PRODUCT SUSTAINABILITY ASSESSMENT IN CONCEPTUALISATION PHASE

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Abstract

Along the design process many decisions and compromises are made in order to reach a final design solution. In literature is commonly accepted that tackling sustainability issues at early stages provides a better opportunity to make a positive contribution. Nevertheless, designers face a paradigm, how can they assess the sustainability of something that is not yet conceptualised? Another important constraint for addressing sustainability issues at early stages is that most tools supporting in this task are designed to assess once the product is defined; there is very little to no tools at all addressing the needs and culture of designers at early stages of design. This paper presents a series of test where designers were asked to follow a design process and given a novel "soft modelling" tool to assess concepts. The results show that designers' primary reaction is to deny the assessment of something they have not defined yet. Nevertheless, if used, the tool was found that it is possible for them to reflect on the options and future decisions. This results show that the "soft modelling" approach if developed could provide important aid to designers at early stages.

Keywords: Ecodesign, New product development, Sustainability, Early stages of design, Soft modeling

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1 INTRODUCTION

The Design field has created a large number of guidelines, checklists and analytical eco-design tools (Tischner, 2001, Baumann et al., 2002, Pigosso et al., 2014, McAloone and Evans, 1997) to help designers deal with the complexity that represents sustainability in the development of new products. Vezzoli and Manzini (2008) identified the efficiency of integrating environmental requirements in the different stages of product development, and the applicability of one of the most widely mentioned tools for product development: Life Cycle Assessment (LCA). Figure 1 shows this relationship.

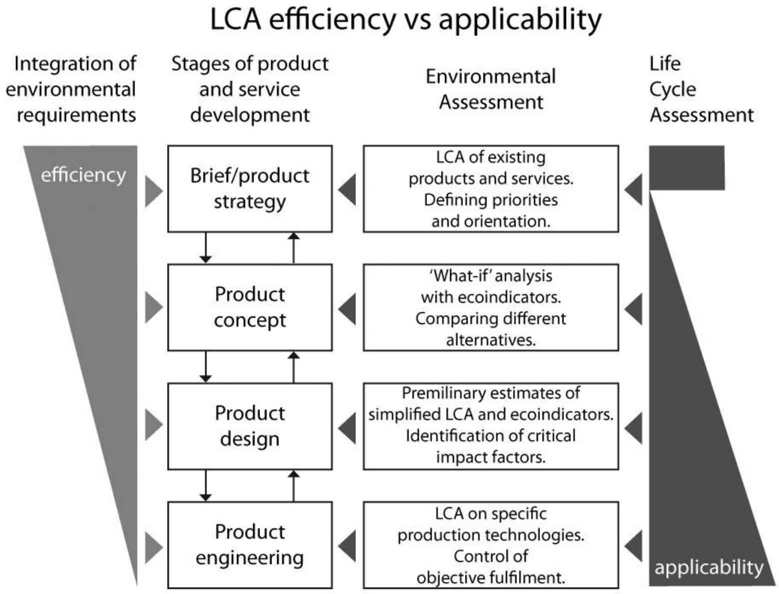

Figure 1. Efficiency and applicability of LCA (Vezzoli and Manzini, 2008)

Other authors agree that the efficiency of integrating environmental requirements is higher at early stages (Matzke et al., 1998, Bhamra et al., 1999, Ritzen, 2000, Sherwin, 2000, Lindahl, 2005) when the problem is first stated (sometimes in the form of a brief), and the product strategy or specification is defined (issue regularly and intrinsically multidisciplinary). This is the point where the information to solve it, if it is not already available, must also be acquired. These early stages are highly relevant because the way the initial configuration of a design problem is defined is crucial for the development of the entire process.

This efficiency then diminishes along the process due to the 'moves' (Schön, 1983) taken by designers and other stakeholders, and the commitments that come along (Goel and Pirolli, 1989), until the product finally reaches the market.

The relevance of the early stages of product development is further supported by the European Commission (2012), which stated through their Enterprise and Industry Department: 'more than 80% of the environmental impact of a product is determined at the design stage'. Similarly, Fabrycky (1987) found that over 70% of the final product is directly influenced in design stages. These findings have also been discussed by other researchers (Andreasen and Hein, 1987, Burall, 1996, McAloone and Evans, 1997).

Despite the demonstrated relevance of early stages, there is evidence of a lack of investigation in creative approaches and the few supporting eco-design tools specifically developed for it (Jones, 2003). Sherwin (2000) takes a step further and concludes that eco-design is not even connected to design itself at all; it has normally been restricted to technical dimensions. Lastly Vallet, Eynard et al. (2013) state: 'the basic culture of designers does not allow them to know which lever is really efficient for environment improvement… new support tools to train designers with strategy definition should be investigated'.

In the literature review some researchers assessing eco-design tools were found, not specifically for early stages, but their conclusions many times pointed out to their importance. Next is presented some of the most relevant findings these researchers produced. Collado-Ruiz and Ostad-Ahmad-Ghorabi (2010) stated that the most differentiating factor among eco-design tools was a high detail in the information, because it does create fixation and diminishes creativity. Therefore, they conclude: 'information must be available, but fixation avoided'. Finally, they define 'soft information' as the most appropriate for designers for its specificity and level of detail, but provide no further definition.

Bovea and Perez (2012) found that although the diversity of tools for integrating environmental aspects in new product development is wide, in real-life scenarios they are scarcely implemented, and they recommend three main characteristics for new tools, one: early integration of environmental aspects into the product design and development process, two: life cycle approach: how the product affects in its different stages, three: multi-criteria approach.

Other researches have explored in higher detail why designers don't engage with eco-design tools. Particularly interesting is the PhD thesis of Stevenson (2013). He sets to investigate through a series of interviews with experienced designers, the influencing factors on design consultants for the adoption of responsible design and what determines it. In the interviews Stevenson (2013) received specific comments related to the eco-design tools designers have available: designers want tools that are efficient in terms of less complexity or even overbearing, appropriate to the way designers work, one of them saying that he 'rather have a "ready reckoner" over a tool that can provide more accuracy but with greater effort', which aligns with other researcher's findings like Shedroff's (2009) when he talks about Total Beauty: 'isn't valuable for its accuracy so much as the general impression… Often, this is what designers need to know most, especially during concept and prototype phases'.

The lack of demand in incorporating environmental or sustainable principles in product development creates in turn no interest in eco-design tools, as found by Luttropp and Lagerstedt (2006). Also taking into account the dependency of decisions made in early stages of product design in relation to future environmental solutions' applicability and cost allocations, many designers see a contradiction between eco-design and economic growth.

These findings indicate the lack of relevance of these tools at early stages of design, with indications that environmental assessment and strategy definition is more influenced by expertise than the use of tools. This in turn may invoke fixation and a predetermined mental set (Sternberg, 2003), probably caused by their experience (Purcell and Gero, 2006) in the form of a 'pre-analytic vision' (Schumpeter, 1954). Another probable cause for fixation might be related to the type of 'external stimulus' these tools represent to designers, and may not reply adequately in the level of abstraction and transformation described by Goldschmidt (2011).

Lastly, in order to build a perspective of the current tools assisting designers in incorporating sustainability issues in their designs, a review of 30 tools commonly referenced in the literature was made. As a summary can be said that these tools are presented in two forms, one of checklists or guides, which are mostly linear and in written containing in-depth information about best practices; and the other in the form of analytical tools as standalone software, web pages or mobile device applications. This category varies greatly in the complexity, quantity and methods in which the information is presented; therefore, it's necessary to review the basic considerations other researchers propose for information visualisation in order to define the appropriate ones for the culture and needs of designers at early stages of product design.

Schneiderman (1996) defines seven tasks in data search: Overview: Gain an overview of the entire collection. Zoom: Zoom in on items of interest. Filter: filter out uninteresting items. Details-on-demand: Select an item or group and get details when needed. Relate: View relationships among items. History: Keep a history of actions to support undo, replay, and progressive refinement. Extract: Allow extraction of sub-collections and of the query parameters.

Based on the findings in the literature review and following Schneiderman's seven tasks in data search can be concluded that a tool better fitted for the early stages of design should mainly focus in "Overview" and "Relate". "Filter" and "Details-on-demand" could be highly beneficial depending on the method and quantity in which the information is delivered. "History" is a basic need for navigability, and "Extract" and "Zoom" are secondary.

Most of the reviewed analytical tools are built as Life Cycle Assessments (LCA), with some rare exceptions, even those marketed as "light" or "simplified" LCA provide a limited capacity of "Overview", this because the process is built through several different screens and inappropriate method of information delivery, as it will be explained further down. The "Zoom" sometimes is not possible once finished the life cycle or is necessary to re-run all sets of screens. The "Filter" task is normally non-existent as very large sets of data are normally presented. "Details-on-demand" is also most of the time not met, as all details are always present. The capacity to "Relate" items is sometimes present or provided in an inappropriate method of information delivery. "History" of actions is most of the time also constantly accessible. "Extract" is one very common and thorough feature. But as mentioned in several occasions it is also very important to consider the method of information delivery. Larkin and Herbert (1987) differentiate between external representations as 'sentential' and 'diagrammatic', and distinguish that diagrammatic representations are normally superior for solving problems because: "Diagrams can group together all information that is used together, thus avoiding large amounts of search for the elements needed to make a problem-solving inference. Diagrams typically use location to group information about a single element, avoiding the need to match symbolic labels. Preserve explicitly the information about the topological and geometric relations among the components of the problem". Therefore, diagrams are ideal for understanding trends, clusters and comparisons. Most of the existent tools use primarily sentential representations; a tool for the early stages should present most of its information in diagrammatic way.

2 TOOL DEVELOPMENT

This research attempts to answer the question: assisted by a soft modelling tool can designers perform a sustainability pre-assessment of a new product development during the conceptualisation stage? Collado and Ostad's (2010) proposition of 'soft information', and the similar reflections by Sherwin (2000) and Lindahl (2005) presented previously became central for this research as the more appropriate way for structuring a new tool which could allow designers a pre-assessment of a product at early stages of design, and lead to seek a deeper understanding of the term "soft information" which is presented next.

The Oxford Dictionary (2014) defines "model" as: 'a simplified description, especially a mathematical one, of a system or process, to assist calculation and predictions'. The terms 'hard' or 'soft' are sometimes added when the model being built considers all factors and possibilities in a deterministic fashion for the former, or a more simplified and holistic approach is taken in order to gain speed and a broader perspective for the latter. This is particularly useful when the researcher faces more qualitative than quantitative information, or when there is no solid ground where to start as is often the case in Social Sciences (Hartmann, 1996).

Falk & Miller (1992) note Professor Herman Wold as the developer of a soft mathematical and statistical model for the social sciences, where 'is soft in the sense that it makes no measurement, distributional, or sample size assumptions'. They explain further: 'as an aid to researchers, soft modelling provides a system for expressing theoretical ideas about a sequence of events. It can be thought of as a tool for assessing ideas by relating theoretical interest to observations of the world as experienced'.

Therefore, the approach was to use a 'soft modelling' system with the goal of creating 'the optimal linear predictive relationships among variables', not a final statement of causality (Falk and Miller 1992). In other words and focusing on this research, it seeks to highlight the connections and interdependencies among the life cycle steps of any given product in order for the designer to make more informed decisions; this is, switching designer's perspective from the particulars to their theoretical coherence (Polanyi, 1969).

In light of the findings in the literature review, the researcher designed a 'soft modelling' tool that attempts to incorporate the recommendations of the above-mentioned researchers, in order to address sustainability issues in early stages of design and in resonance to the particular characteristics of designers' working cultures in such moments. The tool was developed as part of the author's PhD project and the resources and time allowed only one iteration of the design; it is acknowledged that there was no opportunity of user feedback during the design of the tool. In order to make it as accessible as possible it was built online with free access at: www.trophec.com.

As a main characteristic, it was decided to have a life cycle approach and with mainly diagrammatical information, with as little elements and steps as possible to help on the "Overview" and "Relate" tasks. Therefore, having the entire life cycle in one screen only, with colour-coded and simple icons, which should be visualised constantly (Overview and Relate), and the settings of variables rapidly accessible through pop-up windows (Zoom and History). These variables were kept to a minimum by creating groups representing the most commonly found in literature (Filter). As well as five impact calculations that could allow designers to have a reference point (Relate). Due to data availability, it was decided to perform basic calculations of energy use, CO_2 production, and material intensity of solid matter, water

and air only. These were graphically represented by analogies with commonly known objects in the form of icons, in order to provide a reference of the impact dimensions.
In only one screen the user is capable of selecting 13 materials from five different families: plastics, metal, wood, ceramic and glass, as well as define its quantity and the country of origin for each material selected. By following the widely-used code of active tools in colour and inactive in grey the user follows the life cycle, and after selecting the materials the manufacturing becomes active. There are five different processes to select from and six energy intensities; the country of manufacture should also be defined. Both materials and manufacturing processes follow the categories and elements proposed by Thompson (2007). The following step is selecting transportation method from airplane, ship, train or truck. Next comes the selection of usage characteristics: energy consumption, life span, number of uses and country. Lastly the user must define the end of life from five different options: consumers, distributors, producers, compost or landfill.
Recognising that sustainability is more than environmental factors a secondary screen was incorporated containing country-based information of issues like biodiversity, GDP per capita, Human Development Index, energy generation sources among others. More information about the details on the calculation methods and the data sources can be consulted online at:
www.trophec.com/additionalInformation.php

3 TESTS

Designers face a paradigm when trying to incorporate sustainability considerations at early stages of design (when it is more meaningful to do so): it is possible to assess the sustainability of an object that has not been conceptualised yet, but that the designer may have a 'pre-analytic vision' of? (Schumpeter, 1954)
This research attempts to answer the question: assisted by a soft modelling tool can designers perform a sustainability pre-assessment of a new product development during the conceptualisation stage? This as a preliminary requisite for the use of a tool at early stages of design that could provide relevant information in order to make more informed decisions, and therefore design more sustainable products.
In order to find if such pre-assessments occurred or not, we conducted a series of experimental design sessions. The test involved six professional industrial designers working individually, all of them with 15 years of professional experience or more. The protocol was based on the think aloud method (van Someren et al., 1994). Therefore, the sessions were video recorded by a camera focussing on the computer screen and the working area in front of the designers, in order to register their voice, sketch creation sequence, interaction with the computer and any other event.
The test involved solving a design brief that the researcher sourced from a NESTA design contest NESTA (2013). The brief asked the designers to address the problem of bicycles being stolen, and emphasised the aim that 'the winning innovation will be the one that requires the longest time to steal the bike'. There were three other criteria: impact on the environment, cost to buy or implement and adoption at scale through commercialisation and other means.
The test lasted 80 minutes. First the participants were introduced to the test, and next to the soft modelling tool by viewing three videos (8:30 min in total) explaining the purpose and the detailed use of the tool. After viewing the videos ten minutes were allocated for familiarisation by simulating a life cycle and browsing the glossary. Immediately after the test took place, which was divided in 5 different sections:

- Conceptualisation: 20 minutes
- Tool use (1st exploration): 10 minutes
- Refinement: 20 minutes
- Tool use (2nd exploration): 10 minutes
- Definition: 20 minutes

These sections represented three sequential steps of the design process according to the work of Self (2011), in which the 'early stages' and 'final stages' could be distinguished. Between steps one and two, and two and three, a period of ten minutes was allocated for the use of the tool.
The first two designers to perform the test were treated as "control", in which the tool usage period was completely optional, they could freely decide to use the tool or skip the step. The last four designers were asked to use the tool and in case of not knowing what or how to assess they could just review the tool's glossary or create a random product life cycle. All test finished with a semi-structured interview.

4 RESULTS

Professional designer one refused to use Trophec in the first exploration on the grounds of not having an idea to assess, and in the second exploration because his proposal was not an object, but a step in the manufacturing process.

Professional designer two did not use Trophec, arguing in the first exploration that for what he was working on, it was not useful. At that point, he had decided very broad concept categories to develop, rather than any precise idea. In the second exploration, he simply said that he did not want to use Trophec, which he saw as adding another complexity to the process. At this point he already had some of the concepts embodied in clear design proposals.

Professional designer three, and the following four designers had to use the tool as part of the test. It was expected from them to model some random concept or simply navigate the glossary until the time assigned finished. Instead they all modelled at least one of the ideas they were creating, even if in a very conceptual stage. Professional designer three made some important realisations about the environmental (non recyclability of certain materials or the toxicity of batteries) and social impact (potential child labour or slavery in China) of his product. But this made no difference in his final design. Unlike the other participants, this participant's first and second explorations did not increase in complexity, which was expected as part of the natural design process. It seems that the designer had a very clear image of his product very early on; thus, making him impervious to any external influence.

In the case of professional designer four the increase in complexity between the first and second exploration appears in the form of more materials and manufacturing processes as it was expected, but because of his complex solution based in four different but related concepts, he decided to produce two different cycles in the second exploration, which increased the complexity even further. He was the only one to produce two cycles in one exploration.

Professional designer five demonstrated one of the clearest influences of Trophec - the realisation of the recyclability characteristics of materials and subsequent changes to improve sustainability without affecting performance or function; this was identified exclusively through his verbalisations. His design embodiment did not change as a result of this influence, which ultimately allowed him to avoid any part of his product finishing up in landfill. In some statements during the think aloud, he defined the government as the 'owner' of the object, somehow to ensure the appropriate dismantling, disassemble and recycling of the product.

For professional designer six there was only one change between first and second explorations - the addition of stainless steel in the materials selection. This happened when he realised that the product needed a locking system. For the rest of the product natural fibres were selected, which initially made him select 100% compostable, later he added the metallic part therefore diverting 10% of recycling to producers.

The opportunity of having several professional designers involved in this research was maximised by ending the sessions with an unstructured interview. The principal questions addressed the conditions they faced in practice when dealing with the incorporation of sustainability criteria in their projects. The responses were enlightening; professional one and two, for whom the use of Trophec was optional and who decided not to use it, made comments relating to the perception of sustainability as something to add later, supporting the idea that most designers, see the incorporation of sustainability factors as an assessment to perform late in the process, rather than an early aid to build the concepts. And all of them agreeing that designers have very limited capacity for some key decision making regarding sustainability, normally the design brief comes to them from marketing or management departments and there is a generalised view of disconnection between all departments involved in the development of a new product.

The main factors found in literature relating to the reluctance of designers to use the eco-design tools in early stages of design included their complexity level, their time-consuming nature and in many cases the need for special training. As part of the analysis of this research, the length of time that participants used the 'soft modelling' tool was measured in order to provide a reference point and to assess if the tool's complexity was appropriate at least for the time usage point of view. For the first exploration, the average time was 6:55 minutes and for the second exploration 3:54 minutes. This is coherent with the notion of a learning curve; the more the participant uses the tool the faster and more efficient it becomes. It also correlates with the fact that the complexity level of the product being designed increases as it moves along the design process, and the use of the tool changes from exploratory to just adding features

to an already defined object. Lastly, it also correlates with the idea that incorporating sustainability factors is more appropriate, and has greater impact, early in the design process.
The recorded periods could also show that once the user is familiar with the tool, no more than two or three minutes will be required to set up a cycle. As discussed previously, the focus should not be on the final numbers of the impact (because in a 'soft modelling' tool they are just indicative), the focus should be on highlighting and evidencing the connections within the cycle and the impossibilities or implications of certain decisions.

5 DISCUSSION AND CONCLUSIONS

The main question this research looks to answer is: assisted by a soft modelling tool can designers perform a sustainability pre-assessment of a new product development during the conceptualisation stage? When facing broad decisions in the early stages of design, the tool provoked reflections that in some cases led to improvements in designers' concepts in terms of sustainability - mainly in material selection, and the realisation of the 'connections' between different steps of the life cycle. These through an interesting discovery, the counterintuitive response of the designers' capacity of modelling a very early design concept; notions of materials and manufacturing processes appear to come attached to concepts and thus can be challenged when these 'connections' become evident. Nevertheless, the sample size and recurrence of these reflections is believed not to be enough for conclusively responding the research question.
As mentioned previously, because of this research time and resources limitations, Trophec is only in its first version, and requires considerable improvements that will only be achieved through further iterations of testing and redesign, it is therefore recognised that the tool still is not fully suited to be used in early stages, and that a larger sample would also produce more robust results.
Nevertheless, the lack of a clearer and consistent effect of the tool in the designers' working processes is not believed to be because of a flaw in the fundamental principles lying behind the idea of a tool such as Trophec, but because of the mentioned lack of time and resources to appropriately produce an effective solution for a complex tool like Trophec; one single iteration on its design process is clearly not enough.
Nonetheless, it is believed that it does provide certain indications of the positive potential of 'soft modelling' for early stages of design and leaves the door open for future research on this theme.
The evidence from this research, even if limited, shows that the 'ready reckoner' (Stevenson, 2013) that provides a "general impression" (Shedroff, 2009) in just a few minutes can be used by designers at early stages, not without changing first assumptions regarding designers' capacities and relevance of sustainability at this stage. It also reaffirms that designers are not demanded to incorporate sustainability (Luttropp and Lagerstedt, 2006) so they relegate sustainability to a second degree or not even consider it, and the designer's limited influence, in order to provide more thorough sustainable solutions there is the need for better integration of different departments within companies (Sherwin, 2000, Johansson, 2002).
Early stages of design are an appropriate time for the integration of product conceptualisation and sustainability considerations, which therefore requires important changes in the individual's approach to the task, and the training and education to achieve it.
Therefore, this research's contributions are set as the identified initial conditions that could potentially lead to a more robust results and clear influence of a soft modelling tool for early stages of design in future research.

6 IMPROVEMENTS FOR FUTURE 'SOFT MODELLING' TOOLS FOR EARLY STAGES OF NEW PRODUCT DEVELOPMENT

As a result of the participants' comments and the analysis of the sessions, as well as feedback from current users, several areas of improvement were identified. It is important not to lose track the purpose of a 'soft modelling' tool - the natural inclination to move towards more conventional LCA assessment tools could be detrimental to the effort and achievements made so far. From a series of potential improvements here are presented four that are considered basic for a next version of the tool for future research.

- Highlight the ‘connections’ within a cycle, the relationship between the materials selected, the manufacturing processes and the recycling strategy. The most relevant influences of the tool happened when the participants realised the impossibility of certain actions due to past decisions. This is believed to be a central part of a “ready reckoner” tool for early stages. This aspect can be greatly improved; one obvious example could be highlighting the impossibility of selecting ‘compost’ as the end of life if the material being used is ‘metal’. As the tool stands today this nonsensical option is available, and some participants fell into this type of errors.
- Remove the linearity of the process. As mentioned before at the start the tool has only active the materials selection, and each step of the cycle is activated once the previous is finished. Some of the participants wanted to move in a non-linear way, for example to define first usage characteristics, this could be relevant because materials selection or manufacturing processes sometimes follow the need of certain usages. Every designers’ design processes are different and the tool should not constrain them.
- Simplify even further the interface. Some navigational tools where not understood by the participants and found them irrelevant. It is believed that further simplification can be achieved, which will result in a faster processing by the user.
- Provide a downloadable version of the software in the form of an application for personal computers and mobile devices. Depending on an Internet connection proved to be challenging for the tests, especially in an industrial setting. The software nowadays has more than 600 users worldwide and this has been a common request from them.

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