

CAD based material selection for sustainable design

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Abstract—Researchers describe sustainable development as having three dimensions: an economic, a social and an environmental. In the business community, this has been well known as “the triple bottom line” or as “people, profit and planet”, pointing out that sustainable development for business, involves the simultaneous pursuit of economic prosperity, environmental quality and social equity. From the design of product point of view, this approach can be achieved mainly by the Design for Sustainability. Industrial designers should better understand the negative environmental and social impacts of the products they create. They can easily promote a new, more environmental friendly product design, accompanied by culture and lifestyle. In addition, they should understand how to make the required changes, in order to develop products with more sustainable values. However, many of these values are influenced by a range of other factors, such as ergonomics and styling. The present paper considers that sustainability is mainly a direction rather than a destination that will be actually reached. According to this direction, different product designs have been developed using advanced CAD systems. The target is the economic product development, which can be reached by environmental friendly ways, while at the same time they can be socially acceptable.

Keywords—CAD, material selection, industrial design

I. INTRODUCTION

Sustainability in the field of product design, which can be considered as part of the wider research and practice of sustainable development. This was defined by the World Commission on Environment and Development as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ [1]. Many definitions have been given to what sustainability is, but since the mid 1990s it has been widely accepted that sustainability is a multi-oriented concept which considers environmental, social and economic aspects at the same time. These are also known as the three pillars of sustainability or as the triple bottom line - people, profit and planet [2].

Environmental sustainability is about making products that serve useful market and societal functions with less environmental impact than currently available alternatives. Moreover, environmental sustainability necessarily implies a commitment to continuous improvement in environmental performance. This can be done by using processes which reduce energy and material consumption via clean manufacturing, while maximizing the possibility for reuse and recycling through end of life strategies [1].

There is not any accurate definition for social sustainability. This is true because social phenomena are less tangible than economic or environmental, but also social sustainability is referred to both the individual and the collective. Social balance is achieved by community interaction, shared values and equal rights. An inadequate investment in social factors can lead to violence and social problems. Social sustainability concerns, within a business look, to both internal factors (working conditions, wages, access to education etc.) and also external factors (impact on those who live near the operating centers of the business, consumers etc.). These factors have impacts on culture and community, which are difficult to be measured.

Economic sustainability can be considered as the ability to maintain stable monetary capital. At the level of the organisation, economic sustainability is simply how a company stays in business, measured in terms of growth and profit, or by its survival. Good financial performance is necessary for short term survival, but does not necessarily guarantee business success, or positive results for other types of sustainability (social or environmental) [3].

II. DESIGN FOR SUSTAINABILITY

There is plenty of research work about Eco-Design and Design for Environment (DfE), but these do not directly approach the social and economic aspects of sustainability. Design for Sustainability is a larger field than DfE and Eco-Design separately, and includes them as more limited concepts. The Design for Sustainability concept describes methodologies for making sustainable improvements (social, economic and environmental) to products by applying elements of life cycle thinking. Generally speaking, Design for Sustainability is an Eco-Design concept that has evolved to include both the social and economic elements of production. It integrates the three pillars of sustainability by designing green products and tries to fulfill consumer needs in a more sustainable way [4].

A. Social sustainable design

Design helps better meet the needs of consumers and users, as it allows for increased usability and user-friendliness. User-friendly and safe products or services benefit all users. Social sustainability is also the design for all philosophies, targeting to the minority users, such as disabled and elderly individuals, children and individuals from cultural or linguistic minorities. As far as product safety is concerned, design is crucial since it determines, at an early stage of development, critical safety aspects such as product functions, materials used, warning texts, age grading (especially for toys) and mechanical, electrical or chemical characteristics. Design plays a key role for some individuals' ability, to enjoy basic human rights like housing, employment and education.

The toy described in the case study section of the present paper has as a target to introduce the young users in a more sustainable way of life. More specifically, it creates a culture towards recycling. Social sustainability measurements are hard to be performed, especially when comparing them with measurements relevant to the environmental and economic sustainability.

B. Economic Sustainable Design

The use of design has a positive impact on the performance of a company, measured in terms of profitability, share price, employment or exports. At the level of the consumer, design can produce products and services that are accessible to a broader range of users. This can be achieved by creating products and services that are more economic to produce, transport and use, and better adapted to their needs, i.e. developing countries [5].

TABLE I: SUSTAINABILITY CAN BE MANAGED THROUGH PRODUCT DESIGN

	Extract of Raw materials	Manufacture	Distribution	Use & Maintenance	End-of-life
Economic	-Material selection -Use local sources	-Material selection for assembly	-Green logistics saving costs of transportation. -More competitive price policy.	-Cost to repair. -Lifespan. -Design for all.	-Financial impact of disposal -Design for Disassembly
Environmental	Re-place harmful substances with more environmentally friendly alternatives.	-Eco-Design for Environment -Reduce energy and material consumption	-Green logistics -Reduce energy consumption	-Easy use -Re-use -Ease of repair -Less energy consumption -Lifespan	-Recycling for disassembly. -Less impact of disposal.
Social	-Material selection - Local source - Socially responsible sourcing of labor. - Health and safety	-Material selection -Socially responsible sourcing of labor -Health and safety	-Green logistics. -Differential pricing.	-Inclusive design -User safety -Ease of repair.	-Recycling -Local impact of disposal.

C. Environmental sustainable design

Designers make decisions on the use of resources, ways of consumption and the lifecycles of products and services. Environmentally Sustainable Design (also referred to as 'Green Design' or 'Eco-Design') helps products, services and systems to be produced in a more efficient way. It reduces the use of non-renewable resources and minimizes the environmental impact. Some of the rules for managing Environmentally Sustainable Design are: the use of low-impact materials, the smaller consumption of natural resources, the creation of longer-lasting and better-functioning products, which can be reused, recycled or composted after their initial use.

Choosing products based on their carbon footprint is already an important factor for the product's validation [6]. Table I depicts the way that sustainability can be managed through the product design, considering all the three pillars of sustainability (Economic, Environmental, Social) for each stage of the product life cycle. Positive changes that can be applied to each stage in any pillar of sustainability make the product more sustainable. Very often there is an interaction between them, so designer must act in a way that positive changes to one factor, should interact positively to the other factors of sustainability too. If a positive change acts negative to other factors, the measure of the total sustainability will prove if the proposed change was successful or not.

III. CASE STUDY

In the present paper, the product selected to be designed -keeping in mind all the principles previously mentioned- is called 'Eco-Maniac Bin' (Figure 1). It consists of a basic bin, together with a number of additional parts such as bottles, cans, books and tetrapack-like packages. During its design, an effort was made in order to Re-think the product and its functions. The similar existing in the market toys are targeting the development of children wit spark. All toy-pieces should

be entered successfully through the correct holes based on their shape. Traditionally, the shapes used for the pieces are cylindrical, conical, cubical, pyramidal etc. Eco-Maniac Bin transforms these simple geometries to existing products with specific shapes. The result is that the children not only achieve the appropriate selection for every item, but at the same time are getting used in the recycling action [7].

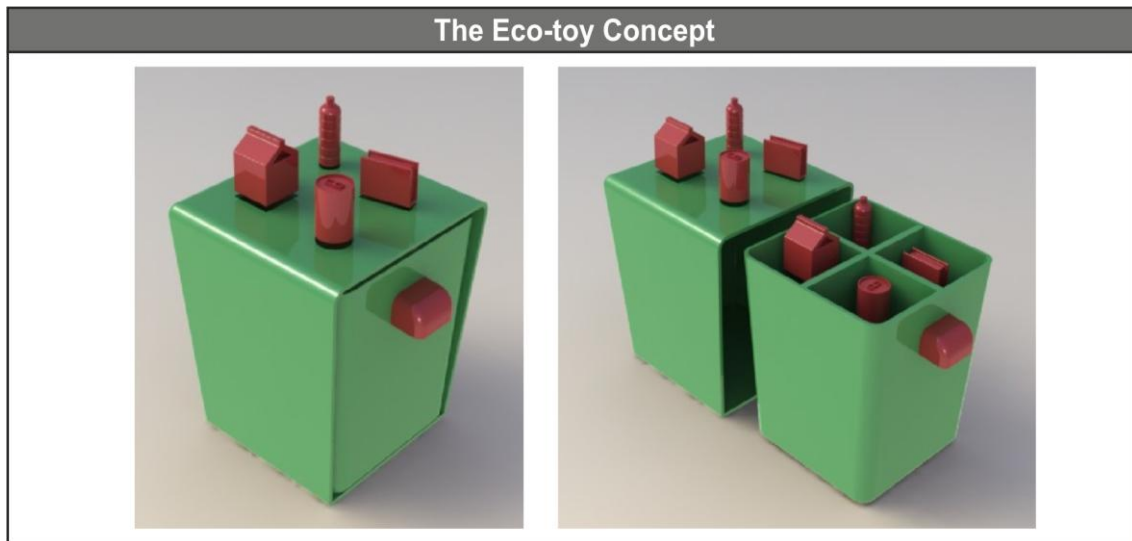


Fig.1: The Eco-Maniac Bin

The goal was the redesign of an existing product for which the specific market and manufacturing conditions are already known, taking into account its primary function and the associated services provided. The toy's improvement potentials can be determined as the product already exists, so market and manufacturing information are readily available. Redesign targets for a more radical approach in terms of economic, social and environmental impacts. The finished, redesigned concepts of the proposed toy should be compared to the consideration and estimation about the sustainability advantages.

Life Cycle Assessment (LCA) is the detailed analysis that gives the pieces of information someone needs to take the most environmentally friendly decisions throughout product design. The analysis looks at a product's entire life, which encompasses extraction, material production, manufacturing, product use, end-of-life disposal and all of the transportation that occurs between these stages.

Dassault's SOLIDWORKS/Sustainability™ piece of software measures four environmental indicators over the life cycle of a product:

- **Carbon Footprint** – Carbon dioxide and other gasses resulting from burning fossil fuels accumulate in the atmosphere, which in turn increases the earth's average temperature. This is widely known as Global Warming Potential (GWP). The carbon footprint is measured in units of carbon dioxide equivalent (CO₂e). Scientists blame global warming for problems like loss of glaciers, extinction of species, and more extreme weather, among others.
- **Water Eutrophication** - Eutrophication occurs when an overabundance of nutrients are added to a water ecosystem. Nitrogen and phosphorous from wastewater and agricultural fertilizers cause an overabundance of algae to bloom, which then depletes the water of oxygen as a result the death of both plant and animal life. This impact is measured in either kg phosphate equivalent (PO₄) or kg of nitrogen (N) equivalent.
- **Air Acidification** – Burning fuels creates sulphur dioxide, nitrous oxides, and other acidic air emissions. This is a main cause for the acidity of rainwater, which in turn acidifies lakes and soil. These acids are the main reason which can make the land and water toxic for plants and aquatic life. Acid rain can also slowly dissolve man-made building materials such as concrete. This impact is typically measured in units of kg sulphur dioxide equivalent (SO₂).
- **Total Energy Consumed** – This is a measure of the non-renewable energy sources associated with the part's lifecycle in units of megajoules (MJ). This impact includes the electricity or fuels used during the product's lifecycle, but also the upstream energy required to obtain and process these fuels, and the embodied energy of materials that would be released if burned. Total energy consumed, represents the net calorific value of primary energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.). Moreover, efficiencies in energy conversion (e.g. power, heat, steam, etc.) are also factors of concerns.

For each of these four environmental indicators the software provides a continuous, real-time assessment for a large amount of material choices. The Environmental Impact dashboard displays a continuous, real-time assessment of each indicator with current values as well as comparisons to the first baseline design. This comprehensive view makes it easy to see the environmental impacts of the design choices and incorporate sustainability as a standard part of the design process. So the designer with the help of the software is more capable to find the right material for the particular job, while it can be

demonstrated how alternative materials compare to the initially used material, in terms of environmental impacts as well as standard engineering properties i.e. thermal conductivity, yield strength.

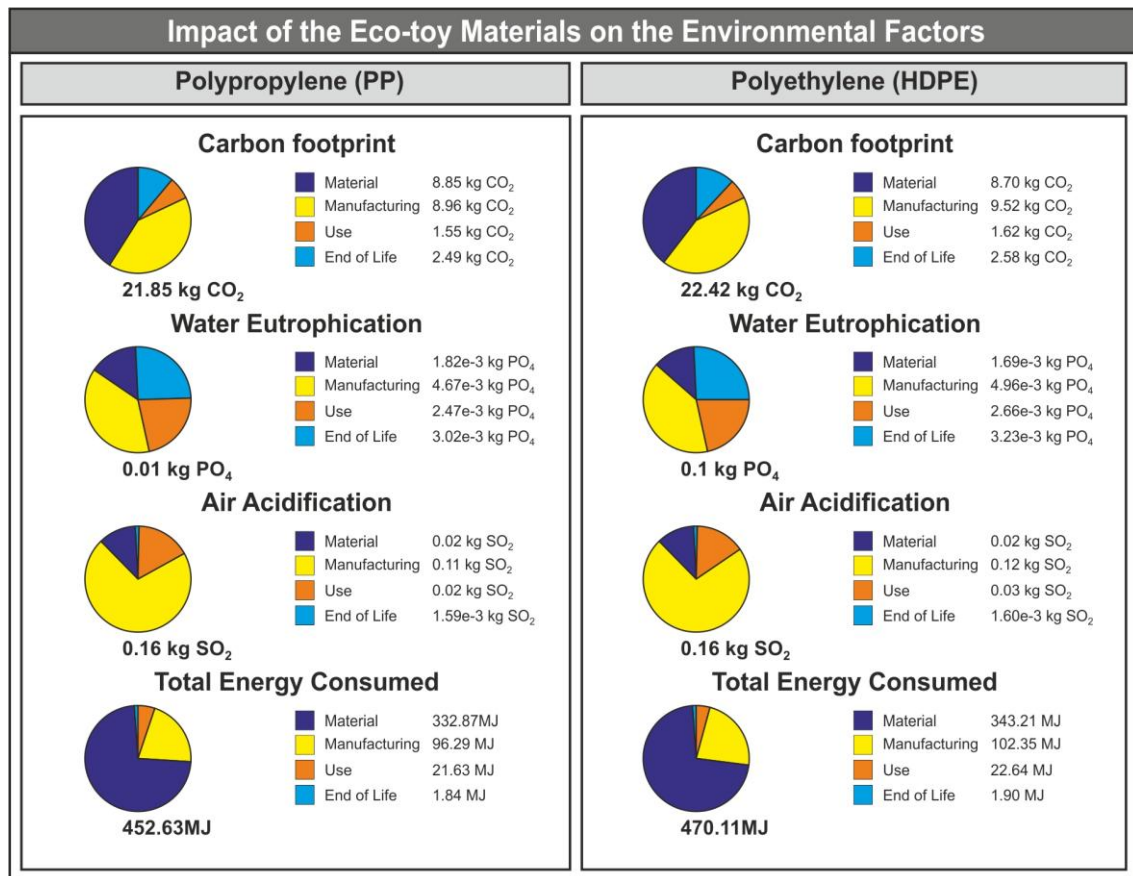


Fig. 2: Impacts of the Eco-toy material on the four crucial environmental factors

SOLIDWORKS/Sustainability™ software demonstrates the real, verifiable steps that should be taken to minimize environmental impacts. There is an automatic way to generate a report with the contact information and company branding that shows the sustainability profile of the product, before/after comparisons, multiple design alternatives, and the entire impact of complex assemblies. Also measures impacts over a design's entire life cycle, which includes extraction of raw materials, manufacturing, product transportation, use, and disposal. Each impact is examined using the science of Life Cycle Assessment (LCA) through a partnership with PE International, a pioneer in the LCA field. PE's extensive GaBi™ life cycle inventory database reflects empirical data gathered over decades, and has become the worldwide standard for environmental impact data [8]. This software removes traditional obstacles to sustainable design, making sustainability a seamless part of the design process, giving both to the designer and environmentally-conscious company a competitive edge.

Measuring these impacts it leads to a successful implementation of Design for the Environment strategies. The same process was used during the redesign of the Eco – toy. The materials selected were polypropylene (PP) and high density polyethylene (HDPE). Both of them can be used in order to produce the Eco-toy. SOLIDWORKS/Sustainability™ looks at how design decisions affect the four aforementioned crucial environmental factors and produces the following graphs.

A comparison table for each stage of the product's life cycle is given, separately for each case of the material used. According to figure 2, the impacts for water eutrophication and air acidification in the whole life cycle of the product are equal for both the materials examined. From the carbon footprint point of view, high density polyethylene is approximately 3% more harmful for the environment than polypropylene, while at the same time it requires 3.8% more energy consumption than polypropylene.

Fig. 3 illustrates that high density polyethylene is more environmental friendly at the stage of material procurement for the carbon footprint, water eutrophication and air acidification, while at the phases of product manufacturing, product use and end of life, polypropylene is less harmful. In addition, high density polyethylene consumes more energy to all stages of its product life cycle than polypropylene. The comparison was made considering that Europe is the place of production and Europeans citizens are the main users. Changes to these issues can change the result of the life cycle assessment for the product into consideration, because LCA is dependent on the environmental conditions of the place of production and also on the place of the product's main use.



Fig. 3: The comparison of the four crucial environmental factors per lifecycle stage.

As a result, the material which was chosen for the Eco-toy was polypropylene. An additional advantage, which is worth mentioning, is the integration of the CAD module of Dassault's SOLIDWORKS™ with the Sustainability™ module. This integration is based on the direct recognition of the material and their properties for all the parts of the product's assembly. The quantities of each material, in the final product assembly, is used for the life cycle assessment. Each impact on the product's entire life cycle during the design process is examined via the extensive use of the appropriate environmental impact data provided by the worldwide leader PE International™.

IV. CONCLUSIONS

There are a number of methodologies available for the product designers to follow in order to produce more environmental friendly products. All of them are dealing with different aspects of the same problem and emphasize one or more of the three pillars of sustainability. Nevertheless, the designers need a more specific tool that can help in assessing the quality of their designs in a more direct and systematic way.

The integrated environment that Dassault is providing within the SOLIDWORKS™ product design platform, is a powerful tool for incorporating sustainability early enough in the product life cycle. As a result, the product designer can use CAD and sustainability principles directly, when designing a product. These principles can give both to the designer and the environmentally conscious company a competitive edge, and lead towards the production of more environmental friendly products. After all, the best evaluation of the overall sustainability will be done after the product is launched, but the

designers are given the chance, via modern CAD systems, to work towards more sustainable designs right from the beginning.

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