Energy 39 (2012) 90–99

Contents lists available at SciVerse ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

From ecodesign products guidelines to materials guidelines for a sustainable product. Qualitative and quantitative multicriteria environmental profile of a material

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ARTICLE INFO

Article history:
Received 27 February 2011
Received in revised form
15 August 2011
Accepted 30 August 2011
Available online 29 September 2011

Keywords:
Environmental guidelines and properties
Life cycle product
Material selection

ABSTRACT

This paper deals with the development of MATto, a virtual and physical library including more than 500 innovative material samples. The most important feature of this material library is to provide a deep analysis of the perceptual performances and eco-properties of the materials in the database.

As far as the material eco-properties are concerned, a study has been carried out and it is aimed at developing a list of ecodesign guidelines to help the material selection; those are derived from the well-known eco-guidelines concept and should be adopted to improve the product life cycle performances.

The material selection guidelines described here have been derived from 3 main eco-strategies: use of resources with a low environmental impact, material's life extension, and environmental ethics and policies. For each material guideline, different quantitative and qualitative parameters/eco-properties have been identified in order to define an environmental multicriteria profile, to describe the material properties and facilitate the choice of the most suitable materials for a green product.

The results collected so far in the process of defining the environmental properties of the MATto materials are described in this paper.

1. Introduction

From an environmental sustainability point of view, thinking the eco-compatibility of a product to be given by the assembly of the best environmental materials only appears to be too simplistic. Moreover, dealing with the concept of the best environmental materials in the absolute sense is meaningless when these materials are assembled together as components of a product.

Even if rankings of the best eco-efficiency materials are available, generally those rankings are elaborated by taking into account the environmental burdens of a material or a semi-finished product only when they are ready to be used. As underlined in another research [1], a common starter for companies implementing Eco-Design is to develop white, gray and black checklists for materials used in company products. Typically, white lists contain materials that should be used. Gray lists contain materials that might be used if there is a good reason and black lists contain materials that are forbidden. Unfortunately, such material rankings generally don't support information about the ecological behavior of the materials, when they are involved in a product, which is generally an assembly of many components made of several materials [2].

Dealing with the eco-compatibility question at the product level means taking into account the environmental performances of the product along all its life cycle, assessing the several input and output flows during the different life cycle phases (pre-production, production, usage and end of life). In this way, a lot of variables have to be considered during the design process: this cannot be focused just on the best environmental material choice, but should also concern the product configuration, its usage context and its end of life scenarios [3,4].

As a result, at the moment of the material selection, adopting a Life Cycle Approach means to design an eco-product, which should be achieved not only by choosing materials which ensure reduced environmental impact from cradle to gate (as should be declared by the suppliers with an environmental declaration), but also by selecting materials, which fulfill different needs during the different life cycle phases [5] such as:

– during the component manufacturing phase: materials which should be correctly assembled together by using reversible fastening with, at the same time, a low amount of scrap and a low energy consumption for their assembling processes;

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doi:10.1016/j.energy.2011.08.055

– during the distribution phase: materials that do not involve high environmental burdens while transported, by opting for materials with a short chain distribution;
– over the products usage phase: by selecting materials with an easy maintenance or replacement;
– at product end of life: by choosing materials which could be easily disassembled and collected, in order to dispose them off at the most suitable waste treatments. As a result, this means choosing materials that are able to save the highest rate of material or energy, with a consequent extension of the material lifespan.

In practice, several factors have to be considered during the material selection: this can complicate the material selection phase, where the designers play an active role, because this choice has to be closely connected to the several needs that have to be satisfy by the life cycle product. In other words the final material selection should be based on the decisions taken along the process design, where all product needs and requirements are defined and the material tasks are fixed [6,7].

Nowadays, the methodology of Life Cycle Assessment (LCA) is one of the most recognized methodologies, in order to measure these variables along the product life cycle performances. As defined into the ISO 14040 standards series [8], the LCA methodology is a very effective tool for assessing the environmental performances of a material or a product, in order to define more strict environmental goals for the product updating or to achieve an EPD certification of an existing product/material. Unfortunately, during the design stage, the adoption of the LCA, can not be used as a practical tool: this is due to the large number of data needed for the assessment, which generally are not available during the design phase. Furthermore, a complete LCA analysis is time consuming and generally a lack of time is typical during these specific design steps [9].

Therefore, the designers in practice use streamlined LCA tool in order to obtain a life cycle product quantitative assessment based on indicators, which are commonly adopted in a LCA assessment, such as: the Ecoaudit tool of CES 2009 [10], which provides a streamlined LCA of a life cycle product, or PIQUET [11] that is a focused tool conceived for assisting packaging design, in conjunction with general Eco-design guidelines (Design for Environment DfE guidelines, The Ten Golden Rules, etc.) [1–12] or focused eco-guidelines (Design for Assembly DfA, Design for Maintenance DfM, Design for Recycling guidelines) [13], which support the design process with qualitative information in order to improve the environmental performances of the product along its life cycle or in some specific life cycle phase.

On these assumptions, in accordance to a design approach oriented to the product life cycle, the final goal of this research is to define a multicriteria system able to link the eco-performances of a material selection to the environmental aspects that are analyzed by adopting a life cycle approach. In other words, by the reading several material parameters, which are representative of the material eco-performances, the designers should select the most suitable materials related to the specific requirements of the product in project.

In this way, in accordance with the sustainability principles and by the right balance between the requirements and performances of the product it will be possible to pursue an eco-product.

2. Research backgrounds

2.1. The role of the designer today

In order to manage the complexity of the design process, due to the high numbers of variables that have to be considered, especially at the moment of the material selection, let us ask ourselves which is the role of the designer today.

If we consider the product development as a chain of several tasks that must be carried out when a new product is developed, tested, refined and market [1–6], in this development process the designer today is obviously a key figure. Thanks to his ability, he has become a real link between different professional skills and know-hows, involved in the product development (planning and design, accounting, management, marketing and sales, engineering, procurement and purchasing, distribution and packaging, etc.) and the complexity, which arise from the environmental issue [C-D].

Since he is involved at the beginning of the product development, he has the chance to improve the environmental product behavior. It is well recognized that nowadays the only way for obtaining a real eco-product is to modify, at the beginning of the product development, the cultural approaches and the strategies that lead to the final product, by changing the business logics and optimizing not only the product life cycle environmental performances, but also its economical performances [15].

Moreover, it is also well well-known that in the early phases of the process design, the knowledge of the product is small, but the designer freedom is large since nothing is settled yet. In the latter design process phase the knowledge of the product is large but the possibilities to change the design according to this knowledge are few since major decision have been taken and only minor change can be made [1].

In theory, outlining an eco-product from a designer viewpoint means to adopt a systematic and anticipative approach to the whole product life cycle, in order to get in advance knowledge of the different activities and the several energy and material flows which are involved over the production, usage and disposal phase of the materials [4–16].

On the other hand, during the product and the concept design, the designers in practice make a material selection usually based on the technical and economical performances, because they only have a partial knowledge of the environmental aspects that could compromise the product performances and about the background of the LCA impact indicators. Furthermore, designers generally choose a material on the basis of their knowledge of traditional materials and not on the real possibilities offered by innovative materials, which are continuously put on the market.

In order to correctly manage this complexity, which arises during the design process, let us discuss the utility of the several Ecotools that nowadays are available for supporting and assisting the designers during the concept and product phase. From this Ecotools analysis, the MATto usefulness during the material selection phase has been originated as described in the following paragraphs.

2.2. Ecotools for pursuing the product eco-compatibility

Several Ecotools have been conceived with the aim to facilitate the designers through the design process for pursuing an eco-compatible product [13].

These Ecotools take into account the environmental performances of a product (a semi-finished product or a material) and, depending on their analysis, they could be divided into two main groups: quantitative or qualitative tools [17–19].

The quantitative Ecotools generally have their theoretical background in the Life Cycle Assessment (LCA) methodology, such as LCA software or LCA/LCI material and process database. Based on quantified inventory of the several inputs and outputs along the analyzed life cycle phases, these tools identify the main impacts and provide a quantitative assessment of these impacts in relation to the main environmental effects at a different scale (global, macro-regional or local level).

On the other hand, the qualitative tools, such as eco-strategies & guidelines, materials library & databases, supply general or specific information about the materials and their manufacturing process or suggest some "best practices" which could be followed in the product design, in order to minimize its environmental and energetic burdens throughout all the life cycle phases or in some specific phase, such as end of life.

On the basis of this classification, let us underline the practical utility of these Ecotools during the different steps of the process design.

If we assume that the process design can be divided into four main steps: needs analysis and requirement definition (meta-project), concept design (preliminary design), product design (definitive design) and engineering (executive design), we can say that the quantitative tools have a direct utility during the meta-project or engineering phases. However, unfortunately, during the concept and product design phases, when designers are personally involved, this kind of Ecotools cannot be considered as a useful operative tool. Firstly, this is because this analysis requires a quantity of data to be processed: those data are not generally available during the concept and product design phase. Secondly, a complete LCA analysis is time consuming and generally requires a specific know-how that generally the designers do not possess [9].

On the contrary, the qualitative tools are more useful during the concept and product design steps, since they are able to lead the designers to move through environmental criteria and consequently to make the right environmental choice in order to obtain an eco-product.

In particular the Life Cycle Design Strategies (such as using low impact materials and processes, opting for a material life extension, etc.) and the connected guidelines are the most widespread and practical tools for the designer in order to take into account the environmental product performances throughout its life cycle [20].

Over the years, these ecodesign product strategies and guidelines have been carried out by several research and design centers [4–21] and they can be summarized as illustrated in the next figure (Fig. 1).

2.3. MATto – a new material library

MATto has been developed, in order to keep the designers up to date about the latest materials available for their project. MATto is a material library, which includes more than 500 samples of new generation materials, particularly used in the field of design and architecture.

Up to now, for each MATto material samples, an analysis sheet is arranged, which reports the technical (physical-mechanical) properties of the materials, its applications, the available format and a cost estimation [22].

According to another ongoing research [23], the latest evolution of this material library is to become a consultancy service

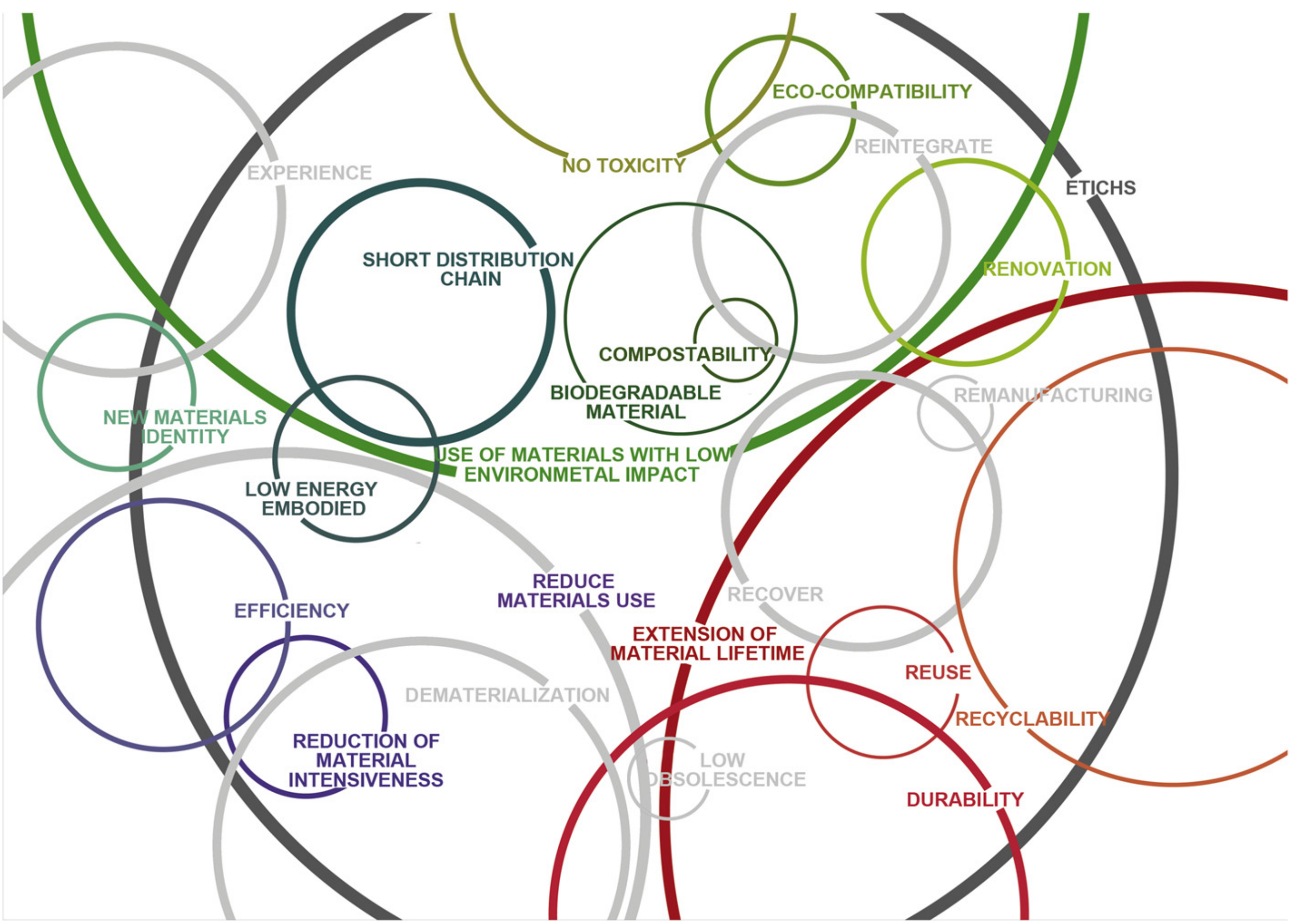

Fig. 1. Guidelines focused on the product eco-compatibility.

supported by Torino Chamber of Commerce for the Small and Medium Enterprises (SMEs) of the Piedmont Region in Italy.

The innovative aspect of MATto consultancy service is to provide meta-project solutions by identifying new materials or semi-finished products suitable for every specific need or request of each firm, where the right material selection is based not only on the technical and economical performances, but also on the sensory and environmental material properties.

The environmental profile is aimed at acquainting the decision maker with the materials environmental aspects by adopting a cradle to grave point of view. Consequently, an eco-profile of MATto material takes into account how the material environmental properties could change in accordance with the product requirements, i.e. a products could have different waste scenarios on the basis of their commercial identification such as WEEE (Waste Electronic and Electric Equipment) or on the basis of their predominant material such as packaging and so the material choice should consider this important aspect. In this way, the decision makers are assisted in order to understand how to improve the product eco-efficiency by choosing materials with lower environmental impacts or by opting for design solutions that do not involve a material replacement, i.e. by adopting design for disassembly solutions.

As a result, MATto is aimed at becoming a tool for the problem setting, by which the designers (and the other figures involved into the product development) are assisted for identifying which material parameters influence the product eco-performances. Consequently, a multidimensional profile is provided and the several parameters are not averaged in a unique performance indicator [24].

At the same time, another important information provided by MATto material library is the sensory profile, which could be useful for considering the human perception of material too.

Specifically, the touch, sight, smell and hearing senses are taken into account separately in order to define a simplified "sensory vocabulary", which will become a universal reference tool. In the vocabulary, the adjectives are specified according to a scale of values (from 0 to 100), which has been identified according to the results of different analysis sessions carried out by "tasters" (groups of 20/30 people, untrained and trained, to test the materials and describe them using specific instruments). The scale of values immediately quantifies the characteristic described by the adjective. In this way, the designers could also be guided, when they are dealing with the expressive-sensory aspects of the materials [25].

Consequently, by using these four research keys/point of views, technical, economical, environmental and perceptual properties, the most suitable materials selection provided by MATto consultancy service, could be compared with the analysis of the traditional material provided by other well-known databases, such as the Cambridge Material EcoSelector, CES2009 [10], and could become the key of the future SMEs development, according to the current sustainability and innovation trends [2].

For this reason, specific studies have been carried out in order to define the most appropriate way for reporting environmental and perceptual material performances. This paper specifically illustrates the multicriteria system, which has been adopted for describing the environmental behavior of a material.

3. Methodological approach to identify the most important environmental features of a material

Starting from the existing eco-product guidelines, which have been conceived by previous studies [4–21] (Fig. 1), specific guidelines have been derived, focusing on the material selection phase in order to obtain a green product. By adopting the same life cycle approach, these revised guidelines concern the specific material behavior, affecting the environmental performances of the product life cycle.

Specifically these material guidelines could be organized into three main eco-strategies which could directly or indirectly pursue the environmental sustainability principles - on one side - and on the other side could lead the designer to make the right choice on most suitable materials for his project (Fig. 2) [20].

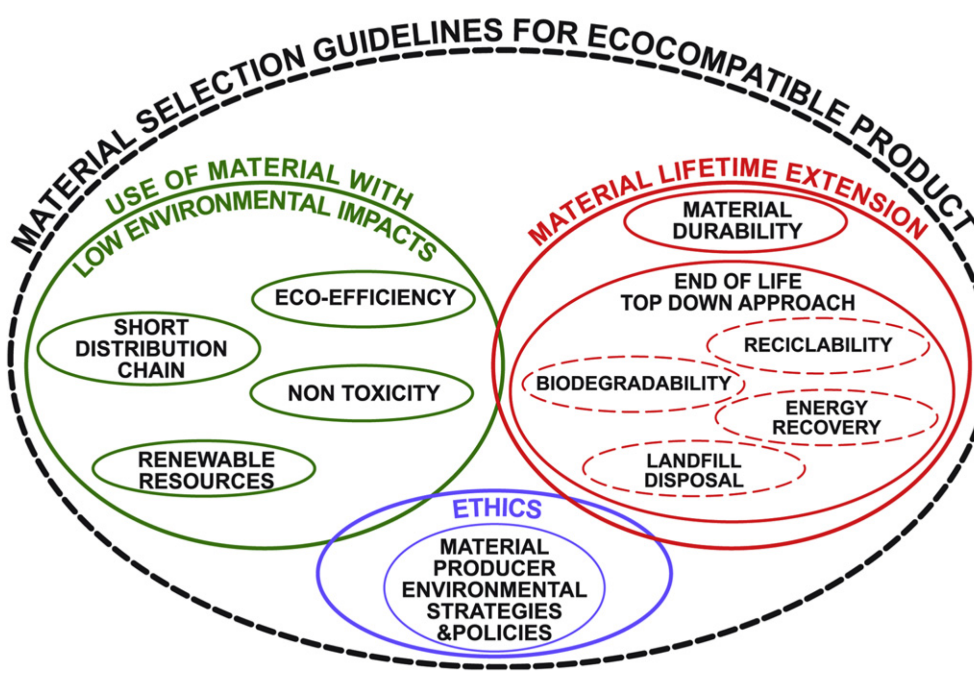

Fig. 2. Eco-strategies and guidelines focused on the material selection phase.

The three main strategies include guidelines, such as the following:

1. use of materials with a low environmental impact: this strategy is directly aimed at minimizing resource consumption and emissions along the product life cycle.

It includes several guidelines for materials selection, which could act in a synergic way, such as: eco-efficiency, short distribution chain, renewable resources and toxicity for human health;

2. material lifetime extension: this strategy is directly focused on the end of life phase because it is aimed at postponing the moment of waste disposal while deferring the usage of new resources for the manufacturing of a new material. In this way, the final aim of reducing resources consumption and emission can be indirectly met.

According to this strategy, two main guidelines emerge: materials durability and a top-down approach to the material end of life.

3. material manufacturer ethics and policies: this strategy is aimed at creating awareness among the material manufacturers of their environmental responsibilities and at fostering those who have adopted an environmentally virtuous behavior.

The resulting guidelines lead to the choice of the material, whose manufacturer should demonstrate its environmental mission by showing certification of its manufacturing processes or of its product.

These strategies and guidelines are able to act in a synergic way to improve product environmental performances, but sometimes they could lead the designers to face contradictory choices of materials. i.e. they could chose a material that is able to ensure good durability but has a high level of embodied energy.

Furthermore, these guidelines will not have the same importance for all kinds of products. In other words, if the product has long, medium or short duration, some guidelines could be complied with or not. For instance, in the case of a short term product, adopting durable material is meaningless, but it is more important to choose recyclable materials with a short distribution chain. On the contrary, in the case of a long term product, it is more important to adopt durable materials, than opt for biodegradable or recycled material (Fig. 3). In other words, it is clearly emphasized that the adoption at the same time of several material selection guidelines should be a compromise between various and sometimes diverging requirements and needs of the product.

In this case the designer plays a central role in assessing the relative importance of the guidelines in relation to the different lifetime extension of a product (short, medium or long) and its usage context [26]. Within this context, several methodological approaches such as multicriteria analysis [6], matrix methods [27] or application of the TRIZ contradiction matrix [28] have been conceived and should be adopted during the material selection phase in order to face with these contradictory requirements and finally to select the best material requirement combination for obtaining a green product.

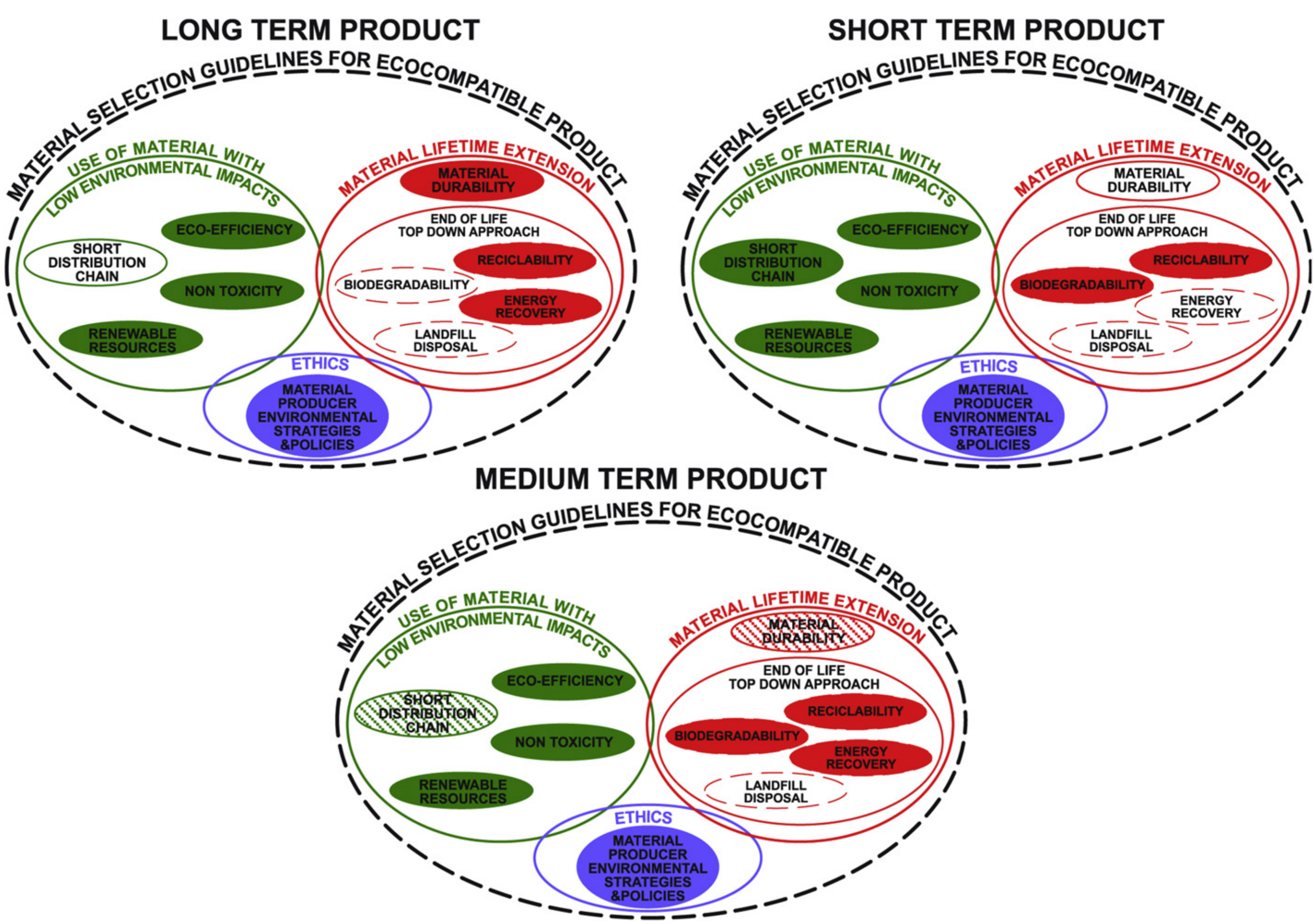

Fig. 3. Relative importance of the Material Selection Guidelines in accordance with the long, medium or short term product.

On these assumptions, once the specific material guidelines have been defined, environmental qualitative and quantitative parameters have been identified. By using these parameters, it has been possible to delineate a multicriteria system which is useful for reading the environmental material behavior in coherence with the product. In other words, by using this environmental profile, based on several criteria, it is possible to measure how much the material corresponds to each specific guideline.

The above mentioned parameters are reported in relation to the three main eco-strategies in the following paragraphs.

3.1. Guidelines for use of materials with a low environmental impacts

3.1.1. Eco-efficiency

If the meaning of Eco-efficiency, as suggested by the World Business Council Sustainable development, is creating more value with less impact [29], it is possible to assume that an eco-efficient material is a semi-finished product or material with a low environmental impact from cradle to gate, when it is delivered on the market.

These impacts could be evaluated by using the LCA methodology, which offers an assessment of a material in relation to the embodied energy or the main environmental effects such as global warming, ozone depletion layer, etc. [30].

3.1.1.1. Qualitative & quantitative parameters. By adopting a simplified LCA approach, an estimation of the materials eco-efficiency level is reported by using two quantitative parameters, generally adopted also in LCA study (Fig. 4), such as follows:

- Embodied Energy (EE): this quantitative parameter expresses a simple estimate of the embodied energy included in a material ready to be used. It is assumed, in the multicriteria system, to be the main representative of the input flows related to the material pre-production and manufacturing phases.

Generally the EE is calculated by the addition of the different rates of energy: direct energy (the energy directly used along with the material manufacturing processes), indirect energy (the required energy for making direct energy available), feedstock energy (the rate of energy included in a material which could be recovered by combustion) and delivery energy (the energy consumption to transport the material) [10].

- CO2 emissions: this quantitative parameter is adopted to give a rough estimation linked to the output flows, which are involved in the activities from cradle to gate and could be related to the known global warming effect. In accordance with the IPCC report, it could be calculated as the amount of kg of CO2 equivalent emissions, by using specific characterization factors [10–31].

Furthermore, these quantitative parameters come with a flow chart, which illustrates how many manufacturing activities are needed to obtain the ready-to-use material and the relationships between these activities.

3.1.2. Short distribution chain

Fostering a short distribution chain means choosing locally available materials.

In this way it is possible not only to minimize the resource consumption and the emissions that are derived from transporting a variety of materials but also to support the local economy and craft and to promote the manufacturing tradition and culture of SMEs, which are typical of the economy system in Italy.

In other words, focusing on the reduction of the distribution impacts means reducing distances and choosing means of transport

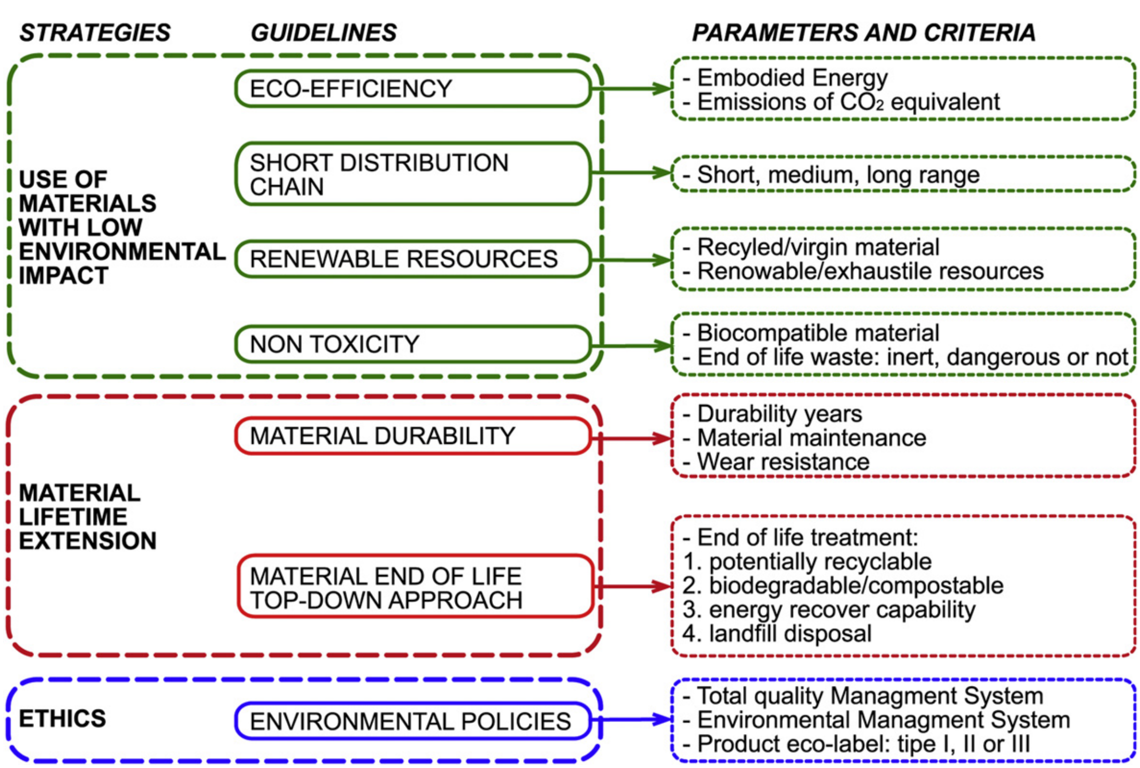

Fig. 4. Multicriteria system, made of quantitative and qualitative parameters and useful for evaluating the environmental materials profile in coherence with the life cycle approach.

with a lower environmental impact, thus giving both environmental and economical benefits [21].

3.1.2.1. Qualitative & quantitative parameters. In order to focus on the reduction distribution impacts, a qualitative parameter must be defined to offer a rough estimation of the distance from the material manufacturing site to the usage site, by adopting the three following measure levels (Fig. 4):

- short distance, when the distance is less than 200 km;
- medium distance, when the distance is between 200 km up to 1200 km;
- long distance, when the distance is over 1200 km.

In addition to this qualitative parameter based on the distance, it is also important to take into account the impacts related to the different means of transport that should be adopted [10].

3.1.3. Renewable resources

This guideline is aimed at encouraging the use of renewable materials.

Semi-finished products and materials are made of raw materials and substances which are derived from resources.

Depending on where the resources come from, they could be classified as non renewable, when they derive from fossil or mineral resources, or renewable, when they come from biomasses.

The renewable capacity of a resource depends on two factors: the re-generation time that is the time during which the ecosystems is able to create new resources and the resource extraction frequency, which depends on oil and mineral deposit availability and the economical feasibility of their extraction.

On the basis of these assumptions, it is possible to define that a material is renewable when the resource extraction frequency is less than the re-generation period [10].

Furthermore, thanks to widespread material recycling techniques, a lot of new generation materials are made with a fraction of recycled materials, thus avoiding new resource consumption. So it is also possible to distinguish the material between recycled materials or primary (virgin) materials.

3.1.3.1. Qualitative & quantitative parameters. According to the resource classification and the material composition, two qualitative parameters are taken into account in the environmental multicriteria system that are expressed as a percentage value (Fig. 4), namely:

– Renewable or non renewable resources: this parameter explains if the raw material comes from renewable or not renewable resources;
– Virgin or recycled materials: this parameter is used to underline if the material includes a ratio of recycled content or not.

3.1.4. Non-toxicity

Depending on the included raw materials and substances, a material could be potentially toxic for human health throughout its life cycle phase or specifically at the end of its life.

Concerning the potential toxicity in the pre-production, production and usage phases, if a material does not release harmful substances during these phases, it is possible to define it as biocompatible.

The most well-known toxic substances could be organic, such as phosphorus, nitrogen compounds or CHO (alcohol ethanol, methanol, ethylene glycol or carbon monoxide) or inorganic such as metal, metalloids and halogen compound. These substances are regulated and appropriately labeled as indicated by national regulations.

Following oral, dermal or inhalation exposure, these substances could be hazardous or lethal to the entire body or to specific organs, causing cancer or major/minor damages. Depending on how and how long people are exposed to these lethal or hazardous substances, five categories of severity can be derived in accordance with Reach, (Registration, Evaluation, Authorisation and restriction of Chemicals) which is the European legislation entered into force on 1st June 2007 with the aim to regulate hazardous chemicals. As a result, tanks to the Reach, it is now possible to identify the following categories of severity: substance as SVHC (Substance of Very High Concern), PBT (Persistent Bioaccumulative), vPvB (Very Persistent and Very Biaccumulative), Carcinogenic, Mutagenic and Toxic for reproduction [10].

In relation to the material end of life, the toxic substances releases are linked to the different end of life material treatments.

Specifically, when treatments such as reuse-recycling-composting (with a material recovery), or incineration or pyrolysis (with an energy recovery) are not possible, the material will be disposed of in a waste landfill, where leakages and residuals could contaminate the surface water, groundwater and soil and, at the same time, gases (notably methane) could be emitted from decaying organic waste. Ideally these gasses should be collected and used to generate electricity in a gas fired power plant. In practice they are frequently emitted into the environment. In the latter scenario they generally contribute to the greenhouse effect on the global scale but, in relation to human health, their concentrations are monitored in order to avoid the build-up of gases at harmful level [32].

Depending on the material composition and its potential capacity to release hazardous substances, different kinds of landfill have been organized in Italy, in accordance with the European landfill directives, such as landfill for inert, hazardous or not hazardous waste.

3.1.4.1. Qualitative & quantitative parameters. In order to report the potential toxicity of a material for human health, the following two qualitative parameters have been adopted (Fig. 4):

- bio-compatibility: this parameter is used for indicating that the material does not release toxic or harmful substances for human health during the production, distribution and usage phases;
- landfill typology: prior knowledge of the landfill where the material will be disposed of, allows us to predict its potential toxicity level at the end of life. Therefore, this qualitative parameter gives an indication of the three waste landfill types: inert waste, hazardous or non hazardous waste.

3.2. Material lifetime extension guidelines

3.2.1. Material durability

A durable product has to withstand wear, stress and environmental deterioration over its expected lifespan in order to ensure its functionality.

Some design details may make a product durable without the use of additional resources. However, enhanced durability may depend on increased resource use. When this happens the impact caused by products should be divided by the estimated duration (short, medium or long term).

Consequently, the appropriateness of making a product durable, depends on its lifespan, because if the product has a lifespan longer than its expected lifespan or if the product components extend their lifespan longer than the product itself, they will become wasteful.

This is true for products which are subject to rapidly changing technology, because if a product quickly becomes obsolete, making it more durable could be pointless. In this case it is not only essential to take into consideration the product durability, but also its adaptibility through a Design-by-Components approach [26].

In accordance to this approach, a product which is made of several components assembled together by using reversible fastening, allows easy upgrading without replacing the entire product and avoiding redundant components. Moreover, if the components lifespan is expected to be short, they should not be designed for an extreme durability because their material may increase waste and have other impacts on disposal.

In conclusion, at a material selection level, this guideline advises the choose materials as durable as necessary but at the same time reliable. In other words it suggests to choose materials, which are able to guarantee their mission in the intended environment for a certain period of time and do not increase any impact through their disposal.

3.2.1.1. Qualitative & quantitative parameters. In order to facilitate the designers in the choice of the necessary durability of the material, three qualitative parameters have been used to describe the material durability (Fig. 4):

- Expected life span: this quantitative index accounts for the number of years for which the material it is expected to maintain its mechanical and physical properties, as declared by the manufacturer [32];
- Maintenance: correct material maintenance is a right way to preserve a constant level of functionality over its expected lifespan. Depending on the requested procedure, material maintenance could be easy or complicated.

Consequently, in the multicriteria system a qualitative parameter is assumed, which gives an evaluation of the complexity level of the material maintenance, based on how many activities are requested and what is needed to keep up material functionality. This parameter is expressed in three measure levels: easy, medium or complicated maintenance [32];

- Wear resistance: a material could wear out if it is used in specific conditions. This qualitative parameter gives an indication of which factors could compromise its reliability, such as its exposure to acid or salty environments, to some elements such as UV rays, rain, freezing cold and a range of temperature [32].

3.2.2. Adopting a top-down approach of the material end of life

When a product is at its end of life, it could be dismantled and the components and materials could be sent for different end of life treatments.

Adopting the end of life top-down approach at product level, means opting for products made of components that have been assembled together using reversible fastening. In this way a high fraction of homogenous materials and components could be recovered thus postponing its end of life.

During the material selection, this approach could be put into practice firstly by opting for materials which could be potentially recyclable or biodegradable or compostable, secondly preferring materials which allow energy or gas recovery. Finally, only when it is not possible to adopt materials which allow their material or energy recovery, this guidelines suggest to use materials which could be only disposed in a landfill [16]. This top-down approach is also adopted into the European Directive on Waste Management, which prompt to pursue waste prevention by following the 3R strategies, Reduce, Reuse and Recycling [33,34].

In this way, it is possible to pursue a material lifetime extension and at the same time avoid both the landfill impacts and the resource consumption.

3.2.2.1. Qualitative & quantitative parameters. In order to facilitate the choice of materials which could have an extended life time, it has been adopted a qualitative evaluation divided in 4 levels of measure (Fig. 4), in coherence to the end of life full-down approach and with the European Directive on Waste Management [33,34], such as:

1. Potentially recyclable: when the material could be process by recycling process by which it is possible to recover secondary recycled material with high or low performances;
2. Biodegradable or compostable: when the material waste could be respectively re-absorbed by the natural environment or could be transformed in compost thanks to the anaerobic digestion of microbes and organic matter;
3. Able to be gas or energy recovery: when the material waste could be subject to an energy recovery treatment, through their combustion in fossil fuel power plants, or to a gas recovery, by pyrolysis and plasma arc gasification;
4. Landfill disposal: when the only possible end of life scenario for the material is the landfill, with the consequences, as we mentioned before.

3.3. Guidelines for promoting the environmental ethic and policies of material manufacturers

3.3.1. Manufacturer declaration

This guideline encourages designers to select materials or semi-finished products made by manufacturers who actively endorse an environmental protective policy.

The manufacturer might implement ethic codes or policies which adhere to sustainability principles or provide certification about the environmental performances of their production process or products (semi-finished products or materials), as indicated into the series ISO 14020 standards [35].

Furthermore, as for instance for manufacturers of electrical and electronic products, the environmental responsibility of the material and product manufacturer should not be limited to the manufacturing processes but extended to the end of life phase [36].

3.3.1.1. Qualitative & quantitative parameters. The material manufacturer's environmental commitment is evaluated by means of a qualitative parameter, which ascertains any existing quality and/or environmental certification, among (Fig. 4) the following:

– Total Quality Management (TQM) certification: this declaration demonstrates that a firm has adopted a quality management system such as the well-known UNI EN ISO 9000/2000 standard. This standard is aimed at certifying the overall organization (processes, human &material resources, suppliers activities, etc.) and not the product itself. In other words, with this certification an industry can prove that it has adopted a more holistic approach to quality management and that is able to check, assure and improve its quality, with the final purpose of favoring commercial exchanges.

If an industry has ISO 9000 certification, that does not mean that the industry is environmentally friendly, but that it has an organization, which is potentially more able to include environmental protection policies [37].

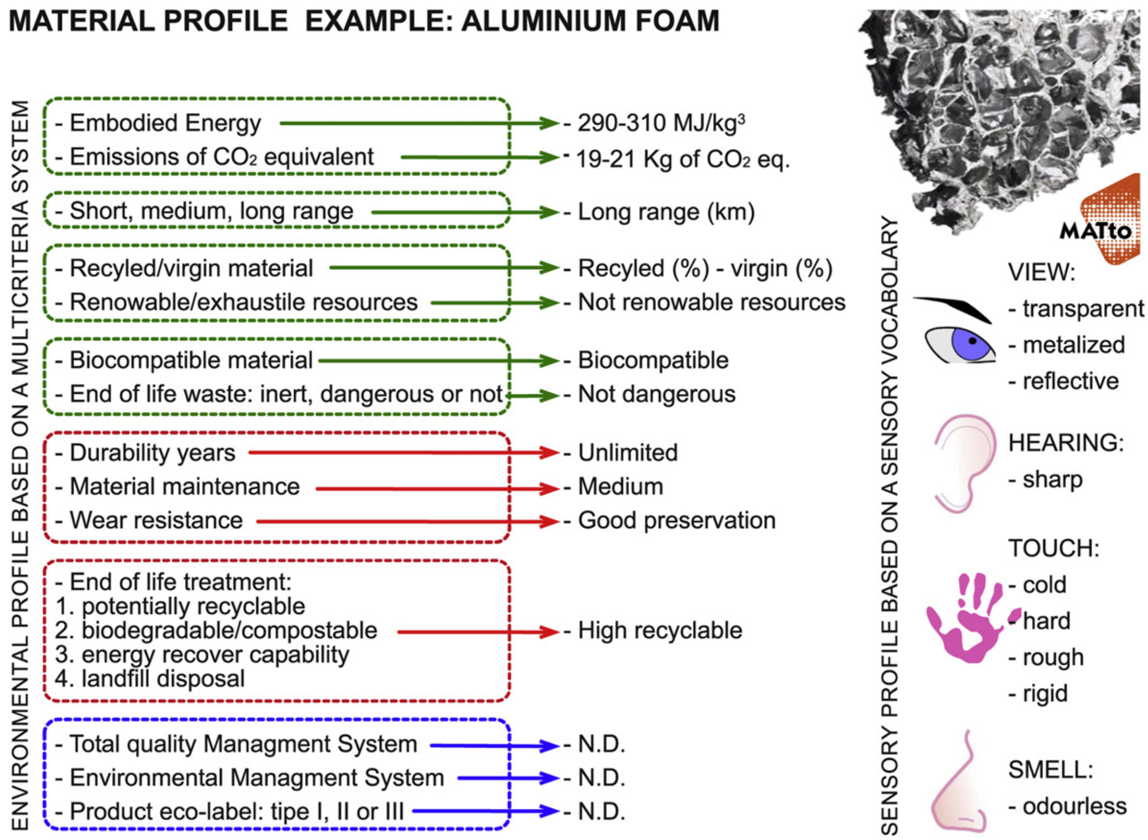

Fig. 5. An example of a MATto material profile sheet, where are reported the environmental and the sensory performances of a material.

– Environmental Management System (EMS) declaration: this information highlights if the producer has obtained EMAS or ISO 14000 standard certification, by which he should demonstrate that he has adopted an environmental policy in a comprehensive, systematic, planned and documented manner. It includes the organizational structure and the planning and resource for developing, implementing and maintaining the policy for environmental protection. If a producer has EMAS or ISO 14000 certification it means that it is focused on a constant improvement of their environmental performances in the overall organization and also that it is able to address the immediate and long-term impacts of the various processes on the environment [37,38].
– Ecolabel product certification: this information highlights that the service and/or the manufactured product, including the semi-finished product has obtained environmental certification, as established in the ISO 14020 standards. Following this standard, a product could be certified in three ways:
  – label I Type such as the European Ecolabel, which is aimed at identifying the best one in a product category, on the basis of a range of environmental criteria related to the whole life cycle. It is a non mandatory certification and it is assigned after verification by an independent body.
  – label II Type: such as the environmental self-declaration made by the manufacturer. This declaration is generally aimed at illustrating a good environmental performance in a specific phase of the product life cycle and it is not verified by an independent body.
  – label III Type: such as the EPD declaration, which provides a detailed environmental profile of the product life cycle performance in order to enable comparisons between products which fulfill the same function. This is a non mandatory certification and its reliability is verified by an independent body. It is based on verified Life Cycle Assessment (LCA) data, Life Cycle Inventory (LCI) data and information modules in accordance with the ISO 14040 series [35].

4. Conclusions

A methodology aimed at reading the environmental profile of a material has been adopted in MATto Material Library in order to catalog and organize the material samples.

In this way, the MATto capability of providing a detailed material profile, not only by the environmental performances but also by a sensory profile (Fig. 5), will offer to the designer the possibility to compare the performances of MATto materials with the material analysis provided by other well-known databases.

As a result, by using four main research keys (technical, economical, environmental and perceptual properties), the designers of the SMEs, which will use this consultancy service, are supported into the material selection phase by adopting a life cycle point of view. Consequently, they could anticipate the choice of the materials at the meta-project phase, where is possible to define which eco-strategies and guidelines could be adopted in order to obtain a green product along its life cycle.

In other words, by following the right guidelines in relation to its product usage context and end of life and by verifying the consequent suitability of the material to these guidelines, the SMEs will be able to conceive a real eco-compatible product.

In this way it could be possible to select the most suitable materials, which should become the key-drive of the future SMEs development according to the current sustainability and innovation trends.

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