
18. Norris, G.A., Yost, P.: A transparent, interactive software environment for communicating life-cycle assessment results: an application to residential windows. J. Ind. Ecol. **5**(4), 15–28 (2001)
19. Gloria, T., Saad, T., Breville, M., O'Connell, M.: Life-cycle assessment: a survey of current implementation. Environ. Qual. Manage. **4**(3), 33–50 (1995)
20. Nielsen, J.: Usability Engineering. Elsevier, Amsterdam (1994)
21. Wang Baldonado, M.Q., Woodruff, A., Kuchinsky, A.: Guidelines for using multiple views in information visualization. In: Proceedings of the Working Conference on Advanced Visual Interfaces, pp. 110–119. ACM (2000)
22. Ainsworth, S., Van Labeke, N.: Using a multi-representational design framework to develop and evaluate a dynamic simulation environment. In: International Workshop on Dynamic Visualizations and Learning, Tubingen, Germany (2002)
23. North, C., Shneiderman, B.: A Taxonomy of Multiple Window Coordinations. University of Maryland. Technical Report #CS-TR-3854 (1997)
24. Purchase, H.C., Andrienko, N., Jankun-Kelly, T.J., Ward, M.: Theoretical foundations of information visualization. In: Information Visualization, pp. 46–64. Springer, Berlin Heidelberg (2008)

AQ5