Application of InDeaTe Design Tool for Designing Sustainable Products—Case Study of a Natural Water Cooler

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Abstract InDeaTe is a design tool developed to support designers to innovate using a methodical process. It has a process template and a linked database of methods. This paper discusses the application of InDeaTe tool for redesigning a natural water cooler developed by a grassroots innovator in Gujarat in order to make it more sustainable and successful in the market. Two design teams were involved in solving the problem at hand: one used the tool; the other did not. The outcomes of the design activities were compared. Analysis of the design documents and recordings showed that the team using the tool covered more aspects of the design and hence generated better design compared to that the team without the tool. This study indicated that InDeaTe toolbox could help in developing better design outcomes for product design problems. Future work on InDeaTe includes expanding its database and improving its usability.

Keywords Eco-design · Design for sustainability · Enabling tools · InDeaTe tool · Product design · Life cycle phases · Stages of design · Design methods

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1 Introduction

In hot and dry climate, people seek cool water for drinking. The drinking water coolers installed at public places need electricity and regular maintenance for sustaining the service. To address these problems, Mr. Arvind Patel, a grassroots innovator in the Indian state of Gujarat, who has been documented by National Innovation Foundation (NIF), Ahmedabad, developed a natural water cooler (NWC) which works on the principle of evaporation and does not need electricity. It is claimed to have low maintenance cost and is hence deemed suitable for public places and at places without electrical power supply.

This case study describes a re-design of the natural water cooler in order to improve its performance and appeal and to make it more sustainable. An experiment performed on students shows the difference that the use of InDeaTe tool brings in designing of a product. The resultant design is evaluated against a design generated without using the tool, to assess the improvement in sustainability considerations with the use of Tool.

2 Design Exercise

2.1 Exercise Summary

The design exercise was undertaken in June 2015 at the Centre for Product Design and Manufacturing (CPDM), Indian Institute of Science (IISc), Bengaluru. The design problem was introduced by a representative from National Innovation Foundation (NIF), Ahmedabad. The exercise was conducted in two sessions with a separate team in each one using the tool and the other without. The design outcomes were presented and feedback was taken from NIF. The design outcomes were primarily analysed for improvement in sustainability of the system.

2.2 Exercise Duration

The exercise was approximately for 16 h, spread over two consecutive days:

Day 1—Introduction to Problem and Task Clarification;

Day 2—Conceptual Design and Embodiment Design.

2.3 Design Teams

There were two teams:

Team 1 without the tool comprised of two PhD and one Undergraduate (UG) student.

One was a senior PhD Student from IISc, working on Design for sustainability, with Bachelors in Mechanical Engineering and Masters in Product Design, with Sustainability as the PhD topic.

The senior PhD Student from UC Berkeley was working on Hydrogen fuel cells, with background in Mechanical Engineering.

The UG student was pursuing B.Tech in Production Engineering from IIT Roorkee India.

Team 2 using the tool comprised of three PhD students and one UG student.

One was a junior PhD Student from IISc, working in the area of Network-enabled Manufacturing, with background in Mechanical and Biomedical Engineering.

One was a junior PhD Student, from IIM Ahmedabad, working in the area of Water-Energy nexus for sustainability, with background in Environmental Engineering.

The third was a junior PhD Student from WSU, working in the area of Life Cycle Assessment (LCA), with background in Mechanical and Civil Engineering.

The UG student was pursuing B.Tech in Mechanical Engineering from IIT Ropar, India.

3 InDeaTe Tool

There are various kinds of design support that focus on sustainability; however, most of these are for assessment and evaluation, such as the Swiss Ecoscarcity methods (Ecopoints) [1]. Certain tools such as DFE Workbench [2] are well-integrated with Solidworks CAD tools, and are able to support designers with respect to specific aspects of a design, environmental aspects in this case. There are other design methods that support only a specific phase of the Life Cycle e.g. the Use-phase [3].

Interaction of methods and tools at the various steps in the process of design has been noted in literature, and the need for interaction between design methods and computer-aided tools to support decision-making has been stressed [4]. Lopez-Mesa [5] enumerated potent findings about the knowledge and use of design methods in practice; she highlighted that very few methods are widely and systematically used, while most people are not aware of the availability of other methods, or believe that a large amount of time is required to use these methods. However, she notes that application of methods supports an array of tasks during the design process and leads to consideration of a large number of ideas.

Lopez-Mesa further stresses that a method contributes better to the design when it is within a computer based system [5]. Thus, there is need for computer-based support that covers all three pillars of sustainability—environment, society and economy—across the entire life cycle of the object of design, and addresses the need for improving sustainability of existing systems, with the systematic integration, to practice, of methods and tools.

The InDeaTe Tool [6] is a knowledge-driven support for designing sustainable products, services and manufacturing systems. It comprises a design process template and a database that work together to support designers through a computer interface. The template is developed from the ACLODS framework [7] as the basis, which presents a new paradigm of design in terms of the dimensions of Activities, Criteria, Lifecycle (LC) phase, Outcomes, Design Stage and Structure. The tool introduces the user explicitly to some of these dimensions, viz. Activities, LC phase and Design Stage, before prescribing the Template. The template offers an overview of the design process and provides a generic guideline to follow during the process. Four stages of design have been prescribed Task Clarification, Conceptual Design, Embodiment Design and Detail Design [8]. Every design has up to five Life cycle phases: Material extraction, Production, Distribution, Use and After Use. The Template encourages designing for the entire LC of the product, with the aim of making it more sustainable. At any point in the design process, designers perform one of these four activities Generate, Evaluate, Modify, and Select; abbreviated as GEMS.

The database consists of sustainability definitions, sustainability indicators and design methods, tools and principles. The definitions are meant to help clarify the design task at hand with respect to the sustainability perspective adopted, while the corresponding indicators prompt the relevant sustainability considerations in the design. The methods are intended to aid the designer in the design process to achieve these sustainability considerations. The tool is a platform where the template is introduced and the details of the design exercise, such as problem brief and details of participants, etc. are collected into a document for future reference. Before starting the design exercise, the user selects the type of design; the InDeaTe tool currently supports design of products, manufacturing systems and service systems.

4 Solution Without Tool

The team without the template first identified the requirements as follows:

- Provide affordability/reduced cost
- Provide accessibility for increased number of users in public (e.g. different heights)
- Provide service entrepreneurship (should provide more employment)
- Reduce weight: ease of packaging and distribution

- Increase indoor use (may affect humidity, space, fungal growth, capacity change)
- Making it multi-functional (e.g. heating up water in winter)
- Arrive at one standardized requirement for cylinder volume
- Decrease water cooling time to serve more people
- Separate containers to avoid loss of cooling
- Reduce size of the whole NWC.

Then they classified the parts of the device as either standard (parts bought off the shelf) or manufactured (non-standard parts specific to the design), as follows.

Manufactured parts: SS tank (Cost: bending, welding, cutting, Grade of steel = SS304), SS sheets, SS frame, Mounts (bending and welding).
Standard parts: Solar panel, viscose around copper tube (bending), bending viscose copper tube, fan assembly, purifier assembly, tap assembly, dripper assembly, and final assembly.
A framework of solutions for manufactured parts was created, wherein the requirements were matched with the manufactured parts. Manufacturing techniques were assessed for their ability to satisfy the requirements and proposed solutions were noted in the corresponding cells. Finally, the team came up with conceptual sketches (Fig. 1) and a new bill of materials (Table 1) showing major cost reduction.

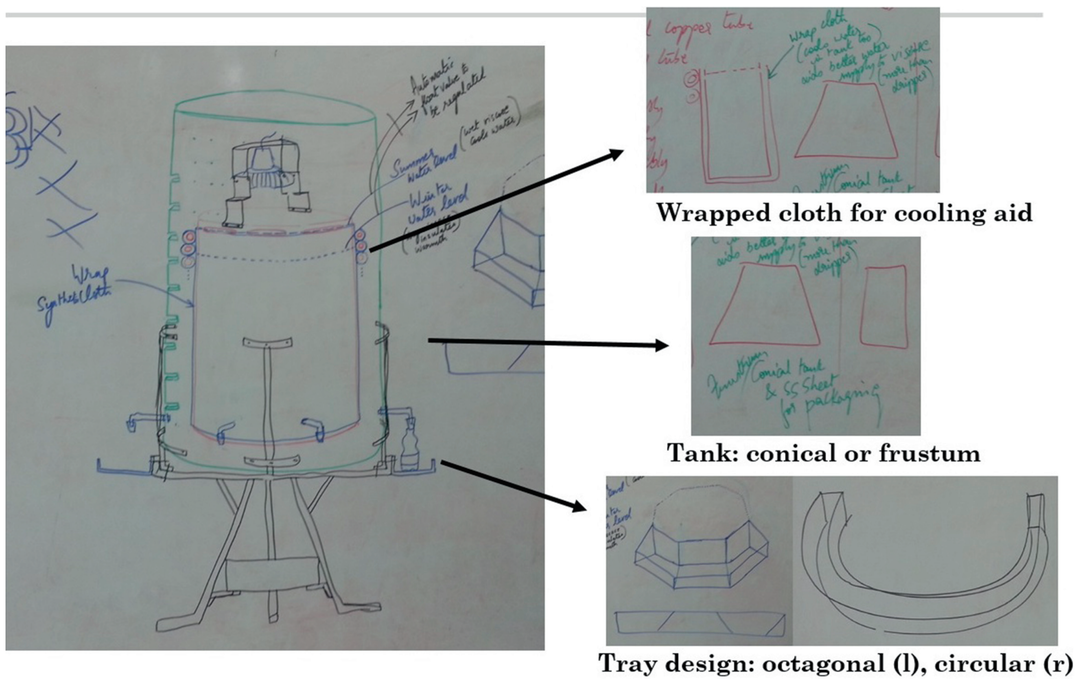

Fig. 1 Sketches of new design of natural water cooler without using InDeaTe tool

Table 1 Bill of materials of the new design created using the tool

	Component		No. of Units			Weight (kg)			Unit cost (₹)			Cost (₹)			Labour cost (₹)			Total cost (₹)		
	O	New	O	A	B	O	A	B	O	A	B	O	A	B	O	A	B	O	A	B
Manufactured parts	Structure including stand (SS304)		1			13	8	13	240/kg			3120	1920	3120	2500	1540	2500	5620	3460	5620
	SS sides of outer body (SS304)		4	1	4	25	22	25	240/kg			6000	5280	6000	1800	1000	1800	7800	6280	7800
	Tray (SS304)		3	1	3	6	18	6	240/kg			1440						1440	1440	1440
	Cylindrical stand (SS304)		1			3			240/kg			720						720	720	720
	Cylindrical tank (SS304)		1			10			240/kg			2400			400			2800	2800	2800
	Tray for drained out water		1									250						250	250	250
Standard parts	Wrapped cloth		0	1	0	0	0.5	0	0	200/kg	0	0	100	0				0	100	0
	Copper coil	Bundy coil				10.5			630/kg	100/kg		6615	1050	1050	300			6915	1350	1350
	Automatic float chamber											300	150	300				300	150	300
	Taps		6	8	6				100/unit			600	800	600				600	800	600
	Nuts/bolts					0.5			500/kg			250						250	250	250
	Plumbing material											1200						1200	1200	1200
	Purifier		1	1	2				700			700	700	1400				700	700	1400
	Miscellaneous											2000						2000	2000	2000
	Viscose cloth					10			150/kg			1500						1500	1500	1500
	Accessories (SS304)					1			240/kg			240						240	240	240
	Solar panel		1									2000						2000	2000	2000
	Blower (12 V DC)		1									900						900	900	900
																		35,235	26,140	30,370

O = original design, A = without tool, B = using tool

5 Solution with Tool

In the Task Clarification stage, the team using the template identified the system boundary, selected the indicators and analysed the current situation. They identified the requirements as per the life cycle phases, generated ideas accordingly in the Conceptual Design stage by brainstorming, and developed solution variants. In the Embodiment stage, the selected concept was evaluated using Fault Tree Analysis. The 6R principle was followed throughout. In the final solution, some modifications were recommended outright, while some were suggested after more detailed analysis.

5.1 Task Clarification

The system boundary was set as follows: The cooling capability of the device should not be compromised, and cost should not increase significantly. The filtration type, energy source, size, materials, and layout can all be changed.

Issues with the current situation were identified as the following:

- Cost is as high as conventional devices in the market
- Filtration and cleanliness of the device must be taken care of by regular maintenance
- It is not easily portable
- Due to modest aesthetics it is perceived as a cheap substitute to conventional devices, which affects its social acceptance to some extent.

The requirements were identified and classified as demands or wishes, as follows:

Demands: cooling, filtration, independent of external power source.
Wishes: inexpensive, durable, low maintenance, aesthetic, portable.
The Problem Statement was stated as the following: Improve the design of the natural water cooler to make it more cost effective over its lifecycle and appealing to users while performing all the necessary functions.

5.2 Conceptual Design

For each major requirement, ideas were generated using brainstorming. Some of these ideas were shortlisted for their relevance and feasibility. The requirements were also classified according to the phases of the lifecycle. During this exercise, some new requirements were also identified, though these were not high on priority. The shortlisted ideas were enlisted along with ideas for the newly identified requirements.

5.3 Embodiment Design

The configuration of the device was determined after the conceptual design stage. In order to make the device more reliable, the proposed design was subjected to a Fault Tree Analysis (FTA). Following the FTA, a final set of recommendations was proposed to design the device.

- Change tubing material from copper to Bundy tube (copper coated steel)
- Move filter from bottom of tank to top of tank
- Use automatic shut-off filter to ensure that water is always clean
- To facilitate automatic shut-off without cutting off water supply use a two filter system with a valve to switch to the other filter when one becomes inoperable
- Move blower from top of device to the bottom to create a more efficient counter-flow heat exchange
- Use spring-loaded taps to reduce water waste from people leaving the tap on
- Recycle drain water to use for evaporation water by way of a sieve and a small solar panel driven pump to reduce water wastage
- Change the shape of the tube (e.g. square cross section) to increase surface area from which to achieve cooling
- LED display light to signal when filter needs change.

Based on these recommendations, the layout of the new design was developed and was compared with that of the old design (Fig. 2).

On the basis of the selected design and configuration, a preliminary cost analysis was done to check whether any cost reduction was achieved (Table 1).

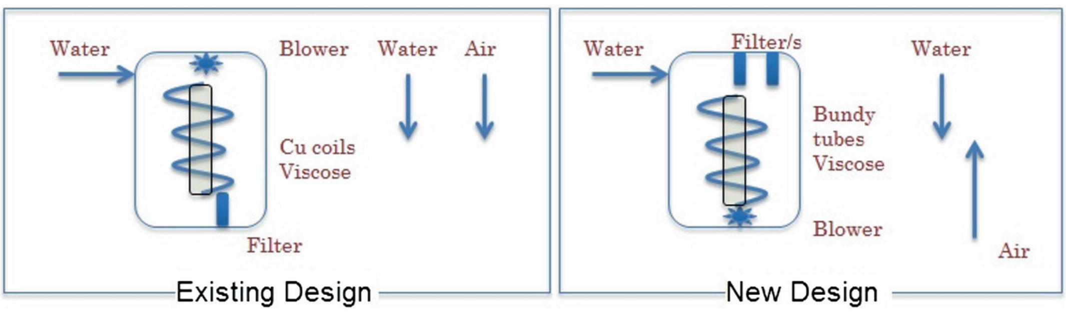

Fig. 2 Schematic diagrams of old and new designs using InDeaTe tool

6 Analysis of Design Processes

The control variables in this study include an engineer/designer, the given problem, template and the database, whereas the discrete, uncontrolled variables consist of the engineer/designers' educational background and prior experience, individual and group dynamics, in addition to expert intervention. Although the team using the tool did not explicitly select any definition of sustainability, it followed the triple bottom line [9] and 6R principles throughout the design process. The team using the tool found it difficult to choose and apply indicators from the database, as these seemed to be too generic for this purpose. Though both teams generated a list of requirements initially, the team without the tool focused mostly on the manufacturing phase of the device. On the other hand, the process followed by the team using the tool was more structured and covered all phases of the life-cycle. Considering the time constraints of the exercise, they chose simpler methods. The choice of methods was also influenced by the participants' prior experience. The team without the tool generated an innovative design with respect to the manufacturing process and cost, but the team using the tool also covered various other considerations in their design. So, the tool seems to provide an edge to the team by aiding to be comprehensive in providing an efficient and effective, sustainable solution by considering all design and LC stages.

The limitation to the experiment is the potential lack of parity in groups with respect to the participants' education and prior experience. It is possible that a participant, who is already a good designer, or has prior knowledge of sustainability, life cycle analysis and/or cost/benefit analysis or any other relevant skill, will bias the experiment. However, the attempt of this experiment is to provide more options, a structure, and considering all aspects of designing and lifecycle stages, in addition to an engineer/designers' prior experience. The study clearly shows that an attempt to provide a more sustainable design in a short period of time with the help of InDeaTe tool is possible. When this exercise was conducted, the tool was in a primitive state. Therefore, the process of using the database was not very clear, and the categorisation of methods was not very convenient. These issues have subsequently been addressed in the later versions of the tool. The team using the tool also felt that following a rigid structure in the given time frame inhibited them from pursuing unconventional ideas. More time during the brainstorming session, and the awareness about the tool to aid at being comprehensive at the design stage and not just as a checklist of tasks, may help. Moreover, the database at that point seemed to lack in methods for certain purposes, e.g. social (human behavioral) systems. Lastly, other factors could have influenced the design processes in both the teams, like group dynamics. These factors also play an important role and impact the groups output to some degree.

7 Conclusions

The participants felt that although the InDeaTe tool provided a structure to the design process, it should not be inhibitive to the designers. The database needs to be populated so as to address a comprehensive set of possible scenarios during the design process. Some of the learnings from the study include addition of the typical duration of time needed to use the tool, and the software skills required to use the database. Future work involves applying the tool on a wider variety of design problems so as to understand the major areas of strengths and weaknesses, so that appropriate modifications could be initiated.

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