4 UNDERSTANDING THE NEEDS OF DESIGNERS FOR DEVELOPING ENVIRONMENTALLY FRIENDLY PRODUCTS

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The companies are aiming towards developing more and more environmentally friendly products. Designers need to put a lot of effort in developing eco-friendly products and they need different aids to help them in fulfilling the requirement. It is found from the literature that there have been lots of aids developed to help designers but very few were used in practice because of gaps in understanding the needs of designer for developing environmentally friendly products. The work reported in this paper tries to understand the needs of designer by analysing 2 sets of questionnaires and video protocol study of 3 sets of design exercises of 8 designers. The study aims at i) finding whether the designers consider environment as a criterion or not, ii) whether it is bettered by providing some help via tool/method/ guidelines, iii) what are the activities that have to be supported while designing and iv) the requirements/needs of designer for developing environmentally friendly products.

Keywords: Design for Environment (DfE), Life Cycle Design, Design stages, Life Cycle Assessment (LCA).

1. INTRODUCTION

Environment is gaining priority in the agenda at strategic level of product development companies because of strict regulations, increasing costs of energy, resources, customer requirements, competitors etc. As a result product developer (designer) is under pressure to develop environmentally friendly products. To help designer there have been lots of aids developed but very few were used in the industry because of theirs lack of fit to the need.

Aids were developed in isolation and due to this they were not entered in to industry. It is important to understand the needs of designers in day to day activity and if the aid fulfills those needs then it will be used for product development. There are some needs identified earlier and reported[1,2] and we are trying to validated those and see whether there are any additional needs of designer for environmentally friendly product design (from now onwards will be written as EFPD).

2. OBJECTIVES AND METHODOLOGY

The work reported in this paper concentrates on finding answers to the following questions

- **What are the primary reasons for little utilisation of Environmentally Friendly Product Design (EFPD) tools/methods/guidelines/methodologies in designing?** This question is answered mainly using review of current literature focusing on identifying the state of the art in the area of EFPD, and using review and analysis of existing methodology and tools for EFPD for proposal(concept/solution/product) Creation and Evaluation.
- **Whether designers generally consider environment as an important criterion in designing?** This question is answered by questionnaire survey and descriptive studies of designers solving problems.

- **How does this consideration change with the availability of information or support for EFPD?** This is explored through descriptive studies of designers solving design problems with increasing amount of information and support available on EFPD. This is also used to understand the specific constraints associated with using information or support for EFPD, to better clarify designers needs for using these.
- **What aspects of general designing must be taken into account while developing support for EFPD?** This question is answered by video protocol study of designers solving problems by finding a) activities performed during creation and evaluation, b) design stages and their outcomes.
- **What are the needs of designers for EFPD?** This question is answered by survey of questionnaire given to the designers participated in exercises after the final exercise.

3. LITERATURE REVIEW

Life Cycle Assessment (LCA)[3] is the most promising method for estimating environmental impacts of a product during its life cycle.[4] LCA tools are not well integrated with other design tools.[5] Consequently, there is a need for an LCA method integrated into the design process that can be used throughout design.

No tools were found which mapped to iterative changes required in product development and this is an area which needs further research.[6] To discourage mass waste because of mass production and mass consumption we need to establish design methodologies for closed life cycles.[7] We need to think about the whole life cycle rather than single phases in all stages of the design so that sustainable development products can occur.

LCA require high volume of product specific data and it consumes large amount of time. Existing tools are not integrated with design process, they cannot be used in earlier phases of design and these phases are the key in product development. Designer has to put up extra effort for modelling the life cycle, finding the inventory values which are not in his normal working procedure. Most tools do not fulfil designer's all requirements like generation, evaluation and selection of product proposals.

Environmental considerations should be integrated into the product development process, in the same sense as quality, cost, safety etc. We need to integrate environmental considerations as early as possible in design, into the project brief or at idea generation stage to get maximum environmental benefit in products.[8] To be able to design more environmentally friendly products, a very important factor is time — to be able to reconsider an idea to develop new concepts for evaluation. Another issue is optimising the current parts in a product for reducing their impact on environment.[9] Understanding of the trade-offs available between different product life-cycle phases is a must for developing environmentally friendly products.[6] Showing the history behind or the intention during a judgement helps another person understand the perspective.[10]

The requirements of the designer for better support for EFPD according to Ref. 1 are: tools should be proactive, easy to learn, understand and use, should allow understanding of design rationale, act as a checklist, reduce total time, store knowledge and experience as know-how backup, should be useful in all stages of design, should not require extra effort for analysis, should be integrated to CAD, should aid in trade off between choices, show uncertainty analysis, contain standards & regulations, aid in analysis & improvement, and consider all lifecycle phases. Major factors to be considered while integrating environmental aspects into product development are management, PD process, DfE Mindset and DfE tools.[11] There is a need of studying the typical activities performed by designers in the process of design. The next section is going to describe the exercises and analysis done in this regard.

4. METHOD

The detailed method followed to answer the questions is given in the following sections.

4.1. In-house Design Exercises Plan

Three types of in-house Design Exercises and two types of questionnaire survey are conducted with 8 designers in order to validate the need for a support for EFPD by finding answers to the following questions:

- **Whether designers generally consider environment as an important criterion in designing?** 1st *question of questionnaire1* and 1st *Exercise are used to answer this question.*
- **How does this consideration change with the availability of information or support for EFPD?** *This is answered by comparing Design exercise 2 and Design Exercise 3 with Design Exercise 1. This is explained in 2nd point in Analysis section.*
- **What aspects of general designing must be taken into account while developing support for EFPD?** *This question is answered by video protocol study of designers solving problems by finding a) design stages and their outcomes, b) activities performed during creation and evaluation. This is explained in 3rd and 4th points in Analysis section.*
- **What are the limitations of the current LCIE (representative) software in Design?** *This is answered by analyzing the design exercise3. This is explained in 1st* point in Analysis section.

Three types of in-house exercises done by each designer; first with design literature, second with design and EFPD literature, third with design literature and LCA software are (4 designers from industry and 4 designers from academia) with the following plan in Table 1. The combination of exercises, problems and designers is given in Table 2.

D1, D2, D3, D4 – Industry Designers D5, D6, D7, D8 – Student Designers

The sequence of questionnaires (Q) filled and design exercises (DE) done are as follows:
First Questinnarie1 (**Q1**) is filled then Design Exercise1 (**DE1**) (normal) is done followed by Design Exercise2 (**DE2**) with the help of EFPD literature and Design Exercise3 (**DE3**) with the help of LCA software and finally Questionnaire2 (**Q2**) is filled.

Questionnaire1 tries to find the following information

- In general what criteria designers use for evaluating their proposals and their priority.
- What kind of aids/processes they use in different stages of design for generation and evaluation and their advantages.

Questionaaire2 tries to find the following information

- What kind of EFPD aid they need.
- What should be the functionality of the aid in different stages of design for creation and evaluation of proposals?

Table 1. Plan for the three Design Exercises.

Design Exercise No 1	Design Exercise No 2	Design Exercise No 3
Give Problem	Give Problem	Give Problem
Give Design literature	Give Design literature and EFPD literature	Give Design literature and LCA Software
Give brief explanation of Product Life Cycle Stages	Give brief explanation of Product Life Cycle Stages and EFPD	Give brief explanation of the software (current) available and ask subjects to use it
Capture whole Design Process by video	Capture whole Design Process by video	Capture whole Design Process by video
Collect Design Documents	Collect Design Documents	Collect Design Documents

Table 2. Combination of Exercises, Designers and Problems.

	P1	P2	P3	P4
DE1 (NORMAL)	D1 D5	D2 D6	D3 D7	D4 D8
DE2 (LITERATURE)	D2 D6	D1 D5	D4 D8	D3 D7
DE3 (SOFTWARE)	D3 D7	D4 D8	D1 D5	D2 D6

Design Exercise1 consists of coming up with a detailed solution to a given problem with their normal design process.

- This used to obtain understanding of the general design procedure and general environmental consciousness of the designers.

Design Exercise2 consists of coming up with a detailed solution to a given problem by using the EFPD literature supplied with their normal design process when necessary.

- This used to understand the effects of EFPD literature.
- Advantages and Shortcomings of this type of support.

Design Exercise3 consists of coming up with a detailed solution to a given problem by using the LCA software supplied with their normal design process when necessary.

- This used to understand the effects of LCA software.
- Advantages and Shortcomings of this type of support.

4.2. *A*nalysis Plan

4.2.1. *E*ffectiveness of LCA Software in Different Stages of Design

Study DE3 to

- See in what stages the software is accessed
- Find out for what information designer accessed software
- Find whether designer got what he wanted

4.2.2. *H*ow Consideration Changed by Using Literature and Software

Compare the DE2 and DE3 with DE1

- For the time spent in terms of trying to do EFPD
- For the environmental impacts of final proposals
- For the no. of ideas/concepts generated and evaluated

4.2.3. Find Different Stages Designers go Through in Design Process and Respective Time Spent in Those Stages

Study all exercises for the following design stages and their outcomes

- **Task Clarification**: *Requirements are studied, clarified and written down*
- **Conceptual Design**: *Establishing principles, functionality of the ideas or solution for the problem specified, rough sketches and abstract material consideration*
- **Embodiment Design**: *Defining the layouts, spatial compatibility between sub-assemblies, relationships between objects and abstract material specification*
- **Detail Design**: *Dimensions, concrete materials and manufacturing tolerances are specified. Parts list, drawings and instructions prepared for other phases of product development*

4.2.4. Find Activities Performed by Designers

All exercises have been analysed for the following activities performed by designers (details can be found in Ref. 12): Product version definition, addition and subtraction of physical objects/information, addition and subtraction of relations between objects, combine objects/information, assessment, association of objects with information, substitution of object/information, focus on object or information, defocus from object or information, change of the view or focus, manipulate object.

Object: An assembly, a component, a feature, or other identifiable physical element that is used in the product being designed. Eg: cap, slot etc
Information: Any property associated with the object being designed. Eg: Material, cost, strength etc.

5. RESULTS AND DISCUSSION

In this section we try to answer the questions one by one using the results of the descriptive studies:

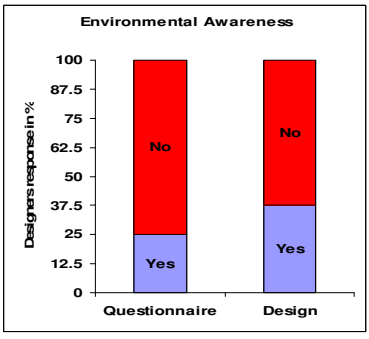

Figure 1. EA by Q1 and DE1.

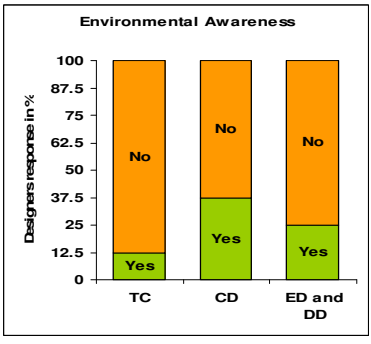

Figure 2. EA in different stages in Design.

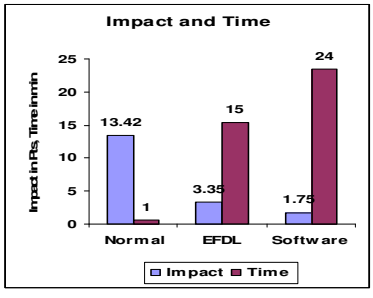

Figure 3. Average Time and Average Impact.

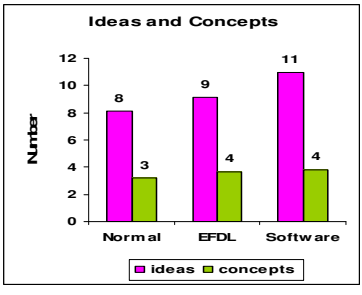

Figure 4. Average Ideas and Concepts.

5.1. Whether Designers Generally Consider Environment as an Important Criterion in Designing?

The following Figure 1 and Figure 2 shows the results from the Questionnaire1 and Design Exercise1 From the Figure 1 we can see that from questionnaire only 25% aware of environment and from design only 37.5% aware of environment. *So we can conclude that most designers are not aware or not considered environment as a major criterion in design*. Figure 2 shows what percentage of designers considered environment in different stages of design.

5.2. How Does this Consideration Change with the Availability of Information or Support for EFPD?

The following Figure 3, 4 shows the average time spent, average impact and average ideas, concepts across all problems for three design exercises.

From the Figure 3 we can see that average time spent on EFPD is increased from Normal to EFDL to Software and average impact is decreased from Normal to EFDL to Software. From the Figure 4 average number of ideas and concepts increased from Normal to EFDL to Software. ***From this we can say that by using EFPD literature and Software the consideration is bettered in terms of decrease in impact, increase in ideas and concepts and increase in awareness***.

5.3. What Aspects of General Designing must be Taken into Account while Developing Support for EFPD?

Following stages are observed in design across all problems

- **Task Clarification**: *Given requirements of the design are studied, clarified and written down.*

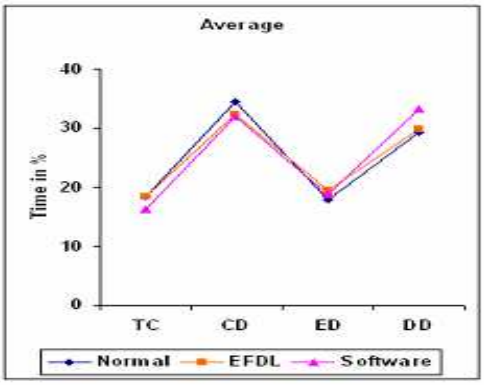

Figure 5. Time spent in different stages.

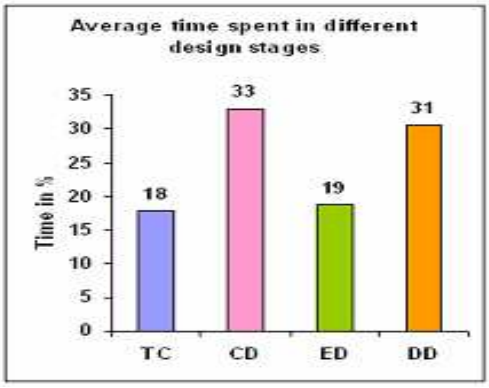

Figure 6. Average time spent in different stages.

- **Conceptual Design**: *Establishing principles, functionality of the ideas or solution for the problem specified, rough sketches and abstract material consideration.*
- **Embodiment Design**: *Defining the layouts, spatial compatibility between sub-assemblies, relationships between objects and abstract material specification.*
- **Detail Design**: *Dimensions, concrete materials and manufacturing tolerances are specified. Parts list, drawings and instructions prepared for other phases of product development.*

From Figure 5 we can see that the profile of time spent in each stage of design is similar across all problems. But time spent in task clarification and conceptual design decreased with EFD literature where as time spent in embodiment and detail design increased with respect to the normal design where as with software time spent on task clarification and conceptual design are still reduced and time spent in detail design still increased with minimal increase in embodiment design compared to normal. From Figure 6 it is clear that the average time spent in conceptual design is most with 33% then in detail design 31% then in embodiment design 19% and then task clarification 18%. From this what we can decipher is for conceptual and detail design similar amount of time is spent around 30% each and for task clarification and embodiment design similar amount of time is spent around 20%. In spite of spending similar amount of time in 3 types of exercises we have seen decrease of impact and increase of ideas and concepts as we go from NORMAL to EFDL to SOFTWARE because of increase in time spent on EFPD.

5.4. What are the Limitations of the Current LCA (Representative) Software in Design?

Below Table 3 consists of the questions asked by designers with frequency of repetition in each stage of the design and how many of them answered by the software satisfactorily. These questions have to be considered while developing support.

From the above table we can infer that current LCA software answered 1/3 questions by type in detail design, 0/1 questions in embodiment design, 1/7 questions in conceptual design and 0/1 questions in Task clarification. So the unanswered question types tell us what type of questions need to be given preference while developing tools for reducing environmental impact of product life cycle in different stages of design.

5.5. What are the Needs of Designers for EFPD?

The needs identified from the Questionnaire survey and from exercises are given in the following Table 4:

6. CONCLUSIONS

The literature survey, questionnaires and design exercises analysis helped in answering the following questions

Table 3. Queries by designers in different stages of Design.

Stage	Question	Frequency	Answered or Not
TC	Can we search the database for materials and processes based on application	1	No
	Can I compare strengths of materials	1	No
	I want to search materials of same strength	1	No
	Can we compare equal functionality material	1	No
CD	Need to compare materials of same strength for impact	1	No
	Can we search the database for materials and processes based on application	1	No
	Need more entries in database	1	No
	Browsing for less impact materials/Processes	1	Yes
ED	Search for processes required for a particular shape	2	No
	Should provide density values for materials	1	No
DD	Is wastage of material in production given	1	No
	Calculate Impact	6	Yes

Table 4. Needs of Designers.

	Generation	Evaluation
Task Clarification	Intended function of product and its importance in the usage environment Region for which product is intended and the local norms and standards Usage pattern of end user and their awareness of EFPD Disposal scenario of end user and region policies	Material's environment hazard indicator for life time Statutory norms and regulations Set targets for EFPD in design Listing down of problems dividing them into segments based on prospective environmental impact
Conceptual Design	Step by step process to help to create the EF concept Information and Clarification on each phase of life cycle Applications of particular materials, processes Comparison of materials of same capacity for environmental impact EFD ranking of different material already in use for same / similar products Guidelines for material selection so as to minimise environmental impact e.g. Fasteners vs. gluing etc Thumb rules for material selection Graphical comparison charts	A list of what else and how else options to minimise Environmental Impact A suggestive tool providing alternative ideas from other good EFD products A flow diagram of the material flow in its life cycle and the hazard indicator at each stage to enable weighting the indices at each stage based on concept assumptions List of materials with their quick calculation impact and comparative charts Recycling possibility Degradability and time required for degradation
Embodiment and Detail Design	Detail information about every material at every stage of lifecycle for impact purposes Material constraints Process constraints Some examples of the material used (applications used) Automated linking of EFD indicator based on 3D CAD model Quick predictive and approximate indication of EFD indices during detail design Optimisation tool aiding towards lower EFD indicator in terms of selection of best raw material and best method of joining vs. cost (A 3D graph would be useful) Graphical representation will be useful	What criteria should be taken care of at the time of evaluating detail design Some key properties of material Auto Link between CAD and Impact calculation Any optimisation should be indicated Normalised EFD indices in terms of their weights A SWOT analysis tool on the different options considered for detailing regarding the EFD indices Software can be made more user friendly so that novice can also use Impact of material through its life cycle - extraction / processing / transportation

- What are the primary reasons for little utilisation of Environmentally Friendly Product Design (EFPD) tools/methods/guidelines/methodologies in designing? *They developed in isolation without taking designer's requirements into consideration.*
- Whether designers generally consider environment as an important criterion in designing? *Designers did not considered environment as an important criterion.*
- How does this consideration change with the availability of information or support for EFPD? *Consideration is bettered by the availability of information or support for EFPD.*
- What aspects of general designing must be taken into account while developing support for EFPD? *Design Stages, requirements and outcomes in those stages and activities performed by designers found in those stages have to be taken into account while developing support of EFPD.*
- The needs of the designers for developing EFP are found and are addressed with development of a framework and tool.

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