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Design for Sustainability Tools: Categories of Classification Towards Practical Use

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ABSTRACT

Since the emergence of early approaches to design for the environment (such as green design or ecodesign), several tools have been developed to support the design process in the integration of environmental, social and, more recently in a comprehensive way, sustainability and circularity criteria. The vast quantity and diversity of tools have required the creation of ways to organize and classify them to facilitate their identification, selection and use by designers, engineers, and other product development professionals, according to the needs of the design practice objectives, and the specificities of the project. This paper aims to analyze the existing knowledge regarding design for sustainability and circularity tools to identify the main categories used to classify these tools. This was done with the aim of synthesizing the most appropriate classification from the point of view of the product designer who will use the tools. To achieve this, the methodology of literature review was employed, which included scientific papers, theses, and reference books in the field. This analysis gathered a wide diversity of classification forms and organized them into 6 overarching categories. It was also possible to verify that certain forms of classification are not particularly relevant for designers when selecting a tool, as they don't clarify the feasibility of applying the tool. It is possible to conclude that there is still a need for homogenization and consensus in academia regarding the best way to classify these tools so that the classification is scientifically sound and useful for designers.

Keywords: Product design, Design for sustainability, Design for circular economy, Design tools, Tools classification

INTRODUCTION

The design practice, focused in essence on responding to society's needs, has within the scope of sustainability a fundamental role in the integration of aspects, considerations and strategies that endow the solutions achieved with an optimization of the sustainability profile of the products and services (Tischner, 2016; Ferreira, 2008) always having a life cycle perspective and the consequent elimination or minimization of impacts.

This integration of sustainability aspects in a holistic way in the design process can be a complex endeavour that is enhanced and supported using different resources and tools to which the design team has access. However, their use is not yet made through a systematized and effective approach in most projects (Camocho, 2022).

In a study of ecodesign tools, Baumann et al. (2002) concluded that there is a surplus of tool development and a scarcity of studies and evaluations of existing tools. This gap is also reflected in the general lack of knowledge that design professionals have about the existence and benefits of using sustainability tools in the development of products and services.

To address this need and to enhance designers' knowledge about tools and their benefits, this paper presents a systematic review of literature. The focus is on the analysis of academic publications, theses and books related to the classification and exploration of sustainability tools that support the design practice and process.

The intention of this work is to advance current knowledge on the subject and foster the development of a shared common language that will allow the development of new tools and guidance aligned with the needs of design professionals and product developers.

When referring to design for sustainability tools in this paper it includes all the narrower approaches that relate design and the environmental and social aspects, like green design, ecodesign, DfX, design for social innovation or design for circular economy.

METHODOLOGY

The literature review was based on the analysis of relevant references identified using Journal of Cleaner Production, Elsevier and other journals databases, internet research and cross references research. This analysis includes peer-reviewed articles, theses and books.

The search of papers was divided in two main stages. Firstly, references focusing on tools related to sustainability, ecodesign, green design, design for sustainability and circular economy were collected. The second stage was based on a deeper analysis and the identification of the references that explore the structure and classification of different types of tools.

This search resulted in the identification of 33 relevant resources that were analyzed in detail which describe ways of classification and explore aspects related to design practice in the context of sustainability.

CLASSIFICATIONS AND CATEGORIES

The 33 references that were analyzed set out from very different types of purpose and context, and, because of that, present a large diversity of points of view on the tools, which originated a wide range of classifications. It is possible to cluster these 33 classifications in 6 larger categories (Table 1), according to their content and common characteristics.

The first category (C1 - SCOPE) joins 3 classifications that groups DfS tools according to their scope in the wide context of sustainability, in the effort to separate the ones that respond to the entire criteria of sustainability and the ones that are target to specific sections, like Ecodesign or DfX (Pighini et al., 2002).

The second category (C2 - MORPHOLOGY) aggregates 3 classifications that mainly identify tools according to their morphology, separating them by their type of structure or form, as checklists or guidelines (Knight & Jenkins, 2009).

The third category (C3 - PURPOSE) groups 9 references that have classified according to the purpose of each tool. This presents a large diversity of classification and sub-classification items, where the most common goals are analysis, assessment, evaluation, comparation, prescription, visualization, strategy and, overall, decision support. Several classifications also add the creative and idea generation support to the environmental side (Bhamra & Lofthouse, 2007, Tyl et al., 2013).

After these 3 categories that united the tools through a classification of one simple type of analysis, the remaining categories reflect a more recent and complex way to look at the tools, were the classification is always made through more than on point of view. The fourth category (C4 - MULTI-CATEGORY) groups 9 references that present a detailed, diverse, and in-depth classification and sub-classifications such as: types of data (input, output); complexity; digital/analogue; cost (Gomes & Santos, 2014); and some of the first 3 categories are also included.

Category 5 (C5 - CROSS-CATEGORY) adds one other level of complexity and detail to the way we look at and organize DfS tools by using the main classes of C4 - Multy-Category in a cross-referenced approach, were two axes of a matrix help to map out the characteristics of the tools. This approach was first use by Tischner et al. (2000).

The final category (C6 - OTHER / MIX) groups 5 types of classifications, that are different from each other and don't fit any of the previously described categories.

Table 1. Classification of design tools for sustainability.

C.	REFERENCE	CLASSIFICATION	SUB-CLASSIFICATION
C1 - SCOPE	Ahmad et al., 2018	Sustainable Product Design Tools; Partial Sustainable Product Design Tools	-
	Pighini et al., 2002	Eco-Design Methods; DfX Techniques for specific eco-problems; Design Methods for Creativity	-
	Lubis et al., 2022	Partial DfS Tools; Full DfS Tools	-
C2 - MORPHOLOGY	Baumann et al., 2002	Frameworks; Analytical tools; Checklists and guidelines; Software and expert systems; Rating and ranking tools; Organizing tools	-
	Knight & Jenkins, 2009	Guidelines; Checklists; Analytical Tools	-
	Ramani et al., 2010	Tools based on checklists; Tools based on life cycle assessment LCA; Tools based on quality function deployment; Integrated tools	-
C3 - PURPOSE	Bhamra & Lofthouse, 2007	Environmental assessment; Strategic design; Idea generation; User-centered design; Information provision	-
	Bocken et al., 2011	Guideline/checklist; Evaluative; Comparative; Trade-off	-
	Byggeth & Hochschorner, 2006	Analysis tools; Comparing tools; Prescribing tools	-
	Casamayor & Su, 2013	Prescriptive tools	Guidelines; Checklists; Regulations;
		Analytical tools	Detailed software-based tools; Streamlined software-based tools; Matrix-based tools
		Databases	Software-based; Non-software-based
	Janin, 2000	Environmental assessment tools	Quantitative; Qualitative
		Environmental improvement tools	Standards; Lists; Guides; Software; Organizational Tools; Other

Table 1. Continued.

		Other	Strategic Tools; Sensibilization Tools; Communication Tools
	Lewis & Gertsakis, 2001	Analytical; Creative	-
	Marseglia, 2017	Visualization; Quantitatively Measuring; Thinking/ Seeing/ Predicting; Evaluate Qualitatively	-
	Sun et al., 2003	Decision making; Design support; Material flow	-
	Tyl et al., 2013	Strategy-oriented tools; Idea-generation-oriented tools.	-
C4 - MULTY-CATEGORY	Camacho-Otero et al., 2019	Scope	Business model; Service; Product
		Type of tool (analogue or online)	Design tool; Analysis tool; Prioritization tool; Identification tool
		Expected outcome	Designs; Opportunities; Strategies
		Consumption and consumer aspects	Explicit; Implicit
	Gomes & Santos, 2014	Type of procedure	Guideline; Matrix; Checklist; Software; Diagram
		Type of result	Analysis; Recommendation; Comparison
		Runtime	Short; Medium; Large
		Cost	High; Low
		Input data	Qualitative; Quantitative; Both
		Output data	Qualitative; Quantitative; Both
		Required previous experience	High; Low
		Product Development process phase	Information; Concept; Detail; All
	Pigosso, 2012	Nature of the main purpose of the method/tool	Prescriptive; Comparative; Analytic
		Type of tool used	Checklist; Guideline; Matrix; Software
		Nature of input and output data	Quantitative; Qualitative
		Research area where it was created	Ecodesign/Environmental Management; Product Development Process
		Current level of development	Theoretical; Experimental; Consolidated
		Level of detail of the method/tool	Superficial; Brief; Complete
		Environmental aspects considered	-
		Life cycle stages considered	-
		Environmental impact assessment method	-
	Rossi et al., 2016	Life Cycle Analysis; CAD Integrated tool; Diagram tools; Check List & Guidelines; Design for X Approach; Methods for supporting the company's ecodesign implementation and generation of eco innovation; Methods for implementing the entire life cycle and user-centered design for sustainability; Methods for integrating different existing tools	-
	Rousseaux et al., 2017	1st level	Regulatory; Non-regulatory
		2nd level	Mandatory; Voluntary; Normative; Non-normative
		3rd level	Generic; Sectorial
		4th level	Environmental; Improvement
		5th level	Quantitative; Qualitative
		6th level	Computerized; Non-computerized
	Royo et al., 2022	Type	Methodology; Tool
		Objective	Create; Assess/Improve ideas
		Medium	Cards; Guided questions; Board game; Use of different tools
		Integrates circularity criteria	-
	Royo et al., 2023	Type of result	Quantitative; Qualitative
		Reference product	Absolute comparison; Relative comparison; Does not compare
		Segregation of results	Segregated; Not segregated

Table 1. Continued.

	Van Stijn & Gruis, 2020	Level	Macro; Meso; Micro
		Discipline	Technical model; Industrial model; Business model
		Type of support	Guidelines or criteria; Step-by-step guide; Design canvas; Design architypes; Design strategies; Design parameters; Design options; Case examples
	Vicente, 2012	Input type	Quantitative; Qualitative
		Complexity	Low; High
		Software	Yes; No
		Scope	Sustainability; Life cycle; End-of-life specific; Other specific
		Purpose	Analysis/Assessment; Setting priorities; Idea generation; Trade-off; Guidance; Cost estimation
		Sectorial	Generalist; Sector specific
C5 - CROSS-CATEGORY	Bovea & Pérez-Belis, 2012	Y Axes - Dificulty level/Time required	Low; Medium; High
		X Axes - Process Design Phase	Function description; Requirements definition; Design alternatives generation; Design alternatives comparation; Best alternative selection
	Chiu & Chu, 2012	Y Axes - Type	Guideline; Metrics; DfX; LC Costing; Methodology
		X Axes - Process Design Phase	Problem Definition; Conceptual Design; Preliminary Design; Detail Design
	Tischner et al., 2000	Y Axes - Complexity/Time requirements	High; Low
		X Axes - Purpose of the tools	Analysis of environmental strengths and weaknesses; Setting priorities and selecting most important potential improvements; Support for idea generation, design and specifying drafts; Coordination with other criteria
	Valls-Val et al., 2022	Y Axe – Level	Nano (divided in Design e Assessment); Micro; Macro
		X Axe – Type of tools	Assessment (divided in Quantitative e qualitative); Guidelines
C6 - OTHER / MIX	Birch et al., 2012	Strategy-specific tools	Output mechanisms 1, 2 & 3
		Product-specific tools	Output mechanisms 4
	Gómez-Navarro et al., 2005	Design stage	Preparing the Project; Environmental Impacts; Improvement Ideas; Conceptual Design; Detail Design; Action Plan; Evaluation of the Process
		Lyfe cycle stage	R.M and Components Elaboration; Production; Distribution; Use and Maintenance; Disposal; All
		Problem level	Ecoinnovation; Ecodesign; Re-design; Adaptation
	Penty, 2019	Quantitative; Qualitative	-
	Varžinskas et al., 2020	For everyone; For designers, engineers and material engineers; For managers	-
	Zetterlund et al., 2016	Explicit and original purpose to support sustainability considerations in product development; Already implemented in the general operations of many companies and have a potential to support sustainability considerations in product development	-

DISCUSSION AND CONCLUSION

From the proposed categorization and from the analysis of Table 1 it is possible to identify very different and scattered forms of classification without a defined harmonization between them. This diversity hinders the development of a common language and occurs because the tools are developed individually, with a focus on specific objectives. Additionally, all the studies analyzed are from academia and these classifications are typically made from the tool's standpoint, analyzing its specific features rather than relating them to the potential added value, interest, and feasibility for designers and the design process in specific project contexts. This means the classifications, which are academic, present some distancing from practice of design. Only Varžinskas et al. (2020) classifies tools according to their intended user. Nevertheless, from a designer point of view, the most useful forms of classification are the ones that indicate the purpose (C3) and the ones that cross those other relevant aspects for designers (C5), as is the case of Tischner et al. 2000.

The 33 references also suggest two other weaknesses that impede the development of a robust common language for the classification of tools. One weakness is related to the lack of a clear definition of what constitutes a DfS tool and its boundaries, since only 3 of these references present short and partial definitions (Baumann et al., 2002; Gómez-Navarro et al., 2005; Rousseaux et al., 2017). The other weakness, which follows from the first, is the absence of clearly defined criteria that substantiate the stated classification and would help establish a link to the design process. Only Bovea & Pérez-Belis (2012) and Byggeth & Hochschorner (2006) indicate the criteria used for classification.

It's clear that, due to their large number, DfS tools need to be classified to facilitate their communication to designers and enhance their usability in the design process for all types of projects. This classification should be clear and practical for the intended users, rather than solely relying on scientific logic or soundness.

The above-mentioned analysis indicates the need for a better definition of what is a DfS tool and the establishment of its boundaries. Additionally, efforts should be made to determine the optimal criteria for creating a useful classification that caters to both design practitioners and academic requirements. This undertaking should also be developed to support and steer the development of new tools that are geared for a more circular and sustainable outcome of the design process.

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