Guidelines for the Sustainable Development of Computing Technology

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Abstract. When referring to sustainability, the expression must be understood in terms of environmental, social and economic factors, with an emphasis on the breadth of its scope. Computational solutions involve consumer goods and hence it should be responsibility of the software and hardware industry, (as well as its designers and developers), to ensure that there is an awareness of the need for sustainability. The literature includes several works that address the question of sustainable design. However, there are few studies that deal with sustainability in terms of design and its Computing technology is still in its early stages. In light of this, this paper has formalized a set of recommendations to guide the designers in the creation of computational solutions, and thus allow the sustainability factors in design to be considered. The guidelines were applied in an academic scenario and three specialists evaluated the solutions made with and without them. The results suggest that the guidelines supported the sustainable development of Computing technologies.

Keywords: Design for Sustainability · Design Sustainability · Sustainable Computing · Guidelines.

1 Introduction

Through Computing it is possible to include concepts of sustainability in people's lives, as pointed out by Spangenberg [14], as well as in the outside world, so that it is everyone's duty to assist in this task.

The increasingly available technology also raises concerns about how people use it and how its data can be generated. With this in mind, sustainability forms an integral part of the context of computational technology, which requires the production, use and correct disposal of computational solutions.

Baranauskas, Souza and Pereira [2] have drawn up a list of challenges in the research field of Human-Computer Interaction in Brazil. Challenge 1 draws attention to the consumer practices of the modern world and how we need to rethink what they involve and the design of interactive goods and services based on new technological solutions that foster sustainability for both individuals and

society. It is necessary to include renewal, reuse and disposal strategies for both hardware and software, as requirements of a sustainable design awareness, as per Neris, Rodrigues and Silva [1].

The area of technology generally has a direct influence on people's behavior, owing to its pervasive presence in modern society and, for this reason; it should be used as a facilitator of sustainable practices that are vital for ensuring the continuity of the world. This factor characterizes design for sustainability, which as already been discussed, (albeit in a tentative way), in the literature by Blevis et al. [5] and also by Neris, Rodrigues and Silva [1].

The other factor, which is the focal point of this work, underlines the value of sustainability in design, which encompasses environmental, economic and social issues in the creative process. It is worth reflecting on how designers and developers can merge sustainability with their creative skills, with the aim of establishing social equality, equity, environmental conservation and an equitable distribution of income.

In this work, we describe the procedure of formalizing a set of recommendations to guide designers in the sustainable development of Computing technology.

2 Sustainable Development

The idea of sustainable development originated with environmental movements a few decades ago. It has undergone a number of transformations since then, and become a broader concept that in addition to encompassing environmental, climate, clean energy and resource consumption patterns, also covers public health, social inclusion and poverty [13].

The United Nations (UN) report entitled "Transforming Our World: 2030 Agenda for Sustainable Development", addresses the objectives of sustainable development, by setting out a road map for the sustainable development of countries and lists 17 sustainability goals for those involved in this undertaking. These objectives include action plans for the next years in crucial areas, such as: people, the well-being of the world, prosperity, peace and partnership [11].

ICTs (Information and Communication Technologies) have come to be seen as engines of development both globally and regionally, which seek to reduce social and economic inequalities while, at the same time providing guidance on the correct way of obtaining benefits, without causing harm to other areas [12]. Gartner's report [10], on ICTs, states that their effect on sustainable development can be divided into 3 orders. The first order concerns the immediate impacts they can have on computational solutions, that is, the direct result of an existing situation. For example, the emission of air pollutants caused by computer solutions, or equipment that is not energy-efficient and the disposal of electronic waste after it is obsolescent. Second-order impacts include the indirect use of computational solutions, that is, they are caused by the use of ICTs, such as the holding of meetings by video link, transport load optimization, operational logistics and data center asset management. All of these processes have an indirect impact on solutions [12]. Third-order impacts occur as a result of the use

of ICTs. For example, the reliance on ICT employees in the workplace, turning off monitors when they are not using the computer, turning off the lights and printing only what is necessary [13]. It takes a long time and a change in habits on the part of people who use ICTs, to implement these changes.

3 Related Works

Burnell [6] defends the incorporation of sustainability in the design of products and commercial artifacts, and examines the sustainability tripod model, according to the environmental, social and economic factors involved in the construction of the products. He handles sustainability in an integrative way, although he states that sometimes it becomes a utopian concept, because of the divergent opinions on the subject.

The author compares this design process with the one described by Waage [15], who also focuses on general design, that is, the design of any type of solution. The author believes that the design phase is the key feature when introducing the concept of sustainability, since decisions made in this phase determine 70% (seventy percent) of the costs that will be involved in product development.

In the opinion of Blevis [4], sustainability is both an ethical and practical issue, and this should be reflected in the design, so that it really corresponds to the author's values. He also discusses other perspectives such as the role of design in product innovation, economic growth and experience, and the aesthetic appeal of the design, but believes that these design perspectives are not exclusive and can coexist with the view that sustainability is fundamental to design.

The design put forward by Mann et al. [9], is regenerative, like that of Blevis [3]; this author has a theory centered on sustainable design that is linked to the environment, and establishes limits in favor of a prosperous future development. The authors believe that the relationship between Computing and regenerative design is difficult to understand, although they are closely linked. The view that there are viable alternatives to design as it is currently carried out, leads to regenerative sustainability.

The new regenerative design is concerned with looking at nature and the ecological system as a means of understanding the interaction between computing, society and biological systems [9]. The authors mention that this relationship must be based on the following features: inclusiveness, harmony, respect, integrity, mutuality, brotherhood, positive reciprocity, responsibility and humility.

4 A Methodological Approach

After conducting an analysis of the data presented in the literature, we carried out exploratory research into other areas that already have clear guidelines for testing sustainability, such as civil engineering. Thus, in the light of these techniques, it was possible to set out a list of recommendations for designers of the area of Computing. A rigorous search was also carried out in two databases,

which were considered to be relevant to the area of Computing. After the application of the search string, and the inclusion and exclusion criteria, ten works were chosen that were returned from the mapping.

Following this, the opinions of the computing community on the subject were analyzed.

4.1 Survey with Computing Community

An online survey was carried out to find out the views of different people about sustainability and Computing.

The survey was answered by 128 people, including students, teachers and other professionals in the field of Computing. The preliminary analysis suggests the need to clarify and reflect more deeply on the aspects that make up the sustainability tripod. In particular, it emphasizes the role of the Brazilian Human Computer Interaction (HCI) community in the subject, particularly in the aspects of accessibility.

As for the profile of the survey respondents, the age range ranged between 20 and 66 years, with an average of 35, and 64% are male. Respondents' background was diversified.

The results suggest that the concern with the environment and the correct disposal of waste, when it comes to sustainability, is still what comes to the minds of respondents in the Brazilian Computing community. The fact that accessibility was not considered relevant to sustainability by half of the respondents reinforces the need for in-depth studies on the subject, which show that the exclusion of minorities does not contribute to a fairer, more egalitarian society that seeks to guarantee a future best everyone.

4.2 Affinity Diagram

The affinities diagram helps in the process of clarifying the dimension and extent of problems and grouping ideas and opinions on subjects that have similarities, that is, affinities with each other.

An affinity diagram was also used to illustrate the concept of sustainability in Computing. This diagram is used in complex situations that are not yet well defined and, helps to group ideas by finding similarities between them.

The profile of the participants was composed of students, who were masters and PhD students in the field of Computing in the Human Computer Interaction research line. The problem question to be solved in the affinity diagram was: What should the designer consider in building a sustainable solution?

The questions considered by the participants around sustainability in the area of computing were extracted from survey. They guided the related areas in which the affinity diagram was divided, the most similar ideas, or that could be considered part of a large area, were grouped and quantified.

The affinities were grouped by the areas of production, documentation, reuse, ecological, social and human, financial and aspects that were not considered.

Through the diagram of affinity it is understood that when we speak of sustainability the largest remembrance that people cling is still in the hardware of solutions. It is a minority that only considers the software as an integral part of the sustainable question.

5 Guidelines for Sustainable Computing Technology

By combining these studies, the literature, the survey of the Computing community and the affinity diagram, a set of guidelines could be created that cover the various stages of the design process. The result was that recommendations were made for computational solutions that could be created in a more sustainable way.

The guidelines were related to stages in the design process of Computing solutions, as these are not isolated. They were also related to the professionals involved in each stage of the design process.

As a result, it was found that 25 (twenty-five) guidelines in which the **phase of the design process** was observed, could be used: these included the categories *Analyze, Design, Prototyping and Implementation*, and also defined the possible professional who would be responsible for that particular guideline. There follows a description of how the roles of the professionals in the study were chosen.

Responsibilities: *Executive Board*: responsible for the company and employees, as well as making decisions about producing new goods and services, and handling financial matters; *Developer*: responsible for back-end solutions, and for making the software applications work; *Architect*: responsible for the hardware design of the solutions; *Designer*: responsible for the visual appearance, form and philosophy of the solution, whether it be hardware or software; *Analyst*: responsible for analyzing the scenarios and the link between the client and the company.

It was also decided to use different forms of relationship (**levels**) with the solution: *a direct relationship with the product* or *process and an indirect relationship or external factors.*

The **guidelines** follow: 1) choosing materials that are suitable for finding computational solutions; 2) adopting fair wage policies that are compatible with the IT market; 3) fostering an awareness of the relationship between suppliers and service providers of technology companies; 4) Improving the relationship between technology companies and the government; 5) reducing incidents that involve civic responsibilities; 6) Optimizing consumption, and the reuse of water; 7) Improving cost control techniques, and having fair operating practices; 8) Creating solutions with good usability principles; 9) Adopting participatory design techniques; 10) Creating an accessible interface; 11) an equitable use of resources; 12) An use simple and intuitive of the interfaces, with easily available information; 13) Requiring a limited physical effort; 14) Creating scalable solutions (both hardware and software); 15) Reducing gas emissions in the atmosphere; 16) Involving the surrounding community, by forming close relationships

and exchanging knowledge; 17) Making the features of sustainability publicly available through documentation and including them in the solution; 18) Flexibility of use; 19) Support for future releases and compatibility; 20) Encouraging ethical practices and respect for human and minority rights; 21) Prioritizing regional labor and culture; 22) The design of the solutions must clearly show their usefulness and include error tolerance; 23) Obtaining and correctly disposing of the computational solution, whether it be hardware or software; 24) Gender equality and; 25) The use of clean energy resources.

In the resulting set of guidelines there is also a brief explanation of how they could be used and what could be addressed by each guideline in question. Finally, mention is made of the reference used in deciding how to plan and draw up the guidelines.

Tables 1-5 illustrate details on the guidelines.

Table 1. Guidelines for the Design of Computational Solutions for Sustainability Awareness.

	Phases of design process	Personnel Responsible	Level	Guidelines	Subsidiary Guidelines	Reference
1	Analysis	Designer Architect Board Analyst	1	1	1.1 Choosing suitable materials that take into account the time and amount of the material that has to be reused , after the product or process has reached the end of its usefulness. 1.2 Prioritizing the use of materials with productive cycles in accordance with the principles of sustainability. 1.3 Prioritizing materials that are easily absorbed from [OR in ?] the environment at the end of their useful life.	Computational ISO 14004 Survey applied to the community
2	Analysis	Board	2	2	2.1 Designing a job and salary structure based on principles of meritocracy. 2.2 Setting up a wage subsidy scheme compatible with the job market in the region and size of the company.	Affinity Diagram
3	Analysis	Board Analyst Architect	2	3	3.1 Prioritizing consumer goods from companies that respect the environment and its operations. 3.2 Prioritizing the workforce of a company that has social and fiscal responsibilities . 3.3 Attempting to establish a close relationship with these companies and thus be in a position to suggest improvements in their processes so that they can become more sustainable.	ISO 14004
4	Analysis	Board Analyst Designer Programmer Architect	2	4	4.1 Complying with legislation applicable to the business sector 4.2 Being innocent of tax evasion 4.3 Finding solutions that do not leave loopholes for corruption	ISO 14004

Table 2. Guidelines for the Design of Computational Solutions for Sustainability Awareness.

	Phases of design process	Personnel Responsible	Level	Guidelines	Subsidiary Guidelines	Reference
5	Analysis of Design Prototyping Implementation	Board Analyst Designer Programmer Architect	2	5	5.1 Meeting the standards required to ensure a healthy environment for employees. 5.2 Meeting the safety standards for the supply of equipment. 5.3 Using PPE's. 5.4 Ensuring there is a suitable environment for work practices, such as activity tables or chairs with armrests, which are designed for the health of employees.	ISO 14004
6	Analysis	Board Analyst Designer Programmer Architect	2	6	6.1 Prioritizing input suppliers that have water optimization policies. 6.2 Designing solutions with a view to reuse and the avoidance of water waste	ISO 14004
7	Analysis of Design	Board	1	7	7.1 Having a fair profit margin , compatible with the market. 7.2 Ensuring transparency in the production chain with practices that are profitable without exploitation .	ISO 14004 ISO 26000
8	Analysis of Design	Designer Analyst	1	8	8.1 Solutions that serve the needs for which they were designed. 8.2 Solutions that are easy for the user to understand , thus avoiding any misuse of the product or stress being caused	Affinity Diagram with a Survey applied to community computing
9	Design	Designer	1	9	9.1 Respect for the users' preferences and limitations. 9.2 Giving the users the right to choose by allowing them to be involved	Mocigemba (2005) Baranaukas (2008)
10	Design	Analyst Designer	1	10	10.1 Creating interfaces that are accessible to different types of users.	W3C Design/ Socially Conscious and Universal Design
11	Design	Analyst Designer	1	11	11.1 Being useful to people with different skills . 11.2 Providing the same (or similar) user experience to different types of users, whenever possible .	Universal Design

5.1 Application and Preliminary Assessment of Guidelines

The set of guidelines was used by undergraduates in the Computer Science course, on the class of "Topics in Informatics". The students were invited, as volunteers, to apply the guidelines in their projects. They signed a consent form with these specifications and were divided into groups. They were asked to develop web applications: two of the groups had to follow the guidelines produced by this work, and the other two had to develop their solutions without the aid of the guidelines.

After the end of the development of the solutions following the guidelines, a questionnaire was applied to students with the in order to gather evidence of how the guidelines have been accepted and used.

Table 3. Guidelines for the Design of Computational Solutions for Sustainability Awareness.

	Phases of design process	Personnel Responsible	Level	Guidelines	Subsidiary Guidelines	Reference
12	Design	Designer	1	12	12.1 Eliminating unnecessary complexity . 12.2 Having a wide range of language skills and levels of instruction. 12.3 Adopting different ways of displaying essential information. 12.4 Being compatible with a wide range of technical equipment, as well as speeding up and simplifying communication .	Universal Design
13	Design	Designer	1	13	13.1 Reducing the need for physical effort by having fewer repetitive operations. 13.2 Allowing the user to be in a comfortable position when finding the solution.	Universal Design
14	Analyze Prototyping Implementation	Analyst Programmer Architect	1	14	14.1 Creating solutions that support hardware upgrades by reusing much of the original design. 14.2 Creating solutions that support software upgrades, with the aim of optimizing the hardware ,and avoiding the need to program obsolescent solutions. 14.3 Finding portable solutions for different computing platforms, by expanding the range of their users .	Affinity Diagram and a Survey applied to community computing
15	Analysis/ Prototyping	Board Analyst Designer Programmer Architect	2	15	15.1 Avoiding the emission of air pollutants , through the solutions designed. 15.2 Avoiding, whenever possible, using fossil fuels for transport. 15.3 Using technology as a means of bringing people together, in meetings for example, avoiding unnecessary displacements.	ISO 14020 Affinity Diagram Raghavan and Pargman, (2007) + a Survey applied to community computing
16	Analysis/ Implementation	Analyst Designer	2	16	16.1 Concern about the company's surroundings when establishing a community t. 16.2 Listening to the community and its needs with regard to the technology solutions created.	ISO 26000
17		Designer	1	17	17.1 Helpful Information for the solution. 17.2 Information about how to present the solution.	Affinity Diagram

The responses to the questionnaire showed that after contact with the guidelines, the view on sustainability has changed. All respondents considered having their thinking changed after the contact the guidelines.

At the end of the research project, the solutions generated by the 4 groups were evaluated, in a preliminary way, by 2 specialists in the design area who already had contact with the design literature on sustainability, and followed the evaluation guidelines recommended by Junior [7].

This meant that it was possible to determine whether the solutions created by the students who followed the guidelines, became more sustainable than the solutions of the students who did not follow them; specialists in the area were invited to assess the solutions. Three specialists on sustainability in the area of

Table 4. Guidelines for the Design of Computational Solutions for Sustainability Awareness.

	Phases of design process	Personnel Responsible	Level	Guidelines	Subsidiary Guidelines	Reference
18	Design/ Implementation	Designer Programmer	1	18	18.1Adapting user preferences, allowing the user to make a choice (for example color, font size) . 18.2 Adapting to the user's work rhythm, (taking time outs to prevent the user experiencing stress).	Universal Design + Survey applied to community computing
19	Design/ Prototyping/ Implementation	Designer Architect Programmer	1	19	19.1 Making the solution compatible with the versions of different manufacturers. 19.2 Ensuring functionality in future versions. 19.3 Updating the solution in accordance with the dictates and requirements of the current market.	ISO 26000 Universal Design + Survey applied to community computing
20	Design/ Prototyping/ Implementation	Board Analyst Designer	1	20	20.1 Computational solutions must prevent unethical, corrupt or any kind of discriminatory activities ?. 20.2 The product design cannot discriminate against any beliefs or cultures, and must ensure that people are shown respect through the solution.	ISO 26000 Universal Design + Survey applied to community computing
21	Design/ Prototyping/ Implementation	Board Analyst Designer Programmer Architect	2	21	21.1 Whenever possible, there is a need to take advantage of labor in regionalized solutions, and thus foster local development. 21.2 Prioritizing regional suppliers. 21.3 Respecting the culture and customs of different kinds of people.	Mucigemba, (2005)

Computing analyzed the prototypes of the projects carried out by the students. Their academic qualifications consisted of a Ph.D student, a MSc. student and a MSc.; all the researchers in the field of Human-Computer Interaction were aged between 30 and 40. In making their evaluation, the specialists used the guidelines recommended in this work and the guidelines employed in the work of Junior [7], which consist of sustainability guidelines in the area of Software Engineering.

In the opinion of the specialists, the solutions created without the support of the guidelines did not have many traces of sustainable solutions. One factor that must be taken into account is that as it was about academic solutions, business matters, such as wages or questions that largely depended on the decisions of the board of directors could not be determined, since they were characterized as "Not applicable". The results suggest that the solutions obtained from following the guidelines were more sustainable than those that did not follow them. The concern of the groups that used the guidelines in making their solutions was remarkable when compared with the attitudes of the others.

It was clear from the data and opinions collected from the students who took part in the study, that there is a need to strengthen other sustainable issues, especially those that are not most common (e.g. those related to the environment). A broader dissemination of information about sustainability and

Table 5. Guidelines for the Design of Computational Solutions for Sustainability Awareness.

	Phases of design process	Personnel Responsible	Level	Guidelines	Subsidiary Guidelines	Reference
22	Design/ Prototyping/ Implementation	Analyst Designer	1	22	22.1There should be clear and concise solutions to help the users and give them a feeling of well-being when they reach the goal of the solution. 22.2 The systems must predict possible errors that the user may make, by displaying error alerts, and help buttons; this can enable him to do what he wants in the solution with the minimum effort.	ISO 14020 ISO 14001
23	Design/ Prototyping/ Implementation	Designer Programmer Architect	1	23	23.1 Creating a life cycle policy in which the company is responsible for the solution from its creation to its correct disposal. 23.2 There is a need to ensure that the software embedded in the hardware also has a) its share of recycling with regard to new models and b) its scalability. 23.3 Creating the reverse logistics mechanism for the hardware after its useful life. 23.4 Finding a destination for the components when the obsolete solution returns to its origin.	ISO 14020 ISO 14001
24	Analysis of Design/ Prototyping/ Implementation	Board Analyst Designer Programmer Architect	2	24	24.1 Different genres must not show any distinction or signs of discrimination when developing a design product. 24.2 The remuneration of different genders must also not be influenced by this factor.	Kannabiran, (2014) Mucigemba, (2005)
25	Analysis of Design Prototyping / Implementation	Board Analyst Designer Programmer Architect	2	25	25.1 Prioritizing the use of solar or wind energy in solutions. 25.2 Prioritization of rechargeable batteries.	Affinity Diagram and Survey applied to the community

instructions for its practice could help to heighten awareness of this topic among the public.

6 Final Remarks

The work developed by Kim et al. [8] applies sustainability indicators to specific hardware. The creation of the guidelines suggested here broadens the view on hardware and also evolves the eight guidelines outlined by Zeid [16]. Both studies focus on the environmental issue. There is, therefore, a need to also guide other processes that encompass the term sustainability.

Our preliminary results suggest that the guidelines set out here can assist designers in creating more sustainable computing technologies.

Future work should include the use and evaluation of the guidelines outside an academic context, in the business environment, from the design of a product, whether software or hardware.

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