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Sustainable Material Selection Framework: Taxonomy and Systematisation of Design Approaches to Sustainable Material Selection

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Abstract: Design can play a fundamental role in addressing the climate crisis and preserving the planet's finite resources. Through design, it is possible to reduce the environmental impact of products and services right from concept stage. The elements that concur within a project are diverse and often have an impact on each other. The material is one of them, being able to influence the product, but also the business model, company relations, etc. To help the designer keep all these aspects under control, various methodologies and tools have been developed, among them design strategies and guidelines. To date, several authors have dealt with the topic, offering different perspectives and generating a critical mass of information, which differs in the level of depth and operability of the suggestions, often differing only in terminology rather than content. This inhomogeneity can confuse both professionals and students. This study proposes an ordered taxonomy of the different levels of detail and a unified terminology of the strategies and guidelines in the literature. To test taxonomy and systematisation, this article focuses on guidelines for material choice, resulting in a framework to guide the selection of materials with a view to sustainability.

Keywords: material selection; sustainability; taxonomy; framework; mapping; design strategy; design guidelines

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1. Introduction

Millions of products are sent to landfill every year due to the throwaway culture permeating society. Because of the increasing global population, this issue will continue to grow and strain the environment in terms of energy and material resources [1]. In fact, the greater the number of people consuming, the greater the rate at which consumption will occur, and, in turn, the demand for materials will rise [2]. As some experts point out [2,3], reserves of some resources, particularly some materials, are reaching a critical threshold, bringing to light the negative impacts that depletion could have on the environment and human activities [4]. Conscious use of resources must be seriously considered and implemented if we wish to succeed in achieving the 17 sustainable development goals—11 of which have direct implications for resource use—[5] and realise the vision of sustainability presented by the Brundtland Commission [6], and other organisations, such as IUCN, UNEP, and WWF [7].

Design and the designer play a fundamental role in achieving this vision and solving these problems since it is during design phase that it is possible to determine more than 80% of a product's environmental impact [8–12]. A design artefact focusing on sustainability must pay attention to several factors, one of which is certainly the material. The latter represents an initial response, a fundamental gateway to creating a sustainable product.

Therefore, designers and companies have contributed to introducing and applying various green materials in the last decade. Usually, during the new product development (NPD) process, it is difficult to assess one material as more or less sustainable than another since this depends on the stakeholders, the contexts in which the product will be introduced and used, and the meanings that the user attributes to the material or the whole object [13–16]. Moreover, the selection of a material for a new product will also influence production processes, relationships that the manufacturing company has, the proximity of suppliers and primary resources, local recycling facilities, and the possibilities of recovering energy at the end of its life cycle. Therefore, restricting selection to properties such as embodied energy or carbon footprint may be simplistic and reductive [2], as well as evaluating a product as sustainable just by looking at the material used to manufacture it [17]. However, the factors listed above must work in synergy as a starting point to develop a product that brings environmental improvement or innovation, guiding the design process, engineering, and, ultimately, also the material selection [18]. The importance of having a holistic vision emerges from the first design phases, acquired by considering the product's whole life cycle and an overall picture of the context and the company.

Although this represents a considerable effort for the designer, different methodologies and design approaches have been developed to support sustainable design over time. Since the early years of the new millennium, three main currents of thought have become more widespread in the literature: ecodesign, design for environment (DfE)/design for sustainability (DfS), and circular design. Although with different characteristics, all the approaches listed above aim to create products and services with the least possible environmental impact throughout their life cycle. To achieve this and to simplify understanding and practical application for designers, several authors have addressed this topic by translating these concepts into strategies and guidelines. In this article, the indications given in the form of strategies and guidelines are interpreted as generalised problem–solution combinations [19]. These can be compared to patterns as described by Alexander and colleagues [20], i.e., "a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice". Like patterns, the indications identified in this article by the various authors are derived from experience and empirical observation and are necessary tools for encoding tacit knowledge into explicit knowledge [19]. The strategies and guidelines are specifically dedicated to the product design field. Although they exist in other knowledge domains, the purpose of the design ones is to guide the designer in simplifying the decision-making process. Furthermore, it is necessary to specify that these, although they may have a high degree of specificity, are qualitative and not quantitative indications. This, especially in material selection, entails parallel work to provide supporting data from LCA or reports to have a complete overview and avoid rebound effects or reductionist choice.

Even though they are not always treated individually within the different approaches, material-related indications are an integral part. By analysing the different perspectives and guidelines, it is possible to find some recurring indications which reach very different levels of specificity and often indicate very similar concepts but with different terms. To clarify and examine this issue, the previously listed approaches and other schools of thought—that cannot be attributed to any of them but are, nevertheless, of equal importance—will be dealt with below, giving some examples of the relevant strategies and guidelines of the different authors and visualised in Figure 1.

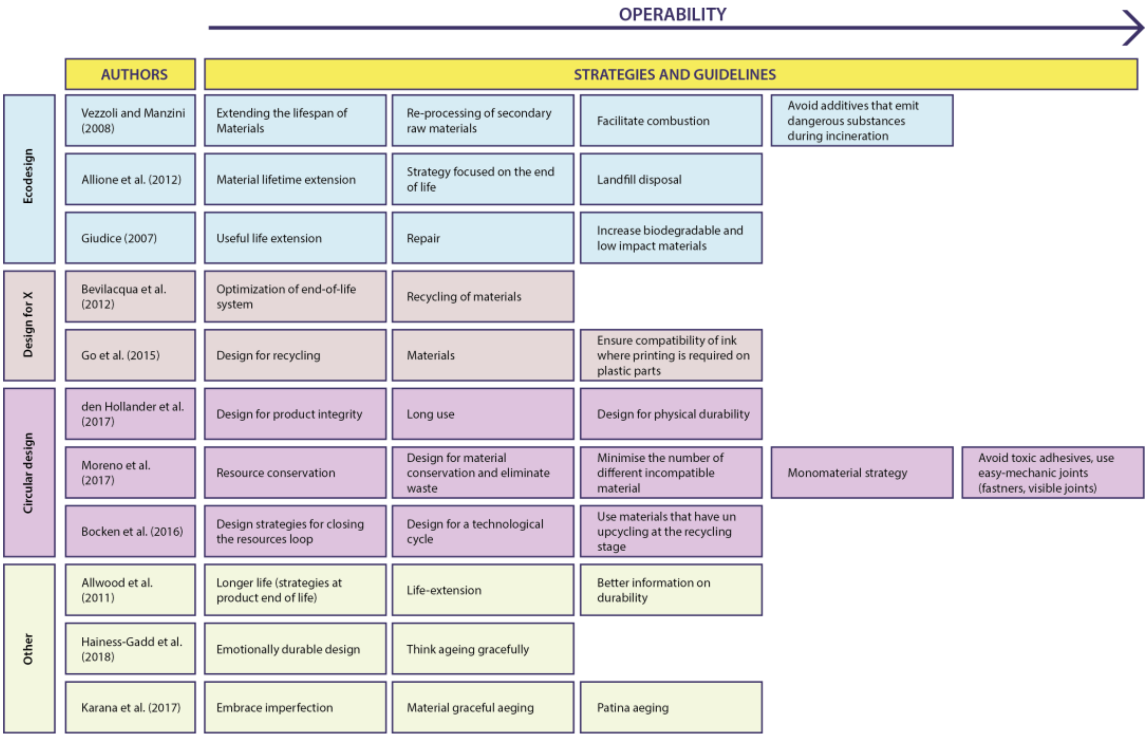

Figure 1. Example of the indications and different levels of depth for each author analysed by design approach [17,21–30].

1.1. Ecodesign Strategies and Guidelines

Ecodesign is the first school of thought that links the field of sustainability to design. Vezzoli and Manzini [17] embrace it, encouraging the designer to develop not the single product but its entire life cycle to reduce the environmental impact in each of its five phases (pre-production, production, distribution, use, and disposal), thus, defining life cycle design (LCD). This perspective leads the authors to specify a plethora of strategies and subsequent increasingly detailed guidelines, ranging from extending the lifespan of materials to more specific indications such as "avoiding additives that emit toxic fumes during incineration". Similarly, Allione et al. [21] also adopt the perspective of ecodesign and LCD, reaching a lower degree of detail. Even these authors, for example, encourage the designer to think about material lifetime extension by simply indicating the possibilities of the material at the end of its life, such as incineration, recycling, biodegradability, or compostability. Giudice [22] does not explicitly state the design approach adopted in his guidelines; however, he also discusses useful life extension, indicating that it is necessary to increase the use of low-impact and biodegradable materials to achieve a sustainable product.

1.2. Design for Environment/Design for Sustainability Strategies and Guidelines

The indications cited in the paragraph above are also echoed by those adopting a DfE/DfS approach. They are both included in this article because, although they have slightly different theoretical aspects, they are often used interchangeably in the literature [31], and both can be linked to design for X (DfX), a design technique that emerged in the early 1980s [32,33]. Among those relying on DfE, it is possible to find Bevilacqua et al. [23]. They, linking back to LCD, aim at life cycle optimisation by including guidelines such as material recycling within the different phases. Go et al. [24] also refer to DfX and other strategies of this technique related to sustainability, such as DfE, but also design for recycling (DfR) or design for disassembly (DfD). Go and his colleagues schematise the different strategies into areas containing the various guidelines. This segmentation allows the authors to achieve a higher level of specificity in their guidelines, even suggesting the use of screws made of materials compatible with the connected parts.

1.3. Circular Design Strategies and Guidelines

The circular economy concept has emerged as the scientific debate on sustainability has evolved and spread in the last decade [34]. Some authors have tried to link strategies and design guidelines to these concepts. It is the case of den Hollander et al. [25], who use circular product design, explicitly distancing themselves from ecodesign (for the authors, a methodology rooted in the linear economy). They developed two design approaches: design for product integrity and design for recycling. However, these have not been explored in depth by the authors, and no guidelines or indications emerge when using the lens of materials. Moreno et al. [26] also adopt circular design, relying extensively on techniques developed within DfX. The framework and the review led Moreno and his team to develop a taxonomy of strategies and guidelines for circular design [35]. This breaks with the previously discussed and analysed approaches, as it starts from the circular design aspect (such as resource conservation), then employs the DfX approach (such as design for material conservation and elimination of waste), and, finally, concludes with strategies and design guidelines of various natures and depth (such as selecting the best materials (non-toxic and pure if possible)). Finally, Bocken et al. [27] also adopt a circular design perspective, focusing on the life cycle of resources. In particular, the authors suggest that slowing down or closing the resource loop is necessary in a circular perspective. In the second case, closing the resources loop, a strategy list concerning the technological cycle is suggested, whereby using materials that have upcycling at the recycling stage.

1.4. Other Perspectives

Finally, it is important to emphasise that the literature contains a range of material-specific recommendations, strategies, and approaches not directly related to the schools of thought mentioned above. These include the material efficiency approach of Allwood et al. [28], which aims to provide the same object functionality but with the lowest possible use of material and manufacturing processes. Or the strategies based on emotional durability developed by Hainess-Gadd et al. [29] and Karana et al. [30], which aim to extend the product's life by stimulating the creation of an emotional bond or transformation over time through the material.

1.5. Research Gap and Objective

At the end of this overview of the different strategies and guidelines for material selection within the different design approaches for sustainability, a lack of an integrated vision emerges. It is noted that although the declared design approaches are different, the selection guidelines often overlap and differ only due to a purely terminological issue. Moreover, the taxonomy's terminology is highly fragmented, feeding confusion about the different levels of detail of the strategies and guidelines proposed by the various authors, which are very different from each other. Therefore, this research aims to propose a precise taxonomy to unify terminology to let practitioners navigate into the different levels of in-depth strategies and guidelines. According to the authors, this procedure will help apply them to an integrated and sustainable materials selection activity. The research proposes a systematisation of the literature strategies and guidelines, positioning them within the presented framework.

2. Methodology

The research takes an exploratory approach, using qualitative methods, to categorise and interpret the current state of the art. The starting point was an extensive analysis of design approaches, strategies, and guidelines in the field of sustainable material selection through an integrative literature review to critically assess and recontextualise the foundations of the topic under analysis [36]. A first set of articles has been analysed using texts derived from the authors' previous research and knowledge to collect referring literature for the work. From that, specific keywords (i.e., sustainability*, material*, selection*, design for*, guidelines*, and circular economy) in different combinations were used by querying on Scopus. Journal articles, conference proceedings, books, and book chapters written in English were analysed. Among these, only the ones without a focus on specific materials families or sectors (e.g., buildings, vehicles, and packaging) have been selected. From these results, other sources were obtained through snowballing sampling analysis [37] of previous and subsequent academic publications discussing sustainable selection of materials in product design.

Of these, some already offered a clear visualisation through schematisation of the strategies and guidelines for designers. In contrast, others discussed them in a more textual way. Of the texts analysed, 11 were considered suitable and, subsequently, used for the mapping activity (Table 1). Since the main purpose of the article is not to provide an extensive overview of all sustainability-oriented strategies and guidelines for material selection, but to explore, propose, and validate a taxonomy for design strategies and guidelines applied in the field of sustainable material selection, the number of contributions selected, according to the authors, reached the quality, diversity, and saturation of the information mapped.

Table 1. Authors and texts selected and used for mapping activity.

Ref.	Authors	Title	Publication Type/Place	Year
[17]	Vezzoli, C., and Manzini, E.	Design for Environmental Sustainability	***Book***. Springer, London	2008
[23]	Bevilacqua, M., Ciarapica, F. E., and Giacchetta, G.	Design for Environment as a Tool for the Development of a Sustainable Supply Chain	***Book (Focus on Chapter 2)***. Springer Science & Business Media	2012
[22]	Giudice, F.	Product Design for the Environment: The Life Cycle Perspective and a Methodological Framework for the Design Process	***Book Chapter***. In Environment Conscious Manufacturing	2007
[21]	Allione, C., De Giorgi, C., Lerma, B., and Petruccelli, L.	From Ecodesign Products Guidelines to Materials Guidelines for a Sustainable Product. Qualitative and Quantitative Multicriteria Environmental Profile of a Material	***Journal article***. Energy	2012
[25]	den Hollander, M. C., Bakker, C. A., and Hultink, E. J.	Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms	***Journal article***. Journal of Industrial Ecology	2017
[27]	Bocken, N. M. P., Pauw, I. de, Bakker, C., and van der Grinten, B.	Product Design and Business Model Strategies for a Circular Economy	***Journal article***. Journal of Industrial and Production Engineering	2016
[26]	Moreno, M., Ponte, O., and Charnley, F.	Taxonomy of Design Strategies for a Circular Design Tool	***Conference proceedings***. Proceedings of the 2nd Conference on Product Lifetimes and the Environment (PLATE)	2017
[28]	Allwood, J. M., Ashby, M. F., Gutowski, T. G., and Worrell, E.	Material Efficiency: A White Paper	***Journal article***. Resources, Conservation and Recycling	2011
[30]	Karana, E., Giaccardi, E., and Rognoli, V	Materially Yours	***Book Chapter***. In Routledge Handbook of Sustainable Product Design	2017
[29]	Haines-Gadd, M., Chapman, J., Lloyd, P., Mason, J., and Aliakseyeu, D.	Emotional Durability Design Nine: A Tool for Product Longevity	***Journal article***. Sustainability	2018
[24]	Go, T. F., Wahab, D. Abd., and Hishamuddin, H.	Multiple Generation Life-Cycles for Product Sustainability: The Way Forward	***Journal article***. Journal of Cleaner Production	2015

The first step (Figure 2) in constructing the sustainable materials selection framework (SMaS framework) was to schematise each contribution extensively. The schematisation was first carried out using a collaborative online platform (Miro boards) to highlight the gap and encourage a more visual and fluid approach in the association of similar strategies and guidelines, and then transferred to Microsoft Excel to construct a structured database that would allow the clustering of indications in systematic taxonomy and allow tracking of aggregation in the following steps. It was also chosen to use Microsoft Excel to enable the subsequent use of an online software for data visualisation (RAWGraphs 2.0) [38].

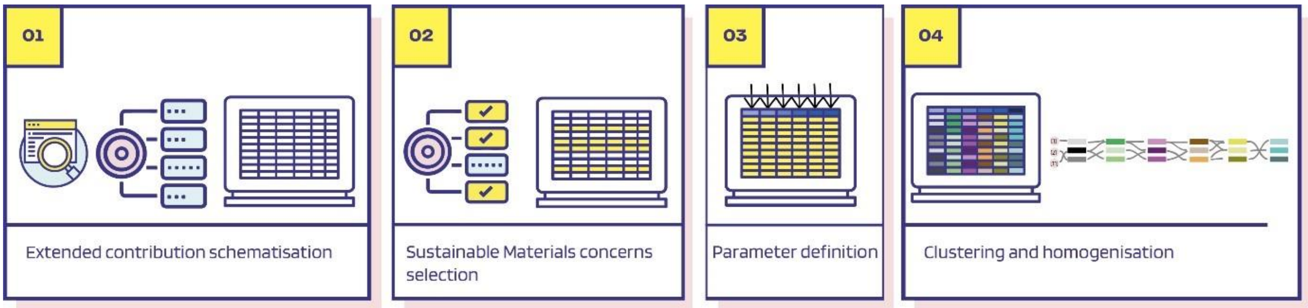

Figure 2. Schematic representation of the workflow adopted for taxonomy homogenisation and information schematisation.

The second step consisted of a selection, within the mapped sources, of information concerning the selection and use of materials in the sustainability project. This activity highlighted about one third of the information derived in step 1 (n = 222 lines out of the initial 675). This activity incontrovertibly confirmed the disuniformity in the terminology used by the authors analysed.

The third step aimed to put in order the information for the designer regarding sustainable materials selection, proposing an orderly and defined systematisation (Figure 3). This led to the definition of the following taxonomy:

- **Author's perspective**: An umbrella term for the many design approaches for sustainability;
- **Objective**: The purpose toward which the design effort is directed and which it seeks to achieve: the aim, goal, or end of action;
- **Strategy**: The act of devising plans which represent the best possible way to deal with a design challenge and have the best possible sustainability benefit;
- **Tactic**: The particular methods, actions, and themes used to achieve a sustainable design objective;
- **Guidelines**: A rule, instruction, or information that guides the designer on how something should be carried out or how something should be. In this case, indication or outline to apply in design activities to foster materials selection;
- **Parameters and criteria**: Standard or sharp information (unambiguous, testable, or measurable) that indicates fixed limits on how something should be, which guide the decision-making process. In this case, limit, indication, or physical properties necessary for materials selection.

These definitions arise by comparing the terminology used by the various authors analysed with different online dictionaries such as the Merriam-Webster or the Oxford Learners (see Appendix A) and gradually developed and implemented during the literature review work, up to reach a reasonable definition of them and to be properly adapted to the design field. This operation on the mapped data made it possible to allocate the information by standardising the degree of specificity, from the most aleatory to the most concrete for design practice (from left to right in Figure 3). Therefore, the listed terms formed a framework to map the strategies and guidelines, allowing a precise data distribution.

The fourth step was aimed to eliminate repetition and redundancy: the same concepts expressed by different authors have been grouped by codes considering the most subtle differences, re-examining the articles, and keeping track of the "history" of each mapped contribution. This operation made it possible to provide a lightened mapping and readable to the last level of detail.

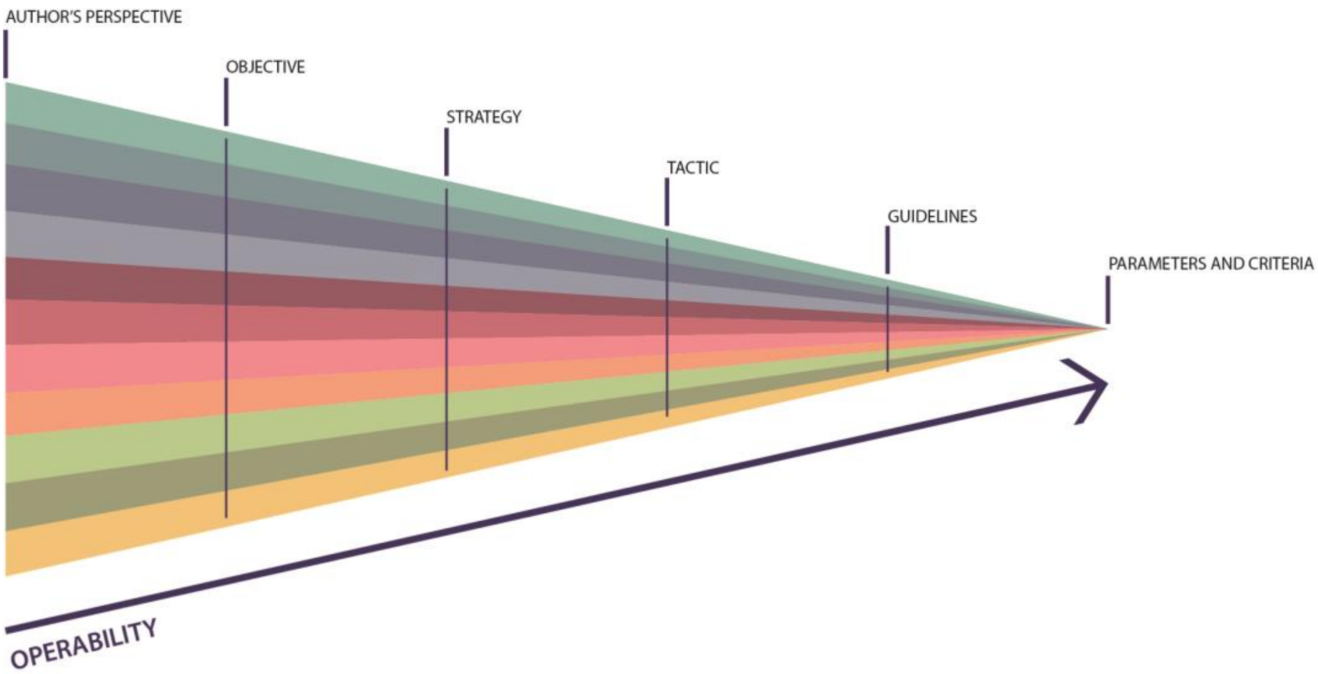

Figure 3. Schematisation of the taxonomy and convergence towards operability of the indications.

Therefore, the flow followed to obtain the mapping was a top–down approach, from the grouping of macro-data to their selection and systematisation down to the smallest detail. The mappings shown below in the results section were obtained using RAWGraph [38], a data visualisation tool developed by the DensityDesign research group of the Department of Design at Politecnico di Milano, and subsequently re-elaborated using Adobe Illustrator.

The overall work has been carried on with a constructivist approach, embracing the possibility that there is no vision of objective external reality independent of individuals [39] and incrementing the notions and the clusters proportionally with information retrieved by the readings. The choice of the constructivist approach is also reflected in the purpose of the strategies and guidelines. The aim of the indications is to be interpreted by the individual researcher or designer (usually in the concept design phase or product development), allowing them to adapt the guidelines to the contextual conditions.

3. Results

The in-depth study of the presented literature (Table 1) has been compulsory to confirm the assumptions expressed in Paragraph 1.5. The indications developed over time to design in the perspective of sustainability, and, in particular, focusing on the material selection, are homogeneous, even if authors refer to different research approaches (e.g., ecodesign, DfX, or others mentioned above). Since some strategies and guidelines are commonly shared by them, independently from the author's perspective, the authors of this article have highlighted and systematised the common elements rising across the diverse research. Consequently, the authors believed it could be worth collecting them according to their purpose (meaning to guide a sustainability-oriented material selection activity) rather than the perspective from which they were conceived.

The literature review and subsequent mapping activity also confirmed how similar concepts, strategies, and guidelines usually may appear as different due to language divergences. The immediate consequence of this language ambiguity results in the difficulty of finding a homogeneous panorama of material selection guidelines for sustainable product design.

Therefore, through the presented methodology and subsequent homogenisation of the clusters definition (see Section 2), it has been possible to depict an overview of sustainable material selection strategies and guidelines, according to different authors, to be implemented in design activity and research. The realisation of an Excel file blindly collecting all the directives emerging from the literature reading is presented in Figure 4, and a total of 222 rows have been collected from the 11 different contributions analysed. Subsequently, some codes have been attributed to each row to group similar elements under the same tag (in Figure 4 represented in the grey columns with E code, G code, I code, K code, and M code; the coding names are derived from the Excel file columns).

AUTHOR'S PERSPECTI		APPROACH		STRATEGY		TACTIC		GUIDELINE		PARAMETERS AND CRITERIA
ECODESIGN	Minimize resource consumption	E1	Minimising material Consumption	G1	Minimising scraps and discards	I1			Select processes that reduce scraps and discarded materials during production	M1
ECODESIGN	Minimize resource consumption	E1	Minimising material Consumption	G1	Minimising materials consumption during usage	I3	Select more consumption-efficient systems	K1	Design for the efficient consumption of operational materials	M4
ECODESIGN	Minimize resource consumption	E1	Minimising material Consumption	G1	Minimising materials consumption during usage	I3	Select more consumption-efficient systems	K1	Design for the more efficient supply of raw materials	M5
ECODESIGN	Minimize resource consumption	E1	Minimising material Consumption	G1	Minimising materials consumption during usage	I3	Select more consumption-efficient systems	K1	Design for the more efficient use of maintenance materials	M6
ECODESIGN	Minimize resource consumption	E1	Minimising material Consumption	G1	Minimising materials consumption during usage	I3	Select more consumption-efficient systems	K1	Design for the cascading of recycling systems	M7
ECODESIGN	Minimize resource consumption	E1	Minimising energy consumption	G2	Minimising energy consumption during pre-production and production	I4			Select materials with low energy intensity	M8
ECODESIGN	Minimize resource consumption	E1	Minimising energy consumption	G2	Minimising energy consumption during transportation and storage	I5			Select local material and energy sources	M11
CIRCULAR DESIGN	Resource Conservation	E1	Design fo material conservation and eliminate waste	G1			Select the best material (non-toxic, pure if possible)	K11		
CIRCULAR DESIGN	Resource Conservation	E1	Design fo material conservation and eliminate waste	G1					Chose local materials (no-rare to avoid scarcity)	M11

Figure 4. Screenshot of the data organisation into the Excel file realised by the authors (extract of the first rows to show the construction of the material guidelines and strategies database).

After grouping certain elements under the same tag, authors were able to realise some terminology homogenisation, realising a systematised group of information divided into approaches, strategies, tactics, guidelines, and parameters and criteria.

In Figure 5, the systematised information emerging from the adopted methodological path is presented graphically and subsequently discussed.

Literature contributions pertaining to a similar author's perspective have been represented with shades of the same colour.

As it can be immediately noticed, some blank spaces in the fluxes emerged. This graphical expedient has been useful for the authors to convey a precise message: due to divergences in terminology and the definition of guidelines according to different operability levels, authors needed to "allocate" in the new taxonomy certain contributions coming for literature. This means that sometimes authors defined "guidelines" extremely operative notions, creating ambiguity with other contributions that, under the term "guidelines", inserted more generic indications. Therefore, it could happen that certain steps defined for the new taxonomy were not completely fulfilled by the literature.

Hence, these blank spaces represent this terminological ambiguity. In this first instance, authors decided to maintain this feature to avoid losing fidelity with the literature analysed that, since no taxonomy was defined before, rightly adopted terminology according to their precise studies.

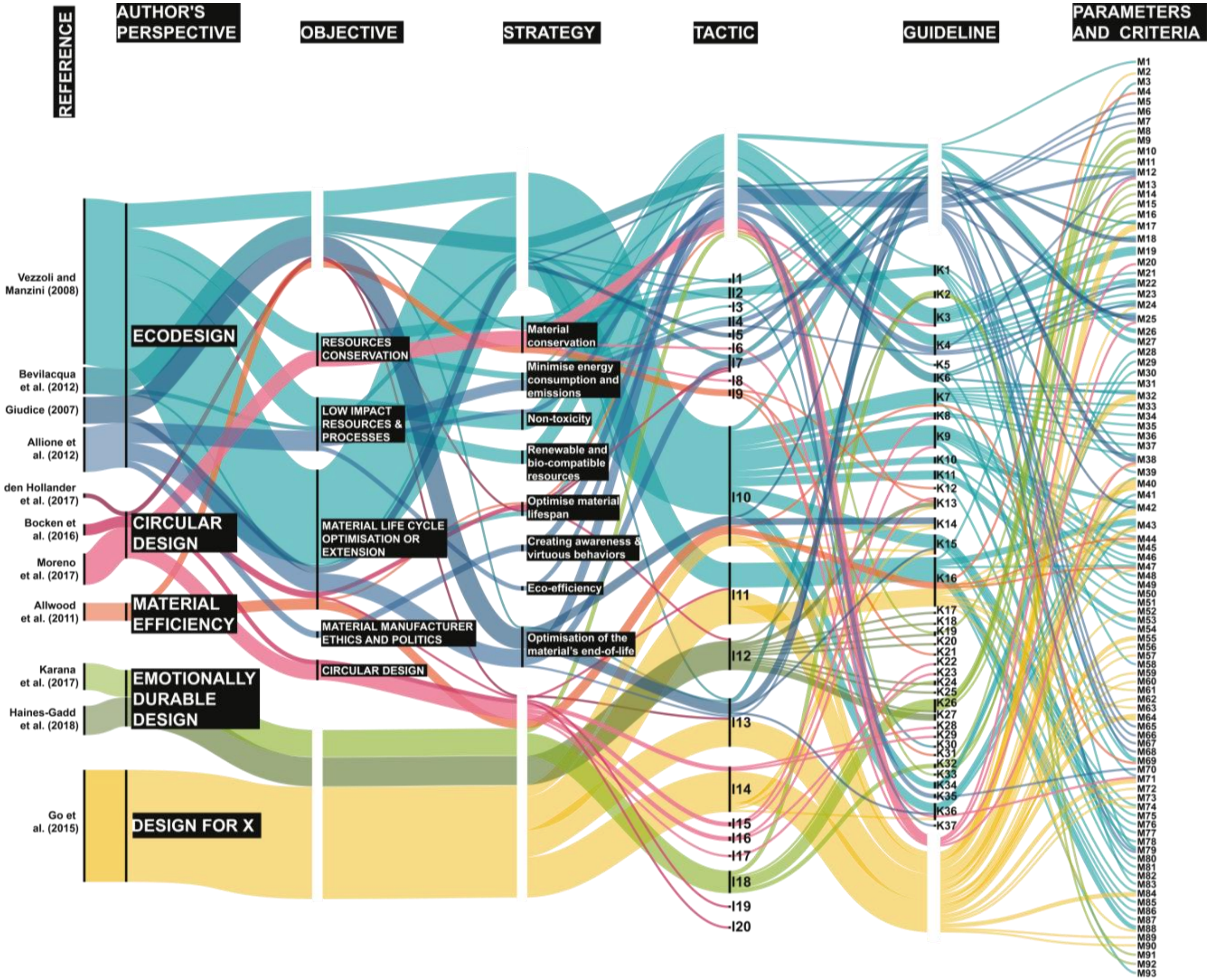

Figure 5. Overview of the SMaS framework showing the different steps within the proposed taxonomy [17,21–30]; the high-quality framework can be found in the Data Availability Statement link.

3.1. Objectives

From the 11 sources (Table 1) analysis, five different authors' perspectives have been highlighted (respectively, ecodesign, circular design, material efficiency, emotionally durable design, and DfX). Each of these perspectives led singular authors to define different ways to pursue a sustainability-oriented material selection activity, providing an objective to be pursued. On a wider level, it has been possible to group these objectives as follows:

1. **Resource conservation**: reflects upon how to manage natural resources without compromising the ecosystem;
2. **Low-impact resources and processes**: focuses on reducing emissions and compromising effect on production processes and energy consumption;
3. **Material life cycle optimisation and/or extension**: characterised by improved LCA efficiency directly in the definition of sustainable material selection activity strategies and guidelines;
4. **Material manufacturer ethics and politics**: focusing on the importance and relevance of creating awareness of the consequences of material manufacturing;
5. **Circular design**: guidelines and strategies explicitly referring to circular economy principles.

3.2. Strategies

This first clustering activity (Figure 6) was quite affected by the author's research field and perspective manifested in the specific resource analysed. However, the subsequent development of these approaches and objectives into strategies, tactics, and guidelines directly drove a series of concepts overlapping, repetitions, and convergences among the different sources analysed, creating mismatched accordance of nomenclature. Using the proposed taxonomy, it already emerges from the first steps how the depth of the indications found in the literature is variable. For emotionally durable design, DfX, and part of ecodesign, the indications found in the literature are too specific to be clustered as objectives or strategies.

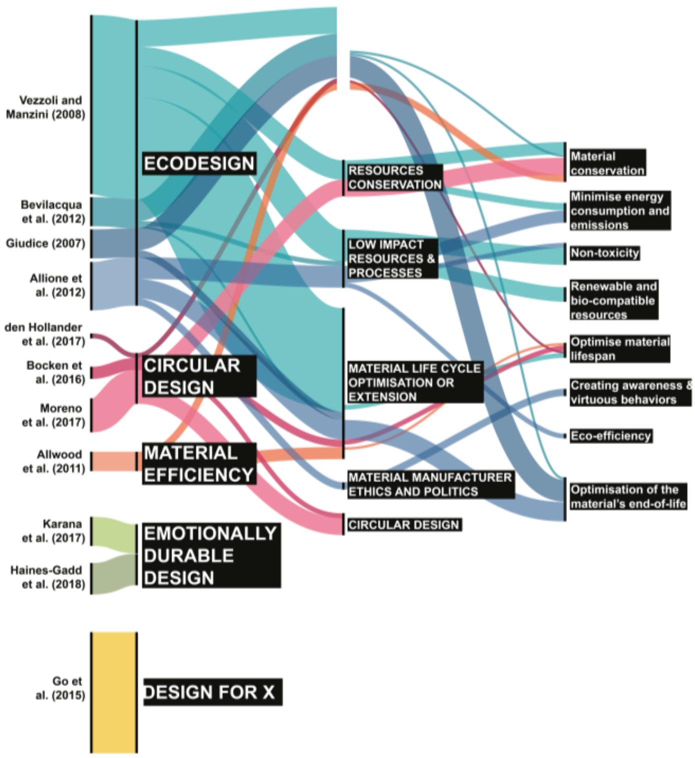

Figure 6. Focus within the SMaS framework on the author's perspective, project objective, and strategy column [17,21–30].

From the analysed sources, by deepening the lecture and analysing selected resources, it has been possible to highlight eight main strategies, evolving from previously analysed approaches.

3.3. Tactics

In some cases, the literature analysed offered some guidelines that were not as punctual as in other retrieved resources; therefore, tactics have been introduced as a mid-cluster to differentiate elements between strategies and guidelines in terms of information specificity. The analysis highlights 20 different tactics (Figure 7) and can be examined in detail in Appendix B. Since the proposed taxonomy of approaches, strategies, and guidelines (defined by authors in Section 2 of this contribution) did not necessarily meet the ones adopted in the different retrieved sources, it happened that, e.g., as highlighted before, during the clustering activity, some authors were referring to "strategies" when mentioning very detailed drivers, more coherent with the definition of "guideline" (or vice versa). Therefore, the authors critically analysed these insights and clustered them according to the proposed taxonomy to homogenise the language and the insights as well. This implied that sometimes, some information was missing, and some "jumps" between the clusters occurred. As explained, these jumps have been represented in the visualisations to maintain a modus operandi as objective as possible. Therefore, these interruptions should not be interpreted as "missing information" but, instead, as a mismatch with the presented taxonomy.

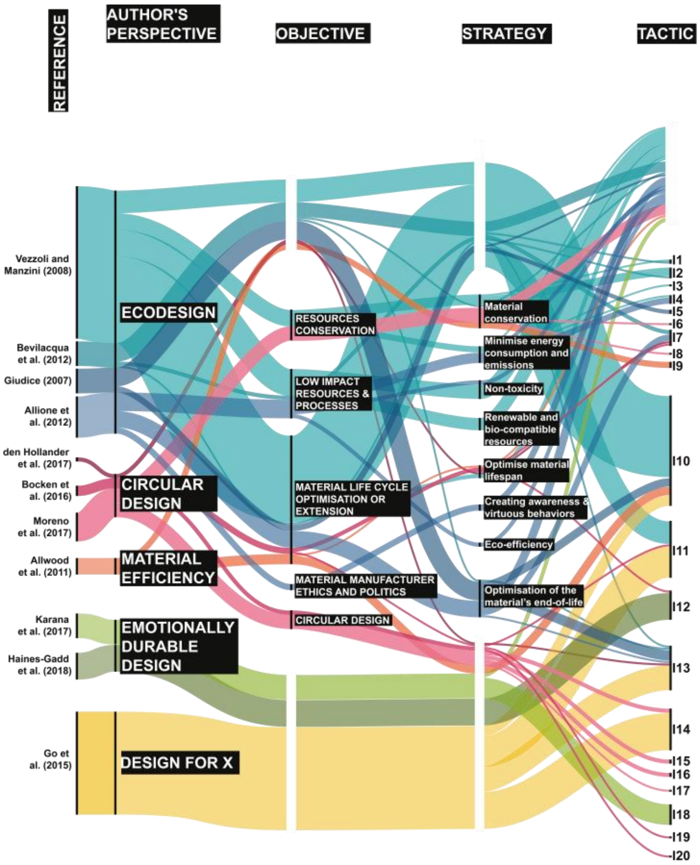

Figure 7. Connections between authors' perspective, objectives, strategy, and sub-strategy within the SMaS framework [17,21–30].

At the same time, these interruptions do not prove that the taxonomy is wrong. Instead, they represent the actual definition gap that provokes a confusing use of the mentioned lemmas, increasing the blurry panorama of guidelines and strategies emerging in the literature for selecting sustainable materials.

The diverse thicknesses of the coloured streams depend on the cumulative count of elements concerning that specific group and have been visualised using the RAWGraphs platform [38].

3.4. Guidelines, Parameters, and Criteria

At this point, the interpolation of the different sources started to be more and more evident: within a collection of 36 different guidelines, it is possible to perceive the detachment from the original, linear division between the analysed authors' works when it comes to specific, operational parameters for a sustainability-oriented material selection, the author's perspective and the research field seems not to affect directly. The guidelines can be analysed in detail in Appendix C. At this level of analysis, research approaches and perspective boundaries become permeable, and it is even difficult to distinguish them if looking at guidelines only (Figure 8).

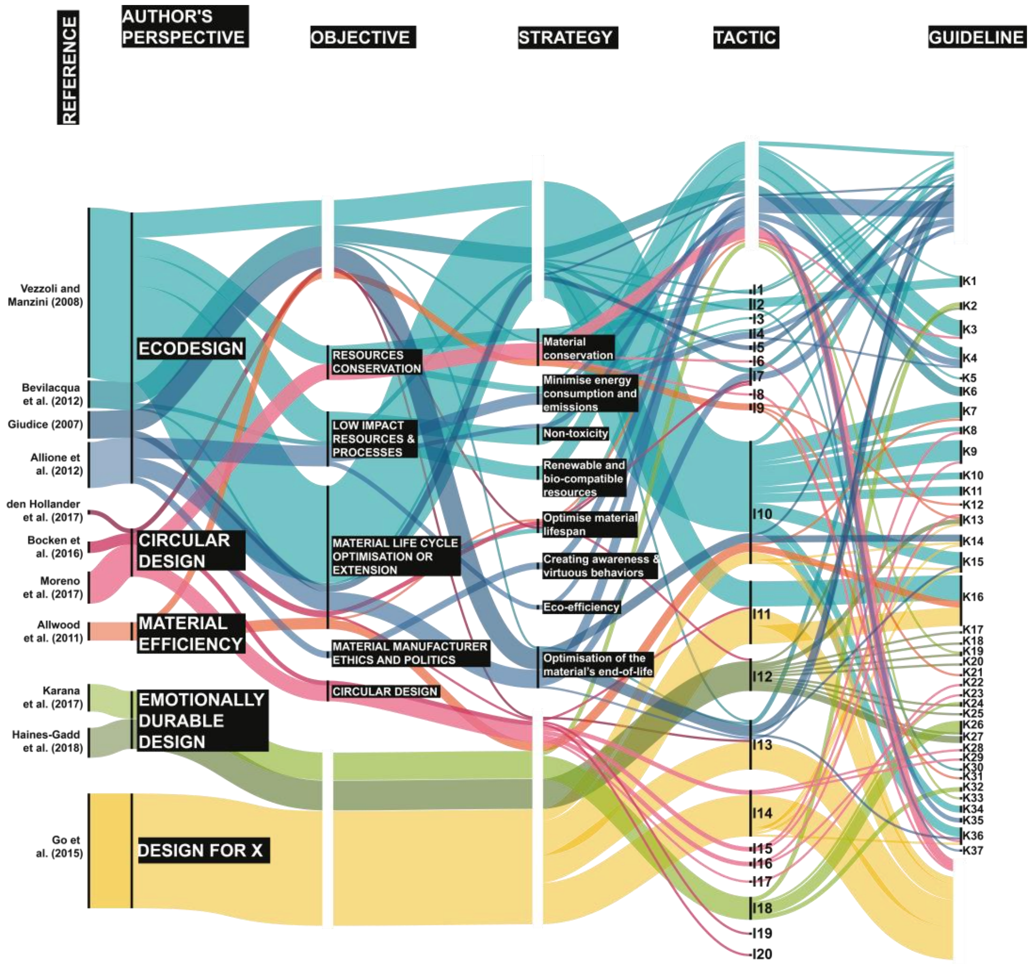

Figure 8. Ramifications of tactics and interpolation with the different guidelines within the SMaS framework [17,21–30].

When authors were extremely precise in providing punctual material selection tips, these insights were clustered as "Parameters and Criteria". A total of 93 different parameters and criteria (Figure 5) for sustainable material selection activity have been collected as follows (the complete legend of the parameters and criteria can be found in Appendix D).

The presented visualisation offers a comprehensive overview of strategies and guidelines for sustainable material selection activity.

Starting from this cumulative visualisation, it is possible to highlight both different guidelines and parameters sets, grouped, e.g., by research approach (Figure 9) and convergences between the different approaches, confirming the necessity for certain cases to adopt similar language for referring to the same concept. These convergences are particularly significant in terms of identifying the possibility of finding a common language concerning material selection oriented to sustainable purposes.

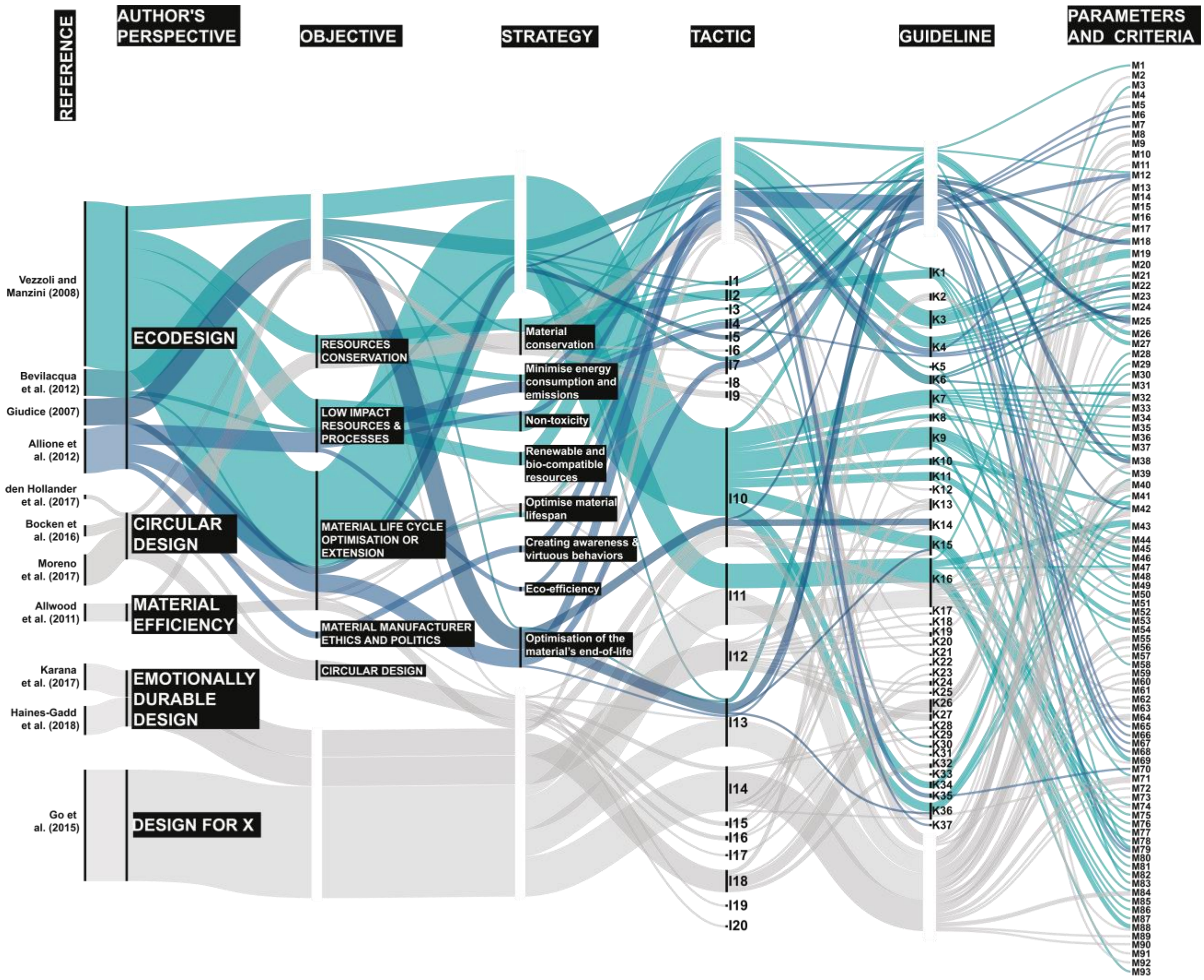

Figure 9. Highlights of the ecodesign authors' perspective and subsequent indications within the SMaS framework [17,21–30].

4. Discussion

Whereas the awareness that the selection of sustainable materials should be framed within a larger and more complex system of design for sustainability, the present work emerged from the shared need to have a holistic view of approaches and strategies for selecting sustainable materials. The multidisciplinary research group has a solid background in materials selection and systemic design. When approaching materials sustainability issues in an academic or industrial context, it has been evident that there is a tendency to follow only a few points of view, missing other possible avenues toward sustainable material selection and application in product design. Moreover, it was noticed that the sector's literature reaches varied levels of comprehensiveness, definition, and criticality, limiting its application in the design practice. Sometimes, on the other hand, authors in the literature were just using different terminology, and, although starting from different perspectives, they arrived at the same strategies. Over time, this has produced a critical mass of non-homogenous research, which, consequently, may generate confusion among practitioners or students looking for a clear direction.

In this work, it has been presented an attempt of a structured systematisation of the strategies and guidelines for a sustainable material selection. The overall organisation has been conducted with a systematic mapping activity, described in detail in the previous paragraphs. The objective of such a detailed description of the procedure adopted for this systematisation activity is to provide a repeatable and clear methodology.

Therefore, the SMaS framework attempt to collect contribution for a readable flow guiding practitioners to a comprehensive vision of the academic perspective of sustainable materials selection and application to product design. The SMaS framework deals not only with selection but generally with the use of materials in the design project since the material is a product pillar able to influence the shape, the assembly, the mode of use, and the interaction with the product.

Design practitioners and researchers can use the SMaS framework either starting from parameters and criteria, climbing up to the design perspectives or vice versa, in a top–down direction. The advantage of this double reading leads the user not only to better understand the framework, but also to adapt to specific situations, e.g., where a brief provides specific parameters and criteria, it becomes possible to open up new possibilities and trace further design approaches, implementing creativity, or in the opposite case where a broader approach and perspective is desired, it is possible to ground these aspects. Such visualisation clearly communicates already existing guidelines and directions to pursue a sustainable material selection activity. The SMaS framework, exploiting all the advantages of the graphic visualisation of data collected, allows practitioners at a didactic and professional level to approach material selection with a broad overview of this process's implications, even though their background knowledge is not technical. This helps envision the motivations why the research "pushes" specific directives towards the sustainable selection of materials and helps to ground the basis for an aware management of material selection activity. This aware management of material-related information is a valid activity both in academics and industrial application, responding actively to the practical difficulties encountered in such a transitional moment.

According to the authors, this systematisation represents the first step towards the subsequent realisation of an integrated tool for sustainable design, capable of guiding the designer step by step towards increasingly specific levels of detail. This concept can be valid for material selection guidelines and strategies and other drivers (e.g., sustainable production guidelines and strategies or sustainable supplier selection strategies). Therefore, the authors believe that the proposed methodology could be adopted and followed to map other relevant guidelines and strategies to pursue sustainable production since, as stated in the introduction section, this not only depends on material selection but also passes through it. Indeed, it is important to reiterate that to avoid rebound effects or a reductionist approach, it is always important to read the indications provided by the framework and the various authors with a critical eye, harmonising the needs and requirements of the material with others imposed by the context.

As future developments of this work, the authors aim to resolve the interruptions in the flux visualisation for better reading and use of the proposed tool. This action implies that the author needs to revise the mapping activity, abandoning the "high-fidelity" approach for collecting information used in this contribution, and make some assumptions to harmonise the records registered in the database with the proposed taxonomy. This means that the resulting visualisation would be clearer in terms of reading but little revised through the lens of author knowledge.

5. Conclusions

The research work proposed within this text pursues the objective of identifying redundancies and unifying methodologies and tools implemented in the design field for sustainability (the so-called sustainable design methods and tools), in line with the objective proposed by Faludi et al. [40]. The effort is aimed at unifying the terminology used in the literature, suggesting to the designer strategies and indications for the realisation of more environmentally aware products. First, this effort led the authors to define a taxonomy of indications, distinguishing between authors' perspectives, objectives, strategies, tactics, guidelines, and parameters and criteria. This systematisation sets out gradually more and more operational indications, thus, moving from generic to more specific information. To simplify the schematisation process, the work proceeded to select indications referring to the material selection, thus, leading to the realisation of the SMaS framework.

As previously mentioned in Section 2, the research used a constructivist epistemological approach. This is because both the schematisation and the realisation of the taxonomy involved, although the proposed methodology tried to avoid this, a work of interpretation by the authors. This could be seen as a limitation to the work carried out; indeed, by adopting either an objectivist or subjectivist epistemological approach, the results derived from both the taxonomy and the subsequent mapping could be different. A further limitation of the research could be seen in the sampling of literature used. The sampling was conditioned not only by the search database initially used (Scopus) but also by the focus identified to simplify and construct the mapping, i.e., the indications regarding material selection. Since the material plays a very important role in sustainability, material selection indications are largely diffused within the design guidelines for sustainability, although they still represent only one of these aspects.

Looking to further development and validation of both the taxonomy and the SMaS framework, one of the future works will be to apply the taxonomy to different clusters of design guidelines. Such an evolution would make the proposed framework an integrated design tool, capable of connecting different aspects of the product and avoiding unforeseen consequences for sustainability. However, this extension work, already envisaged by the authors, requires a previous effort in terms of data accessibility and information visualisation, which is still a critical point to date.

Indeed, this optimisation reveals several future opportunities for the work, such as its transformation into a template or open-source software capable of being navigated and updated easily by operators. In addition, a simplification in usability would allow further expansion and the addition of further information to support the guidelines, such as case studies and best practice examples. Looking in particular at the indications contained within the parameters and criteria, it might be interesting to combine the indications that are qualitative to date with quantitative information wherever possible.

The SMaS framework could have various applications and practical implications within both the academic and professional worlds. Regarding the academic world, the framework could be applied to educational activities. Including sustainability considerations and information from the early academic years would enable students to learn from their first design experiences the most important strategies and main considerations to be made when designing a sustainable artefact. Moreover, the different levels of depth fit well with teaching techniques such as project-based learning (PBL), a widely used teaching approach in design education [41,42]. Within the professional world, on the other hand, the SMaS framework positions itself as an exploratory and communicative tool, allowing experienced designers and companies to be inspired and guide design in directions that have yet to be explored. In addition, the tool can be used by designers as a single platform to develop co-design actions, facilitating development work, and identifying possible problems and limitations of certain choices.

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Appendix A

Table A1. Different definitions provided by online dictionaries.

	Cambridge (https://dictionary.cambridge.org/dictionary/english/ accessed on 5 December 2023)	**Oxford** (https://www.oxfordlearnersdictionaries.com/ accessed on 5 December 2023)	**Merriam-Webster** (https://www.merriam-webster.com/ accessed on 5 December 2023)	**Collins** (https://www.collinsdictionary.com/it/ accessed on 5 December 2023)
Objective	Something that you plan to do or achieve.	Something that you are trying to achieve.	Something toward which effort is directed: an aim, goal, or end of action. A strategic position to be attended or a purpose to be achieved by a military operation.	Your objective is what you are trying to achieve. The object of one's endeavors, goal, or aim.
Strategy	A way of doing something or dealing with something. A long-range plan for achieving something or reaching a goal, or the skill of making such plans.	A plan that is intended to achieve a particular purpose. Strategy to do/for doing something. The process of planning something or putting a plan into creation.	A careful plan or method: a clever stratagem. The art of devising or employing plans or stratagems toward a goal.	A strategy is a general plan or set of plans intended to achieve something, especially over a long period. Strategy is the art of planning the best way to gain an advantage or achieve success, especially in war.
Tactic	A planned way of doing something. A specific action intended to achieve a particular result.	The particular method you use to achieve something.	A device for accomplishing an end. Of, relating to, or having (such) an arrangement or pattern.	Tactics are the methods that you choose to use in order to achieve what you want in a particular situation. Having a specified kind of pattern or arrangement or having an orientation determined by a specified force.
Guideline	Information intended to advise people on how something should be carried out or what something should be. A piece of information that suggest how something should be done.	A set of rules or instruction that are given by an official organization telling you how to do something, especially something difficult. Something that can be used to help you make a decision or form an opinion.	A line by which one is guided such as: • An indication or outline of policy or conduct.	If an organization issues guidelines on something, it issues official advice about how to do it. A guideline is something that can be used to help you plan your actions or to form an opinion about something.
Parameter	A set of facts or a fixed limit that establishes or limits how something can or must happen or be done. A set of facts which describes and puts limits on how something should happen or be done.	Something that decide or limits the way in which something can be done.	An arbitrary constant whose value characterizes a member of a system (such as a family of curves). Any of a set of physical properties whose values determine the characteristics or behavior of something. Something represented by a parameter: a characteristic element. Limit or boundary.	Parameters are factors or limits which affect the way that something can be carried out or made.

Table A1. *Cont.*

	Cambridge (https://dictionary.cambridge.org/dictionary/english/ accessed on 5 December 2023)	Oxford (https://www.oxfordlearnersdictionaries.com/ accessed on 5 December 2023)	Merriam-Webster (https://www.merriam-webster.com/ accessed on 5 December 2023)	Collins (https://www.collinsdictionary.com/it/ accessed on 5 December 2023)
Criteria	A standard by which you judge, decide about, or deal with something. A condition or a fact used as a standard by which something can be judged or considered.	A standard or principle by which something is judged, or with the help of which a decision is made.	A standard on which a judgment or decision may be based. A characterizing mark or trait.	A criterion is a factor on which you judge or decide something.

Appendix B

Table A2. Extended version of tactics.

Code	Tactic
I1	Minimising scraps and discards
I2	Minimising resources and materials consumption during usage
I3	Minimising energy consumption and emission during pre-production and production
I4	Short distribution chain: minimising energy consumption and emissions during transportation and storage
I5	Design for repair
I6	Minimise the number of different incompatible materials
I7	Design for physical reliability and durability
I8	Consider a healthy material flow
I9	Material upgrade
I10	Design for re-manufacturing and re-use
I11	Design for dis- and re-assembly
I12	Design for emotional durability
I13	Design for recycling
I14	Design for environment
I15	Design for multiple life cycles
I16	Design for users
I17	Design for the present towards the future
I18	Design for embracing material imperfection
I19	Design for the technological cycle
I20	Design for the biological cycle

Appendix C

Table A3. Extended version of the guidelines.

Code	Guideline
K1	Select more consumption-efficient systems
K2	Graceful ageing
K3	Non-toxic/non-harmful/non-restricted materials
K4	Renewable and biocompatible materials

Table A3. *Cont.*

Code	Guideline
K5	Select renewable and biocompatible energy resources
K6	Select low-impact materials
K7	Select materials with the most efficient recycling technologies
K8	Facilitate end-of-life collection and transportation
K9	Facilitate cleaning
K10	Facilitate composting
K11	Facilitate combustion
K12	Improve processes
K13	Optimise material durability
K14	Optimize performance, resistance, and reliability
K15	Identify materials
K16	Reduce and facilitate operations of disassembly and separation
K17	Create a sense of nostalgia
K18	Use artefacts with existing stories
K19	Elicit a sense of ambiguity, curiosity, and surprise
K20	Create a little magic
K21	Local properties control
K22	Select innovative materials
K23	Select materials based on their timeless aesthetics
K24	Celebrate imperfection
K25	Engage the senses
K26	Make it unique
K27	Consider materials' responses to environmental conditions/human interaction over time
K28	Create regenerative systems (biomimicry)
K29	Care about social impact
K30	No energy/auxiliary material use
K31	Material substitution (changing material)
K32	Generate a deeper and enduring relationship with the product through the material
K33	Materials supporting multi-functional products
K34	Engage a cascade approach
K35	Consider landfill typology
K36	Reduce material variety
K37	Gas or energy recovery

Appendix D

Table A4. Extended version of the parameters and criteria.

Code	Parameters and Criteria
M1	Processes to reduce scraps
M2	Mark all plastic and similar parts for ease of identification

Table A4. *Cont.*

Code	Parameters and Criteria
M3	Employ joining elements that can be chemically or physically destroyed
M4	Avoid welding
M5	Total quality management (TQM certification)
M6	Environmental management system EMS declaration
M7	Eco label product certification
M8	Prefer unprocessed, natural, and raw materials to emphasize their uniqueness (emotional bond)
M9	Use recycled materials (from food waste, re-used materials, and discarded objects) for their unique textural and visual experience
M10	Designing with anomalies and effects inherent to the materials through manufacturing processes
M11	Designing with anomalies and effects inherent to the materials through unique handmade objects
M12	Select local material and energy sources
M13	Envelop and normalise scratches, color changes, wear, and tear
M14	Design with and for imperfection, visible human traces
M15	DIY manual labour and craftsmanship to relate with products
M16	Select multi-situated and ambiguous materials: ability to support a variety of different functions
M17	Avoid toxic, regulated, restricted, or harmful materials for product components
M18	Minimise the hazard of toxic and harmful materials
M19	Avoid materials that emit toxic or harmful substances during life cycle
M20	Avoid toxic adhesives, use easy-mechanic joints (fasteners and visible joints)
M21	Avoid toxic or harmful surface treatments
M22	Use of renewable/non-exhaustible materials
M23	Use residual materials from production processes
M24	Use recycled materials, alone or combined with primary materials
M25	Use biodegradable materials
M26	Select materials with durability according to the product performance and lifespan
M27	Design for excessive use of materials in places more subject to deterioration
M28	Arrange and facilitate recycling of materials in components with lower mechanical requirements
M29	Arrange and facilitate recycling of materials in components with lower aesthetical requirements
M30	Arrange and facilitate energy recovery from materials throughout combustion
M31	Select materials that easily recover after recycling the original performance characteristics
M32	Use recyclable materials
M33	Engage geometrical solutions like ribbing to increase polymer stiffness instead of reinforcing fibres
M34	Prefer thermoplastic polymers to thermosetting
M35	Prefer heat-proof thermoplastic polymers to fireproof additives
M36	Design taking into consideration the secondary use of the materials once recycled
M37	Design in compliance with a product retrieval system
M38	Reduce/minimise material weight
M39	Design for the efficient consumption of operational materials
M40	Monomaterial product or sub-assembly
M41	Use only one material, but process in sandwich structures

Table A4. *Cont.*

Code	Parameters and Criteria
M42	Use compatible materials (that can be recycled/composted together) within the product or sub-assembly
M43	For joining, use the same or compatible materials as in the components (to be joined, including fasteners, screws, rivets, staples, etc.)
M44	Avoid unnecessary/secondary coatings procedures (paintings, coatings, platings, etc.)
M45	Avoiding irremovable coating materials/facilitate coatings removal
M46	Use coating procedures in compliance with coated materials
M47	Avoid adhesives or choose in compliance with materials to be recycled
M48	Prefer dyeing internal polymers, rather than surface painting
M49	Design for the more efficient supply of raw materials
M50	Avoid using additional materials for marking or codification
M51	Eliminate incompatible paints on parts e use label imprints or even inserts
M52	Select materials that degrade in the expected end-of-life environment
M53	Avoid materials and additives that emit dangerous substances during incineration
M54	Select high-energy materials for products that are going to be incinerated
M55	Ensure compatibility of ink where printing is required on plastic parts
M56	Use high strength-to-weight materials on moving parts
M57	Use low-alloy metals which are more recyclable than high-alloy ones
M58	Design for the more efficient use of maintenance materials
M59	Use unplated metals which are more recyclable than plated
M60	Increase corrosion resistance of fasteners
M61	Group harmful materials in sub-assemblies
M62	Avoid the combination of ageing and corrosive materials
M63	Avoid parts and materials likely to damage machinery (shredder)
M64	Avoid moulded-in metal inserts or reinforcements in plastic parts
M65	Select materials with low-C02-equivalent emission
M66	Provide material maintenance procedure
M67	Select materials according to their contextual wear resistance
M68	Use compostable materials
M69	Design for the cascading of recycling systems
M70	Provide indication on landfill typology (inert, hazardous, or non-hazardous)
M71	Avoid composite materials
M72	Eliminate incompatible labels on plastic parts
M73	Standardise and use common parts and materials
M74	Codify different materials to facilitate their identification/separation
M75	Provide additional information about the material's age, number of times recycled, and additives used
M76	Use standardised materials identification systems
M77	Arrange codifications in easily visible places
M78	Avoid codifying after component production stages
M79	Select materials with low embodied energy
M80	Mark and codify materials during moulding

Table A4. *Cont.*

Code	Parameters and Criteria
M81	Codify polymers with a laser
M82	Facilitate the separation of materials that might compromise the efficiency of combustion (with a low energy value)
M83	Use highly caulked materials and technical components
M84	Hazardous parts should be clearly marked and easily removed
M85	Avoid additional materials while welding
M86	Weld with compatible materials
M87	Prefer ultrasonic and vibration welding with polymers
M88	Provide easy access to harmful, valuable, or reusable parts
M89	Minimise fragile parts
M90	Protect subassemblies against soiling and corrosion
M91	Prefer natural materials due to their graceful ageing (e.g., maturity of natural materials)
M92	Select materials in prevision of their patina ageing
M93	Employ easily removable adhesives

References

1. OECD. *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences*; OECD: Paris, France, 2019. [CrossRef]
2. Ashby, M.F. *Materials and the Environment: Eco-Informed Material Choice*; Butterworth-Heinemann: Oxford, UK, 2009; ISBN 978-0-08-088448-6.
3. Miller, G.T. *Energetics, Kinetics and Life: Ecological Approach*; Wadsworth Publishing Co., Inc.: Belmont, CA, USA, 1972; ISBN 978-0-534-00136-0.
4. Steffen, W.; Broadgate, W.; Deutsch, L.; Gaffney, O.; Ludwig, C. The Trajectory of the Anthropocene: The Great Acceleration. *Anthr. Rev.* **2015**, *2*, 81–98. [CrossRef]
5. United Nations (UN). *Transforming Our World: The 2030 Agenda for Sustainable Development*; United Nations: New York, NY, USA, 2015.
6. WCED. *Our Common Future*; UN: New York, NY, USA, 1987.
7. IUCN; UNEP; WWF. *Caring for the Earth: A Strategy for Sustainable Living*; IUCN/UNEP/WWF: Gland, Switzerland, 1991; ISBN 978-2-8317-0074-8.
8. Thackara, J. *The Bubble: Designing in a Complex World*; MIT Press: Cambridge, MA, USA, 2005; ISBN 978-0-262-20157-5.
9. Ceschin, F.; Gaziulusoy, I.A. Evolution of Design for Sustainability: From Product Design to Design for System Innovations and Transitions. *Des. Stud.* **2016**, *47*, 118–163. [CrossRef]
10. Mendoza, J.M.F.; Sharmina, M.; Gallego-Schmid, A.; Heyes, G.; Azapagic, A. Integrating Backcasting and Eco-Design for the Circular Economy: The BECE Framework. *J. Ind. Ecol.* **2017**, *21*, 526–544. [CrossRef]
11. Vezzoli, C. *Design for Environmental Sustainability: Life Cycle Design of Products*, 2nd ed.; Springer: London, UK, 2018; ISBN 978-1-4471-7363-2.
12. European Union. *Ecodesign Your Future*; Publications Office of the European Union: Luxembourg, 2014.
13. Bonilla Hernández, A.E. On How the Selection of Materials Affects Sustainability. *Procedia Manuf.* **2019**, *33*, 625–631. [CrossRef]
14. Bahrudin, F.I.; Aurisicchio, M.; Baxter, W. Sustainable Materials in Design Projects. In Proceedings of the EKSIG 2017: Alive. Active. Adaptive, Rotterdam, The Netherlands, 19–20 June 2017.
15. Graedel, T.; Barr, R.; Chandler, C.; Chase, T.R.; Choi, J.; Christoffersen, L.; Friedlander, E.; Henly, C.; Jun, C.; Nassar, N.T.; et al. Methodology of Metal Criticality Determination. *Environ. Sci. Technol.* **2012**, *46*, 1063–1070. [CrossRef] [PubMed]
16. Shove, E.; Watson, M.; Hand, M.; Ingram, J. *The Design of Everyday Life*; Cultures of Consumption Series; Berg Publishers: Oxford, UK, 2007; ISBN 978-1-84520-683-3.
17. Vezzoli, C.; Manzini, E. *Design for Environmental Sustainability*; Springer: London, UK, 2008; ISBN 978-1-84800-163-3.
18. Boks, C. The Soft Side of Ecodesign. *J. Clean. Prod.* **2006**, *14*, 1346–1356. [CrossRef]
19. Leitner, H. *Pattern Theory: Introduction and Perspectives on the Tracks of Christopher Alexander*; CreateSpace Independent Publishing Platform: Scotts Valley, CA, USA, 2015; ISBN 978-1-5056-3743-4.
20. Alexander, C.S.; Ishikawa, S.; Silverstein, M.; Jacobson, M.; Fiksdahl-King, I.; Angel, S. *A Pattern Language: Towns, Buildings, Construction*; Oxford University Press: Cambridge, UK, 1977.
21. Allione, C.; De Giorgi, C.; Lerma, B.; Petruccelli, L. From Ecodesign Products Guidelines to Materials Guidelines for a Sustainable Product. Qualitative and Quantitative Multicriteria Environmental Profile of a Material. *Energy* **2012**, *39*, 90–99. [CrossRef]

22. Giudice, F. Product Design for the Environment: The Life Cycle Perspective and a Methodological Framework for the Design Process. In *Environment Conscious Manufacturing*; CRC Press: Boca Raton, FL, USA, 2007; pp. 33–90. ISBN 978-0-429-11797-8.
23. Bevilacqua, M.; Ciarapica, F.E.; Giacchetta, G. *Design for Environment as a Tool for the Development of a Sustainable Supply Chain*; Springer Science and Business Media: Berlin/Heidelberg, Germany, 2012; ISBN 978-1-4471-2461-0.
24. Go, T.F.; Wahab, D.A.; Hishamuddin, H. Multiple Generation Life-Cycles for Product Sustainability: The Way Forward. *J. Clean. Prod.* **2015**, *95*, 16–29. [CrossRef]
25. den Hollander, M.C.; Bakker, C.A.; Hultink, E.J. Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms. *J. Ind. Ecol.* **2017**, *21*, 517–525. [CrossRef]
26. Moreno, M.; De los Rios, C.; Rowe, Z.; Charnley, F. A Conceptual Framework for Circular Design. *Sustainability* **2016**, *8*, 937. [CrossRef]
27. Bocken, N.M.P.; de Pauw, I.; Bakker, C.; Grinten, B. van der Product Design and Business Model Strategies for a Circular Economy. *J. Ind. Prod. Eng.* **2016**, *33*, 308–320. [CrossRef]
28. Allwood, J.M.; Ashby, M.F.; Gutowski, T.G.; Worrell, E. Material Efficiency: A White Paper. *Resour. Conserv. Recycl.* **2011**, *55*, 362–381. [CrossRef]
29. Haines-Gadd, M.; Chapman, J.; Lloyd, P.; Mason, J.; Aliakseyeu, D. Emotional Durability Design Nine-A Tool for Product Longevity. *Sustainability* **2018**, *10*, 1948. [CrossRef]
30. Karana, E.; Giaccardi, E.; Rognoli, V. Materially Yours. In *Routledge Handbook of Sustainable Product Design*; Routledge: London, UK, 2017; pp. 206–221. ISBN 978-1-138-91017-1.
31. Prendeville, S. *Envisioning Ecodesign: Definitions, Case Studies and Best Practices*; ENEC: Cardiff, UK, 2014.
32. Meerkamm, H.; Koch, M.R. Design for X. In *Design Process Improvement: A Review of Current Practice*; Springer Science and Business Media: Berlin/Heidelberg, Germany, 2005; pp. 306–323. ISBN 978-1-85233-701-8.
33. Benabdellah, A.C.; Bouhaddou, I.; Benghabrit, A.; Benghabrit, O. A Systematic Review of Design for X Techniques from 1980 to 2018: Concepts, Applications, and Perspectives. *Int. J. Adv. Manuf. Technol.* **2019**, *102*, 3473–3502. [CrossRef]
34. Ellen MacArthur Foundation. *Towards the Circular Economy: An Economic and Business Rationale for an Accelerated Transition*; Ellen MacArthur Foundation: Cowes, UK, 2013.
35. Moreno, M.; Ponte, O.; Charnley, F. Taxonomy of Design Strategies for a Circular Design Tool. In Proceedings of the 2nd Conference on Product Lifetimes and the Environment (PLATE), Delft, The Netherlands, 8–10 November 2017; IOS Press: Delft, The Netherlands, 2017.
36. Snyder, H. Literature Review as a Research Methodology: An Overview and Guidelines. *J. Bus. Res.* **2019**, *104*, 333–339. [CrossRef]
37. Wohlin, C. Guidelines for Snowballing in Systematic Literature Studies and a Replication in Software Engineering. In Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering, London, UK, 13–14 May 2014; Association for Computing Machinery: New York, NY, USA, 2014; pp. 1–10.
38. Mauri, M.; Elli, T.; Caviglia, G.; Uboldi, G.; Azzi, M. RAWGraphs: A Visualisation Platform to Create Open Outputs. In Proceedings of the 12th Biannual Conference on Italian SIGCHI Chapter, Cagliari, Italy, 18–20 September 2017; Association for Computing Machinery: New York, NY, USA; pp. 1–5. [CrossRef]
39. Costantino, T.E. Constructivism. In *The SAGE Encyclopedia of Qualitative Research Methods*; Sage Publications: Thousand Oaks, CA, USA, 2008; pp. 116–120.
40. Faludi, J.; Hoffenson, S.; Kwok, S.; Saidani, M.; Hallstedt, S.I.; Telenko, C.; Martinez, V. A Research Roadmap for Sustainable Design Methods and Tools. *Sustainability* **2020**, *12*, 8174. [CrossRef]
41. Brundiers, K.; Wiek, A. Do We Teach What We Preach? An International Comparison of Problem- and Project-Based Learning Courses in Sustainability. *Sustainability* **2013**, *5*, 1725–1746. [CrossRef]
42. Faludi, J.; Gilbert, C. Best Practices for Teaching Green Invention: Interviews on Design, Engineering, and Business Education. *J. Clean. Prod.* **2019**, *234*, 1246–1261. [CrossRef]