Towards Indicators of Sustainable Product Design

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Abstract— **This paper aims in presenting a proposal of a set of indicators of sustainable and responsible product design. The main idea is to develop a conceptual model of indicators, which will be presented and applied to design process in general. The proposed set of indicators is discussed and suggested as basis for the development of tools that offer a broader sense of sustainability in order to support the main decisions during the product development.**

I. Introduction

The search for understanding the functioning and ideal conditions of a natural system, as well as its potential risks of impacts and damages, requires a model of identification and measurement aimed in efficiently collect and present its internal and external characteristics together with the relationships between the system and the outside environment. This means, understanding the limits and specific roles of each element of the system itself. As [1] pointed out, when analyzing social and environmental systems, for instance, it is crucial to develop a model of measurement of quality, both objective and subjective, in order to make correct decisions and implement policies aimed in offering a higher level of harmony between human and environmental needs. These monitoring and controlling actions must be oriented in order to reduce impacts of potentially dangerous processes, e.g. damages from industrial plants, and enhance human quality of life.

In this sense, the need of a better harmony between industrial processes and ecosystems is seem as immediate priority. According to [2], the humane sustainability is directly influenced by dynamics of technology, economy itself as well as the accelerate rates of social and environmental changes generated by anthropical activities. Besides, the ineffectiveness of industrial production in terms of social and environmental requirements will negatively influence sustainability ecosystem dynamics, mostly damaging nature itself in an irreversible way.

The main goal of this research is to identify, characterize and propose a set of indicators specifically developed to help designers to make decisions within the design process according to sustainable development and social responsibility patterns of quality, trying to achieve a higher performance of product development in comparison to the present levels of sustainability of industrial plants.

II. Indicator of Sustainability: conceptualization

According to [3], indicators of sustainability are typically measurable signs, which can reflect a quantitative or qualitative characteristic, considered vital to analyse and make judgments on present, past and future conditions associated to a particular system. This means, adopting a set of specific indicators determines the quality of the system itself, its history, interests, needs, objectives and trends in a pragmatical way.

An indicator can only be useful to the decision making process if it is able to present measurable and interpretable information. The quality of information is directly related to the accuracy obtained from data collection together with indicator's reading and understanding. As [4, p.6] pointed out, "indicators are partial reflections of reality, based on uncertainty and imperfect models", working as abstractions of systems, assuming their state of functioning, presenting their weakness and strengths. Consequently, indicators reveal the characteristics and specific aspects of a system, particularly ones that mostly need to be measured and controlled.

III. Methodology and criteria adopted towards indicators of sustainability

Despite the fact that indicators are reflections of reality basically presented by a single value, i.e. index, which is mostly related to quantitative interpretations, in this research we use a set of reflections based on subjective data, obtained from qualitative analyses and judgments according to information gathered by check lists and literature review. Thus, we consider as methodology the Qualitative Research, which focus on the production of knowledge aimed in explaining social phenomena, e.g. sustainable development, environmental impacts.

According to [5], the qualitative research is a kind of research that produces results that cannot be achieved by statistics or other kinds of quantification processes. Consequently, this method deals with qualitative data, including documents and texts, e.g. articles and books, interviews and surveys, participatory observation, impressions of the researcher as well as his/her reactions in order to understand and explain the cultural and social phenomenon [5], [6].

Other important qualitative research method used in this research is the Grounded Theory [7]. This method aims in developing a theory directly from data collection and systematic analyses. Firstly, the goal of the study is defined and precisely set; secondly, the data collection is performed and analysed; thirdly, the obtained data are organized according to defined criteria (e.g. chronology, space, technical aspects, social patterns, economical values); after that, the results are

TABLE I

CHECKLIST OF PERFORMANCE AND VIABILITY CRITERIA ASSOCIATED TO NATURAL SYSTEM ANALYSES

Viability criteria associated to natural systems	Check list of performance
1. Existence	Can the system exist within the environment where it is placed? Does the system influence or contribute for other system's existence?
2. Effectiveness	Does the system effectively work? Is it self-sufficient? Does the system positively or negatively contribute for the effectiveness of other system?
3. Freedom of actions	Does the system have enough freedom of action to respond and react to surviving demands? Does the system positively or negatively contribute for the freedom of action of other system?
4. Security	Is the system secure, trustful and stable? Does the system contribute to the security, trustworthiness and stability of other system?
5. Adaptability	Can the system be adapted to new changes and challenges? Does the system contribute to the flexibility and adaptability of other system?
6. Coexistence	Is the system compatible with the existence and interaction with other system? Does the system contribute to the compatibility of other system?
7. Psychological needs	Is the system compatible with psychological and cultural needs of its components or subsystems? Does the system contribute to the well-being and psychological needs of other system?

codified, classified and compared to other results and related patterns; and finally, the theory is generated and presented.

In the first part of our study, based on the preliminary studies of [2], we discuss the checklist of viability and performance of natural systems, considering interdependence and influences among systems and subsystems, understood as essential elements in order to define and measure sustainability levels. The following Table I briefly presents the viability criteria proposed by [2].

The proposed set of indicators is analyzed according to the checklist of viability and performance [2], focusing on the impacts of general situations in regard to human quality of life and production system adequacy as well. This approach offers an easy way to express in a qualitative scale the whole design system promoting solutions highly oriented to sustainable patters within the decision making process itself.

We have adopted a simplified scale for the viability levels (Figure 1), assuming ranges from -2 (minus two points) to +2 (plus two points), i.e. from the weakest sustainability level (-2) to the strongest sustainability level (+2), in search for a better visualization system for the generated set of indicators. The values are estimated according to the answers obtained from the checklists and organized in a way that results from 0 (zero)

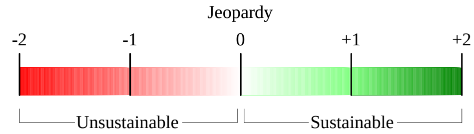

Fig. 1. Proposed scale for viability levels

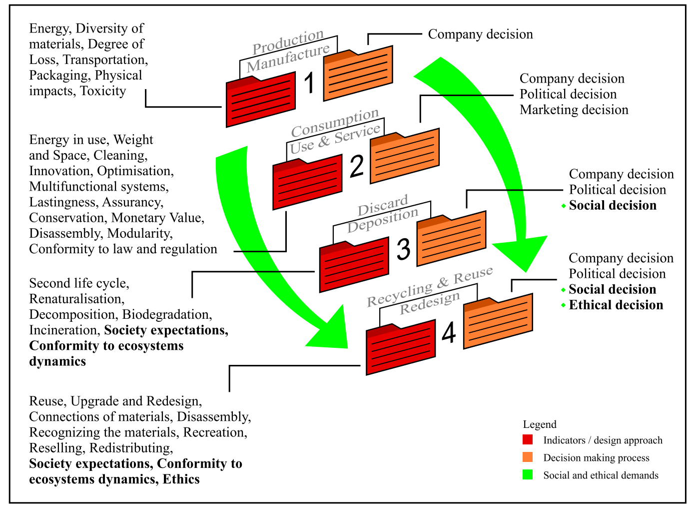

Fig. 2. Indicators associated to design phases

to +2 (plus two) represent sustainable levels. Results from -2 (minus two) to 0 (zero) are considered unsustainable levels. Indicators which results are set as 0 (zero) are considered in jeopardy, requiring special attention from designers and decision makers in order to adjust and solve the problem related to the particular aspect analyzed.

IV. INDICATORS APPLIED TO DESIGN PROCESS

According to [8], the search for sustainability and the socially responsible attitude from designers is strongly related to the capacity of implementing production systems aimed in responding to some social and environmental demands in the product as a whole, using less natural resources in comparison to present industrial patterns. In this sense, designers and decision makers must coordinate processes, services and communications in a way that we can clearly identify alternatives and design solutions that effectively respond to social and cultural innovation needs.

[9] presented a theoretical model of indicators associated to the decision making process, taking into account the increasing need of attending to social and ethical demands within the design process. The authors consider the design process as four different phases as shown in Figure 2.

On one hand, indicators of sustainability and social responsibility within the design process must comprise aspects of adequacy related to production plants, e.g. demand of energy, diversity of materials, environmental impacts and damages, toxicity. On the other hand, adequacy of decisions and solutions with respect to society expectations and ethics overall.

Based on the theoretical model proposed by [9], we have developed, from the Figure 2, a preliminary set of indicators related to sustainable and socially responsible attitudes within the design process, considering the environmental, social, economical and institutional perspectives of sustainable development:

- Phase 1 - Production/Manufacture
  - **Demand of energy within the production plant**: (1) Use of alternative energy, e.g. solar, wind; (2) Use of natural resources as energy; and (3) Exploration of forest areas in order to transmit and receive energy;
  - **Diversity of materials in production**: This means high complexity when connecting parts, difficulties in assembling and, consequently, high demands of energy during the manufacture;
  - **Degree of toxicity in production and/or final product**: Measures the impacts of production processes in terms of toxicity, gaseous diffusion, toxic materials etc.;
  - **Normalization**: Accordance of production to international standards, e.g. ISO;
  - **Effluent discharges and residues**: (1) Quantity of effluent discharges in rivers from production plant (m^3/day);and (2) Residues generation (m^3/day);
- Phase 2 - Consumption/Use/Service
  - **Conformity to law and regulation**: (1) Accordance to environmental protection laws, e.g. number of legal proceedings and prosecutions per year;
  - **Packaging impacts**: Residues from packaging post-use, e.g. return and amount of used packs to production plants for reprocessing;
  - **Consumption of energy in use**: Measures the quality of responsible products in terms of low consumption of energy in use, according to international standards;
  - **Multifunctional systems**: Allows a diverse use of a product/system, optimisation of use and an equalized demand of energy in use;
  - **Well-being**: Verifies the degree of satisfaction and consequently the lastingness of a product, e.g. low degree of complains and requests for technical assistance;
- Phase 3 - Discard/Deposition
  - **Discard and deposition**: Amount of organic and inorganic matters discarded from production plants and disposed in nature;
  - **Recycling of matters**: Quantifies the use of recycle matters within the production system and/or the possibilities of recycling the final matters/products;
  - **Disassembling**: Identifies the quality of Design for Disassembly and the possibilities of reuse of parts/materials from production system;
  - **Code of ethics**: Reveals positive attitudes of companies in order to attend society expectations and needs. Accordance to Corporate Social Responsibility (CSR) standards;
  - **Anticipation**: Identifies the ability in preventing damages and impacts to natural systems, e.g. contingency plan;
- Phase 4 - Recycling/Reuse/Redesign
  - **Reuse**: Accordance to Life Cycle Design patterns, e.g. possibility to use the same product in different contexts, or second life cycle;
  - **Upgrading**: Identifies the possibilities of upgrading and adapting the product in order to extend its life cycle, e.g. restyling and release of new accessories for the old product;
  - **Recognizing of materials**: Specifications and detailing of materials in order to simplify the disassembling and recycling processes;
  - **Redesign**: Improvements in form and performance of a product, e.g. new ideas for the same concept, adjusts in order to extend the life cycles of products;
  - **Reselling/redistribution**: Insertion of the product in new markets, redistributing in order to achieve new consumer for the product.

In order to present the applicability of the proposed set of indicators, we describe, as an example, the associated sustainability indexes generated from the first design phase, i.e. production/manufacture, of a coffee machine, according to viability criteria and answers to the check list of performance (Table I). Due to the Conference limitation with respect to the numbers of pages, we will present a possible analysis and results obtained from the model application of the first design phase only. The other 3 phases can be inferred from this exemplification.

- Phase 1 - Production/Manufacture
  - **Existence**
    * **Answers to the Check list of Performance**: Yes. Although we must consider the fact that these materials are done under highly aggressive conditions for the environment;
      Yes. Choosing plastic matters influence the whole production system, in a negative perspective for the environment;
    * **Set of analyzed Indicators**: Energy in production, Toxicity, Residues/effluents;
    * **Generated Sustainability Index**: -0.5;
  - **Effectiveness**
    * **Answers to the Check list of Performance**: No. The system is not self-sufficient once it depends on the functioning of other systems. It also contributes negatively for other near systems;
    * **Set of analyzed Indicators**: Diversity of materials;
    * **Generated Sustainability Index**: 0;
  - **Freedom of actions**
    * **Answers to the Check list of Performance**: Yes. In this sense the designer can and should adopt other kind of materials, e.g. recycled matters, in order to produce less residues and impacts;

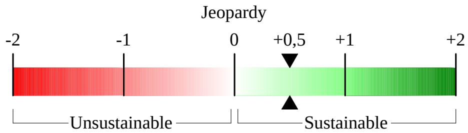

Fig. 3. Weak sustainability level associated to the first design phase of a coffee machine

    * **Set of analyzed Indicators**: Diversity of materials;
    * **Generated Sustainability Index**: 1;
- **Security**
    * **Answers to the Check list of Performance**: Yes. We have already tested such systems before. We can easily predict the constraints of this kind of design;
    * **Set of analyzed Indicators**: Normalization;
    * **Generated Sustainability Index**: 2;
- **5.Adaptability**
    * **Answers to the Check list of Performance**: Yes. This product is also easy to be adapted to new patterns of production and contribute to other system's flexibility as well;
    * **Set of analyzed Indicators**: Energy in production, Diversity of materials;
    * **Generated Sustainability Index**: 2;
- **Coexistence**
    * **Answers to the Check list of Performance**: No. If we assume a low environmental impact as basis for production this system cannot coexist;
    * **Set of analyzed Indicators**: Energy in production, Residues/effluents, Toxicity;
    * **Generated Sustainability Index**: -2;
- **Psychological needs**
    * **Answers to the Check list of Performance**: No. Psychologically thinking we cannot accept production plants that impact nature and human quality of life;
    * **Set of analyzed Indicators**: Normalization;
    * **Generated Sustainability Index**: -2.

In our example, we have generated some indexes for every analyzed situation within the Production/Manufacture design phase. These indexes can now be separately organized and discussed, according to the viability scale adopted for the whole set of indicators. For this calculation process we have used the five-degree Likert's scale. If we consider the arithmetic average of all indexes at this phase we can visualize the sustainability state for this design phase as a weak sustainable level (+0,5). Figure 3 graphically shows this result.

V. Concluding Remarks

Nowadays, Social Responsibility and Sustainability are important concerns in whole world. In the fields of Product Design, determining indicators of sustainability means attempting to parameters that define techniques, materials, quality of processes and the relevant impacts of production. For this, it takes into account the life cycle of matters, streaming of energy and mass within industrial plants, and, in a broader sense, influencing the way people live and obtain satisfaction.

From the results obtained from the proposed set of sustainability indicators model, we have verified the possibilities of more detailed and accurate analyses of design products and services. This means, the proposed indicators model can quantitatively diagnose, and in a pragmatical way, the concrete situation of a design project, suggesting interventions towards a higher quality and adequacy of the product/service according to sustainability and social responsibility perspectives.

The next step of this study is the development of tools that help designers and decision makers better visualize the sustainability conditions associated to a design project. We will try to implement a dashboard indicators software, where the whole set of information can be changed and adapted to each condition of development and industrial context, particularly in Brazilian scenario. The main contribution of this study is gathering information in order to visualize the conditions of sustainability and social responsibility that characterize the design process itself.

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