Adding quality of life to design for Eco-Efficiency

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This paper aims at contributing to Eco-Efficiency and Design for Sustainability by debating on the impact of design choices on Quality of Life. During the last two decades Eco-Efficiency has been characterized by an unbalanced evolution: the progression of scientific knowledge and industrial practice on resources assessment has not been followed by an equivalent attention to the contribution of product functionality and related performance to users' quality of life. Starting from this consideration, the paper highlights that by concentrating resources on attributes that effectively improve the quality of life, a company would be able to enhance product sustainability. Actually, the typical background of a product designer is often limited in terms of specific tools and techniques for sustainability practices, and certainly there is a lack of means to analyze the relationship between customer requirements and product impact on customer's life. The present work proposes to connect the ultimate objectives of design, quality of life or well being, to product requirements, with the aim of maximizing their proper fulfillment within a sustainable approach. The proposed prototype procedure drives the development team to consider the final effect of each characteristic of the product within the customer's life and assists the selection of different conceptual solutions. A case study related to Beauty and Grooming illustrates the proposed procedure and allows to discuss its potential and limits.

Keywords:
Sustainable development
Degrowth
Product development
Quality of life
Customer satisfaction
Effective solution

1. Introduction

The Brundtland Commission suggested a relation between improvements in human welfare and changes in Natural Capital (WCED, 1987). The World Business Council for Sustainable Development defined Eco-Efficiency as the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity (DeSimone and Popoff, 2000). Costanza and Daly pointed out how improvements in human welfare can come about by pushing more matter-energy through the economy or by squeezing more human satisfaction out of each unit of matter-energy that passes through (1992). More recently, the theme of sustainable degrowth, as for instance proposed by Schneider et al. (2010), has raised attention to the possibility to down-scale production and consumption still resulting in equitable increase of human well-being and improved ecological conditions at local and level.

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Although sustainability concerns both the achievement of human needs satisfaction and the preservation of environmental resources, in the last two decades, the environmental impact of human products and processes has received a growing attention, while few researchers have addressed the consequences on human satisfaction of product modifications conceived for a lower consumption of resources. The Life Cycle Assessment community took an important role in this direction. Indeed, in the mid-nineties, the LCA community “decided to stick with traditional physical descriptions of functional units”, rather than giving importance to product value (Hofstetter et al., 2006). Although this choice has probably favored the development of the Life Cycle Assessment framework, it has also generated some limitations in product development.

Various models are available in engineering design literature for describing the design process and, from a broader perspective, the product development cycle (Hubka and Eder, 1988; Pahl et al., 2007; Pugh, 1991; Yadav and Singh, 2008; Zeng and Gu, 1999). Although they differ in nomenclature and focus, all of them identify four main subsequent phases of product development: product planning, conceptual design, embodiment design, and detailed design. In particular, the phase of conceptual design transforms a list of requirements into several subsequently compared and

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assessed conceptual solutions. Design solutions consume resources in order to satisfy a set of desires. If requirements do not appropriately reflect these desires, inadequate solutions follow. Karlsson and Luttropp (2006) emphasize this issue and they conclude that Eco-Efficiency is not sufficient without delivering effective products. Certainly, market priorities affect this process, but they are unlikely to make the development team reflect on their design choices. Moreover, as claimed by the degrowth movement, market priorities are usually defined into a market economy and its goals can differ from the pursuit of well-being (Latouche, 2010).

Within this context, the present work proposes the introduction of means to dedicate a proper attention on the product planning phase and subsequently in the concept selection phase for assessing the contribution of a technical solution to the end-user well-being. The original contribution consists then in a prototype approach to improve the awareness of the development team with respect to the misuse of resources with respect to their real impact on customer life. In turn, this implies linking product attributes also to secondary aspects of customer satisfaction/dissatisfaction, so as to highlight when the reduction of resources consumption generates critical contradictions with other product requirements. Ultimately, the authors think that channeling environmental resources into product attributes directly linked to quality of life aspects can be seen as a new driver for sustainable development.

This paper is divided into five sections. Section 2 introduces previous works that constitute the premises of the proposed contribution. Section 3 outlines a prototype procedure for applying this approach and it offers an illustrative example. Section 4 discusses current issues regarding the application of the procedure and further developments of the proposed approach. Lastly, Section 5 provides discussion and the paper conclusion.

2. Methodological background

Terms such as quality of life and well-being are often used in a vague form; for this reason this section starts with a more rigorous description of their appropriate meaning in scientific literature. Then, a link to the concept of customer satisfaction in Product-Service-System design is proposed to better position the present work. Finally, this section summarizes the reference models adopted in this study, specifically for what concerns the representation of quality of life and for dealing with multi-criteria decisions.

2.1. Quality of life, well-being, needs and value scales

Various classifications and conceptualizations of the terms quality of life, well-being, value scales, and human needs have been proposed in literature. These concepts are not synonymous, but are strictly related to each other. While quality of life (hereafter QoL) and well-being are concerned with the assessment of human satisfaction, value scales and human needs are related to human drivers.

QoL is a matter discussed in different domains such as Economics, Medicine, and Social Sciences even if they address different aspects of the same subject. Sociology started searching indicators about the standard of living before other disciplines: in a seminal article William Ogburn presented forty-one charts in order to represent a general picture of the course of social trends and fluctuation (Ogburn, 1935). Some years later, UN established a commission with the purpose of improving the awareness on standards, and ultimately, the level of living, by means of a proper definition and measurement of sustainability. In the second half of nineteenth century a growing interest promoted the definition and the diffusion of various approaches. Some of them found an operational outcome in the Human Development Index (Anand and Sen, 1994) a well-know composite indicator of human “achievements, freedoms and capabilities”.

However, QoL is not only characterized by a pluralism of indicators, but it also needs to incorporate the systems perspective because, as noted by Schalock (2004 p. 206), “people live in a number of systems (micro, meso and macro) that influence the development of their values, beliefs and attitudes”. Besides, in the current industrial practice, product development does not directly benefit from the conceptualization and the measurement of QoL, even if it is evident that, at least at macro level, product development could take advantage of QoL when the measurement focuses on individuals.

It is a main hypothesis of this work that well-being is able to contextualize the benefits generated by a product. In this paper, well-being is used to refer to personal satisfaction with life conditions, while the term quality of life indicates the whole state of individuals or societies. Although, as stated by Galloway (2006), “some regard the terms of well-being and quality of life as interchangeable”, the authors consider well-being as one component of the broader concept of QoL because according to Haas (1999) it represents a “different level and aspect of the broad concept of quality of life”.

2.2. From customer satisfaction models to a QoL perspective

Referring to the overview proposed by Karlsson and Luttropp in the special issue on Eco-Design published in 2006, since the 90s, various methods and tools have been proposed in order to consider sustainability during product development (Karlsson and Luttropp, 2006). The authors adopted the definition of sustainable solutions formerly introduced by Charter and Tischner, i.e. solutions “that minimize negative and maximize positive sustainability impacts”. Accordingly, Eco-Design fosters environmental load reduction for exploiting a certain set of functions. Another literature review by Boks and McAloone (2009) followed a few years later, identifying a transition from environmental to a sustainability context since 2003. During this transition, a new awareness of the role of customer satisfaction emerged also in relation with business strategies, as reflected by the Product Service System (PSS) design. As Boks and McAloone highlight, PSS methodologies represent a transition from a product to a system perspective and to a synergy of product and service capable of jointly fulfilling user needs (Vezzoli, 2010).

The design of PSS is a business activity that aims at reducing negative impacts on social, environmental, and economic spheres. PSS methodologies interested in sustainability (Tukker and Tischner, 2006; Vezzoli and Manzini, 2008; Vezzoli, 2010) pro-pose tools and checklists for an in-depth analysis of interactions and resources flows. These methodologies focus on the impact of solutions in customers’ satisfaction, but they are more interested in providing an effective business strategy for all stakeholders than understanding benefits in customers' lives.

Service Engineering or Service-Product Engineering (Arai and Shimomura, 2004; Sakao and Shimomura, 2007; Shimomura et al., 2009) partially answers to this lack by means of a “View model”, which connects customer value with functions and attri-butes that generate it (Hara et al., 2009). Shimomura et al. (2009) clearly specify that customer value must be scientifically evalu-ated. In particular the customer value is described through the introduction of the concept of Receiver State Parameters: they are indices of state changes of the receiver (e.g. noise in a facility) and they are related to customer's expectation. Parameters from the List of Values proposed by Kahle et al. (1986) and Kahle and Kennedy (1988) tower over the hierarchy generated by Receiver State Pa-rameters. This list of nine values was formerly introduced in

marketing for understanding customers under the assumption that their purchases partially reflect their values.

Although Service-Product Engineering successfully introduces in the product development process the assessment of impact on customer's life, the use of List of Values has two limitations. The first is that product design is not directly interested in human drivers while it is important to understand the effects of different solutions. The second is the introduction of a ranking principle for modeling customer desires that is not directly connected with their life and which breaks the holistic model of customer satisfactions. This work desires to address both limitations by means of an adaptation of Felce's (1997) QoL model, briefly introduced in the next section.

More in detail, the key concept is to link a design solution described in terms of product attributes, with the QoL aspects, as represented in the Felce's model. This means going beyond the traditional interpretation of design requirements. Actually, the standard ISO 9001 establishes that "the organization shall determine:

a) Requirements specified by the customer, including the requirements for delivery and post-delivery activities
b) Requirements not stated by the customer, but necessary for specified or intended use, where known
c) Statutory and regulatory requirements applicable to the product
d) Any additional requirements considered necessary by the organization" (ISO, 2008, p.19).

The process of requirement identification starts from customer analysis (e.g. marketing research), but later involves the problem perception by the development team. Ericson et al. discern two contexts connected by the representation of needs, "where values and needs are perceived by the users and where requirements and specifications are designed by the development team" (Ericson et al., 2009, p.65). The representation of needs plays a central role in maintaining the original motivation of a design requirement.

Specifically, product functionalities impact various spheres of human life. For example, food is first related to nutrition, but it also affects emotions or social life. Indeed, nutrition could become in specific circumstances a secondary aspect because the importance of each sphere depends on several factors (e.g. context, customers). The development team usually has a perception of these factors and it relies on its interpretation for decision making. As a matter of fact, Hauser and Clausing, while describing one of the classical tools of Quality Function Deployment, report that "experienced users of the house of quality try to preserve customers' phrases and even clichés — knowing that they will be suitably translated by product planners, design engineers, manufacturing engineers, and sales people" (Hauser and Clausing, 1988, p.5). Nevertheless, the team does not regard product impact on human life in a structured way.

According to the lessons learned from the above-mentioned studies, this work proposes a representation of conceptual solutions as a set of attributes. According to Krishnan and Ulrich (2001), the term attribute refers to both customer requirements and technical performance metrics. They form a vector that describes the product and its desired effects. Therefore, this work exploits a broader definition of design requirements in conjunction with the expression of their aims. In other terms, the assumption is that the development team gains a better understanding of the role of each product characteristic by considering its aim.

2.3. The reference model for quality of life description

This work introduces the domain areas of QoL with the intent to inform, stimulate reflections, and guide the development team to the final effects of its decisions. It is necessary to underlie that the original objectives of QoL research are not directly related to product development. However, the model proposed by Felce (1997) here adopted as a reference, provides a categorization of spheres of interest relevant to the QoL that appears suitable for the objectives of this work. In fact, the Felce's model mainly addresses the assessment of service support for adults with learning disabilities; nonetheless, it was chosen based on two considerations. First, it appears to be sufficiently comprehensive, but also simple, so that it could be easily implemented in conceptual design activities. Second, it is based on aspects that describe human life aiming to be universal. Therefore, these aspects are not screened, for example, by market economy, as it happens with the degrowth school of thought. Actually, the Felce's model has been already adopted by other scholars with different purposes; for instance it was exploited in order to understand the consequences of transport pricing pol-icies (De Groot and Steg, 2006a) through a survey. Even if De Groot and Steg (2006b) refer to different indicators, a direct relation with Felce's six domains can be established.

The Felce's six-headings categorization (Fig. 1) reports the majority of aspects of the individual's life mentioned in fifteen key literature sources with the intent to set up a common ground with respect to previous works. This classification benefits from Felce's collaborations with Perry (Felce and Perry, 1995) and with Schalock (1996). The six domains depict the holistic approach of QoL that has generally accepted characteristics: each of them may dramatically influence the other. The six-headings categorization proposed in Fig. 1 substantially reflects the Felce's proposal with minor modifications. In particular, the six-heading categorization proposed by Felce (1997) was compared with the categorization proposed by Felce in 1995 in order to highlight the meaning of the different levels of detail. Accordingly, the second layer of the categorization was simplified for favoring its introduction in product development.

Fig. 1 lists the main aspects related to each domain of QoL, according to Felce's description (Felce, 1997); their brief description is reported hereafter:

- Physical well-being subsumes health, nutrition, fitness, mobility, and personal safety;
- Material well-being comprises wealth or ownership, various aspects of the living environment and the accessibility to transport;
- Social well-being includes two main dimensions, interpersonal relationship and community involvement, that are both broken up by different aspects;
- Productive well-being embraces three connected areas: the acquisition of personal competence or independence, the autonomy of choices and the person's ability to use their time according to their tenets. The three areas could be expressed through pursuits in home, work, leisure and education;
- Emotional well-being encompasses happiness, freedom from stress, mental state, self-esteem, spirituality, sexuality and contentment;
- Civic well-being covers aspects related to the role as citizen.

It is worth underlying that the Felce's model is not considered as an assessment framework, but its six domains are introduced to help and guide the development team more systematically.

2.4. The analytic hierarchy process

The analytic hierarchy process (AHP) is a multi-criteria decision making technique originally developed by Saaty (1980, 2008). It is a widely known method for structuring decisions, for multi-criteria

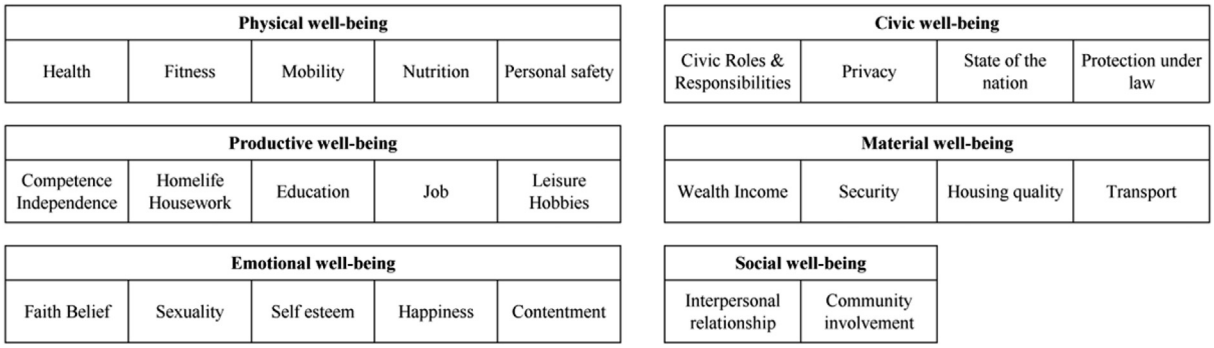


Fig. 1. Domains relevant to quality of life from Felce (1997) with minor modifications proposed by the authors.

measurement and for synthesis purposes (Vaidya and Kumar, 2006; Sipahi and Timor, 2010). Antonsson and Otto (1995, p.6) describe it as "a formal method for determining relationship between discrete alternatives". A complex scenario can be structured into homogeneous clusters of factors. By applying the analytic hierarchy process it is possible to determine a relative scale between criteria, possibly divided in sub-criteria; the alternatives have to be assessed with respect to each criterion. Eventually, the relative scales are combined according to the hierarchy that describes the relations between criteria and sub-criteria. Five steps compose the decision process: selection of the evaluation criteria, definition of the comparison scale, pair-wise comparison of the alternatives with respect to each criterion, consistency check and score calculation. By making a pair-wise comparison using numerical judgments from an established scale, the analytic hierarchy process allows to define a relative scale. The pair-wise comparison is particularly convenient when it is asked to compare intangible characteristics, but of course it can be combined also with tangible measurements. The analytic hierarchy process is also used in product design for formulating and analyzing decisions. Park and Kim (1998, p.570) refer to it as a "powerful and widely-used multi-criteria decision making technique for prioritizing decision alternatives of interest". Among the others, in his literature review on AHP applications, Ho (2008) highlights its advantages in product design selection with a manufacturing perspective.

Various reasons motivated the introduction of AHP in this work. First of all, the authors focused their attention on methods that had been already applied in the area of product design. Moreover, AHP emerged for its capability to connect different kinds of aspects. As well, it was considered well-structured and sufficiently easy to manage also within an industrial context.

3. Connecting requirements with well-being in conceptual design

Conceptual design typically consists of three activities: translation of the design task into a list of requirements, concept generation, and concept selection. The original procedure proposed in this paper introduces a new step and assists the development team during the last step.

The introduction of a QoL perspective in the traditional process of conceptual design is outlined in Fig. 2: once requirements have been identified, they are validated with respect to QoL aspects before proceeding with concept generation. The first part of the procedure described in the next section aims at supporting such validation step. Customers rarely perceive all parameters involved in product design; instead, they look upon the impact in their life produced by goods and services. The first part of the procedure drives the development team to consider the final effect of each product characteristic in customer's life. Product characteristics are connected with customer's life by means of a categorization of QoL aspects. The expected outcome is a new ranking of requirements that better fits the contribution perceived by customers, enabling improvements in their satisfaction.

After conceptual solutions have been generated, the second part of the procedure assists their selection: it estimates changes on the contribution to QoL produced by competitive solutions.

3.1. Prototype procedure for embedding a QoL perspective in conceptual design activities

This section describes the prototype procedure that was developed in order to provide a repeatable instrument for the application of the novel approach proposed in this paper. Table 1 and Table 2 depict the entire structure of the procedure. For each step, a brief description, its motivation and its inputs and outputs are reported. Before introducing each phase, Table 3 summarizes nomenclature that will be used below so that it could be used as reference during the reading.

3.1.1. Phase I – Defining attribute aims

It is assumed that the procedure starts after a vector of product attributes has been defined through the application of traditional methods of product development (e.g. Voice of Customer, QFD, checklists). This phase intends to help the development team in understanding the potential impact of each attribute. In accordance with the "Five Ws" approach, a full picture is achieved after five questions are answered. Therefore, applying this pragmatic approach to the attributes description a simple classification emerges: the pronouns, "who, where, and when" describe the user-profile, the pronouns "what and why" depict the desire that is satisfied. In fact, the description of what is desired is not sufficient for describing an attribute, but it is also necessary to specify its end. Defining the aim is easier when the development team has explicitly described the user's context. In a corresponding manner, attributes are stated pursuant to the relational structure "an attribute X in order to Y" (e.g. a cold drink in order to feel fresher). Explicit aims enable the identification of similar attributes described by different words. Moreover, such description facilitates

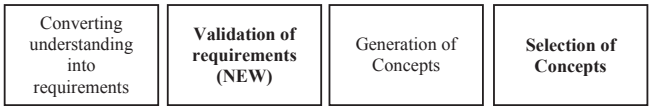


Fig. 2. Adding a quality of life perspective into the traditional phases of conceptual design (new/modified steps in bold).

Table 1
First part of the proposed procedure: validation of attributes.

Phase	Input	Description	Output	Motivations
I) Defining attributes aims	Vector of attributes	It is assumed that a vector of attributes was formerly defined. During this phase, the goal of each attribute is expressed explicitly using the description model: "an attribute X in order to Y".	Vector of attributes and their aims	Facilitate the identification of goals described by the attributes.
II) Assessing attributes weights	Vector of attributes and their aims	The development team asserts the contribution of each attribute to user satisfaction by means of Analytic Hierarchy Process.	Vector of attributes clustered and weighted through AHP	The assessment reflects the development team's understanding of customer desires.
III) Connecting attributes with domains	Vector of attributes and their aims	The development team identifies those domains of Quality of Life that are affected by the attributes.	Vector of attribute − domain connections	Understanding domains that are involved in the customer satisfaction.
IV) Comparing rankings	*Matrix of clustered and weighted attributes and attribute − domain connections*	*By means of domains relevance, the relative weight of each attribute is identified in relation to domains satisfaction is identified.*	*Validated Product Profile*	*Rethink the role of each attribute in order to improve the effectiveness of the following steps of product development.*

Table 2
Second part of the proposed procedure: comparison of conceptual solutions.

Phase	Input	Description	Output	Motivations
V) Assessment of attributes fulfillment for each solution	Vector of attributes and conceptual solutions	The product development team evaluate how much each solution fulfills an attribute	Matrix of attributes fulfillment	Identifying the effect of different designs on attributes fulfillment
VI) Assisting concept selection	*Matrix of attributes fulfillment*	*Differences between competitive solutions are expressed in terms of domain satisfaction through a radar plot. This plot facilitates the concept selection phase.*	*Concept selection*	*Selecting solutions on the basis of their final effect in customer's life*

the match between attributes and domains relevant to quality of life.

3.1.2. Phase II − Assessing attributes weights

In this phase, attributes contribution to customer satisfaction are prioritized using the first part of the analytic hierarchy process. Each attribute is pair-wise compared with each other, with the intent to supply a ranking. A judgmental matrix A is built as follows:

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} \quad (1)$$

where a_{ij}, the value of the pair-wise comparison of attributes, is governed by the rule summarized in Table 4. Following Saaty, the priorities of the attributes can be estimated by finding the principal eigenvector of matrix A. Finally, after the consistency has been calculated, judgment should be reviewed or elements should be discarded in order to obtain a consistent matrix. With this aim, attributes that do not have any role in customer satisfaction or dissatisfaction in comparison with others are discarded. The elicitation of attributes is strongly influenced by designer's experience in the product field: it results that some attributes are more detailed than others. In this context the classification of Becattini et al. (2011) could be adopted for identifying attributes that have not been considered or that have been decomposed in too many details and, consequently, for taking into consideration the axiomatic founda-tion of the analytic hierarchy process (Forman and Gass, 2001).

Table 3
Nomenclature used in the proposed procedure.

Phase	Description	Symbol	Value range
−	Attributes	a	1, …, n
−	Domains	d	Refer to Fig. 1
−	Solutions	s	A, B, C, …
II)	Attribute pair-wise comparison	a_{ij}	Refer to Table 4
II) − IV)	Attribute weight	w_a	1,…, n
III)	Attribute − Domain match	m_{ad}	0, 1
IV)	Relative relevance of a domain	r_d	0−100
V)	Attribute fulfillment provided by a solution	f_{as}	1−3
VI)	Relative solution contribution to a domain satisfaction		0−100

3.1.3. Phase III − Connecting attributes with domains of quality of life

This phase needs more attention during first applications of the procedure, because it directly concerns the novelty of the approach. Dissimilar aspects, attributes, and domains of QoL are connected according to the aims defined in Phase I. Each category of product is usually oriented towards a specific domain, but it also involves other spheres (e.g. a surveillance system is mainly associated with the security, but it could negatively affect the privacy). An attribute is connected to a domain when it potentially contributes to satisfy or dissatisfy one component of that domain. Fig. 1 presents the components of each domain. The user of this procedure is facilitated in identifying these connections by a synthetic description of quality of life components (e.g. Security in Material well-being: the degree of goods protection against dangerous agents). A matrix of connections is the output of this phase: to make it simple, each match between an attribute and a domain (m_{ad}) can take a binary value, 1 if the attribute has an impact on a certain domain, otherwise 0. Therefore, both positive and negative impacts are judged as they have the same weight on customer satisfaction or

Table 4
Pair-wise comparison scale for the analytic hierarchy process.

Numerical rating (a_{ij})	Verbal judgment of preferences
1	Both attributes contribute to QoL equally
3	Attribute i contributes slightly more to QoL than attribute j
5	Attribute i contributes significantly more to QoL than attribute j
7	Attribute i contribute definitely more to QoL than attribute j
9	Attribute j's contribution is insignificant compared to attribute i

dissatisfaction. Moreover, it is not considered the intensity of contribution to satisfaction or dissatisfaction provided by each attribute, to reduce the impact of subjective judgment.

3.1.4. Phase IV – Comparison of the new rankings with the original one

In this phase, new attributes weights are proposed because of the matrix of connections and domains relevancies. Therefore, the development team is able to compare the new ranking with the original one and identify mismatches, in order to rethink the contribution of each attribute. It is supposed that domain relevancies for a certain context are an external input of the procedure. For example, they can come from customers' interviews or they can derive from data of expenditures for each domain; experts and policy makers usually have a clearer vision in this task.

The attribute weight w_a is obtained from the equation:

$$\frac{\sum_d m_{ad} r_d}{\sum_a \sum_d m_{ad} r_d} \cdot 100 \tag{2}$$

where m_{ad} is the match between an attribute and a domain and r_d is the relative relevance of a domain.

Finally, the procedure supplies a new attribute ranking. In the authors' vision, this ranking is not important per se. However, it is useful for the development team to acquire new awareness of products: discrepancies with the previous rankings are underlined so that it would be possible to analyze the impact of attributes according to the goals of this approach. Now, the final decision on attribute weights is left to the development team. After attributes weights are validated, product development usually continues with the identification and the selection of competitive solutions. Phase V and Phase VI assist the latter step.

3.1.5. Phase V – Assessing attributes fulfillment for each solution

Once a conceptual solution has been identified, it is possible to establish how the solution is estimated to fulfill each attribute f_{as}. This evaluation uses the simple scale reported in Table 5; however, it is expected that it follows evidence from technical considerations specific for each case. Accordingly, proper and more complex weight scales could be introduced once conceptual solutions are described with a level of detail that allow technical considerations.

3.1.6. Phase VI – Comparing rankings

Based on the attribute fulfillment provided by a solution, f_{as}, the attribute weights w_a and the attribute – domain match m_{ad}, solutions can be compared. The relative solution contribution to a domain satisfaction is defined as the ratio between the domain satisfaction provided by the solution and the satisfaction that would be provided in the case of full fulfillment (f_{as} equal to f_{max}) of all attributes. It is obtained by the formula:

$$\frac{\sum_a w_a m_{ad} f_{as}}{\sum_a w_a m_{ad} f_{\max}} \cdot 100 \tag{3}$$

The contribution of different solutions can be compared for each domain of QoL: a radar plot could be used for assisting the solution selection and for facilitating the identification of further improvements. Actually, when a lack of satisfaction is identified, it is possible to proceed backward in order to identify missed fulfillments that cause it. This last action can help the development team identify further changes in the preferred solutions. In the case that a domain is not related to any attribute, then all m_{ad}s are equal to zero, thus it is not possible to investigate backwardly in order to improve the solution. In these cases the radar plot shows the domains as completely satisfied also if the product is not connected with them on the basis of the current set of attributes. At the same time, similar outputs highlight new directions for innovation, because new product attributes can fill the gaps. The innovation process can take advantage of other methodologies, for example Blue Ocean Strategy (Kim and Mauborgne, 2005) or the outcome-based methodology proposed by Ulwick (2002).

The procedure described in this section is the final outcome of a research activity developed in accordance with the Design Research Framework proposed by Blessing and Chakrabarti (2009). The illustrative case described in the next section constitutes the pre-scriptive study according to said research framework. It allowed to point out how, at this level of development, the applied procedure is characterized by some limitations that differentiate it from the desired support (e.g. because of efforts required for improving its usability). These limitations (e.g. the use of a simple scale as the one reported in Table 5) have been accurately considered in the eval-uation of outlines and for defining conclusions of Section 5.

Table 5
Evaluation criteria of attribute fulfillment offered by different solutions.

Scale	Description
1	Attribute not satisfied
2	Attribute partially satisfied
3	Attribute satisfied

4. Application to an industrial case study and results

This section details an industrial application of the proposed procedure, so as to offer a deeper understanding of phases and indicators introduced in the previous section, as well as the opinion of the participants.

The application of the procedure refers to a case study that involved an Italian SME leader in the production of body care and home cleaning products. The activities of the case study were developed within a period of twelve months by a fellow researcher in conjunction with the company's R&D and marketing departments. Their main goal was the identification of new market opportunities for goods produced exploiting in house processes. One of the most interesting characteristics of this case study is that it suggested the implementation of the approach proposed in this paper and the inability to reduce environmental impacts without negative side effects on products. More specifically, independent market surveys had indicated that customers desire new functionalities that require new resources, while retailers force for environmental labeling. The proposed procedure that was carried out during two one-day meetings was integrated in the first phase of the case study and aimed at modeling the AS-IS processes and at identifying relevant attributes.

After a brief description of the products involved in the case study, the following paragraphs report the procedure as a stand-alone application.

The case study regarded three different lines of body sponges that constitute a significant portion of company production. Due to confidentiality issues, the details about the products were limited to the essential information for describing the case study. Products are simply labeled as Solution A, B, and C. Fig. 3 portrays some examples of products similar to those involved in the case study. All sponges of this brand are characterized by a nice design, but they are obtained through different production processes applied to different materials: Solution C is made from cellulose, while Solu-tions A and B are made from different types of polyurethane. So-lution A is produced through a new manufacturing line that allows to mold the sponge in different forms. Notwithstanding its manufacturing process is still not optimized. Solution B is currently perceived as the product with the highest performance because its characteristics are quite similar to features of Solution C, but it is more comfortable and long living. Both Solution B and C undergo several mechanical processes: cutting, embossing, and rounding off. Their shelf prices vary from 5 Euro of Solution A to approximately 1 Euro of Solution C.

4.1. First part of the procedure: attributes validation

At the beginning of the study case, a vector of attributes was not available. Consequently, the fellow researcher, in collaboration with experts of R&D and Marketing departments, built a list of product attributes. Indeed, the elicitation of attributes took advantage of a questionnaire that had previously been submitted to a group of a hundred prospects of the company.

In Phases I and II, the fellow researcher operated as facilitator: he helped experts in defining attributes aim and he managed the pair-wise comparisons. What immediately resulted during the first phase was that the definition of the requirements aim is simpler once the description of the context of use has been made explicit. After specifying attributes aims, the experts were guided to compare them using the standard classification. Hence, several attributes were mixed with others because they describe different aspects of the same class (e.g. color stability and breaking strength are both related to product life). The final vector of attributes and their aims contains 7 elements, from an initial vector of 42 with a homogeneous capability to satisfy customers. They are listed on the left side of Table 6, while the right columns have been added to illustrate the second part of the procedure. The involved experts using a pair-wise comparison based on the scale of Table 4 prioritized these attributes. Eigen values of the judgment matrix reported in Table 7 represent the importance weights of attributes, without considering well-being. According to Saaty's theory, since the consistency ratio turns out to be lower than 0,1, judgments of the importance of problems are acceptable.

During Phase III, the research fellow identified contributions of each attribute to items of QoL. An attribute affects a domain when it has a contribution to one of its features. Table 8 depicts connections between attributes and domains: black filled cells identify matches m_{ad}s that have value equal to 1.

In this application of the procedure, it was considered convenient a direct judgment of the relative relevance of each domain by the development team. When the team members were not able to find consensus on a certain relevancy, the whole range was recorded. In that case, a Monte Carlo-like approach was used in order to consider multiple sets of possible profiles of relevancies.

In the beginning of Phase IV, the concept of QoL and its domains were introduced to all the people involved in the case study. The development team was asked to indicate, giving a range, the relative relevance of each domain to the whole contribution to QoL, r_d. The calculation of the new ranking began from a combination of relative relevancies r_d. Their values ranges, reported on the top of Table 8, were used for identifying discrete values on the basis of an incremental count. These discrete values generate a set of possible combinations that were used for generating weights according to Equation (2). The final attribute weights w_as are the mean values that derive by the application of the Equation (2) to all combinations of domains relevancies.

Fig. 4 summarizes the picture offered by the first phase: the weights derived by QoL domains were compared with weights derived by traditional pair-wise comparison. The error bars describe the deviation from the mean value determined by the use of a Monte Carlo-like approach when dealing with lack of consensus, as mentioned above. Therefore, suggestions could be discussed also considering the level of confidence. Differences between rankings and relevant gaps between weights recommend further reflections and debate by the development team.

The proposed comparison immediately highlighted that the general pictures offered by the two rankings vary significantly. The involved experts mainly directed their attention to three attributes. They immediately recognized that the traditional ranking did not reflect the fundamental role played by the bubble effect in customer fulfillment. While product security is a mandatory requirement and beauty treatments are able to differentiate the product from other sponges, the bubble effect represents the main customers' motivation to buy a sponge. Moreover, usability is hardly considered during purchasing, however it is an essential characteristic that can foster disaffection. On the other hand, they argued with the low weight related with the attribute “price”.

The attribute validation ended by performing once again the pair-wise comparison of Phase II in order to obtain a definitive ranking.

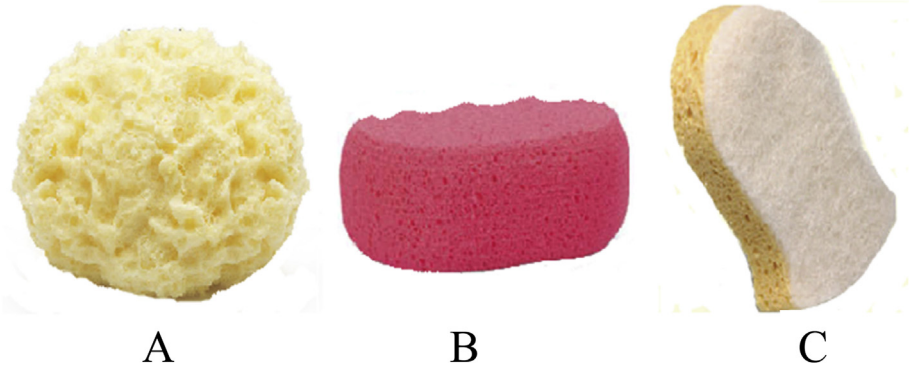


Fig. 3. Sponges that have similar characteristics to the product of the case study.

Table 6
The table is divided in two parts: the left side presents the vector of attributes and attributes classification based on the proposal of Becattini et al. (2011); on the right side there are attribute fulfillments of each solution defined in Phase V).

Vector of attributes			Standard classification		Solutions fulfillment		
ID	Attribute	Motivation			A	B	C
1	Pleasant to touch and design	Gratifies customer and invites to buy	Performance	Threshold achievement	3	2	1
2	Water distribution on skin and favor bubble effect	Guarantee functionality	Performance	Threshold achievement	1	3	3
3	Secure to health and favor substances flows	Safeguards customer health	Harmful effects	Object	1	2	2
4	Price	Invites to buy	Resources consumption	Information	1	3	3
5	Usability	Easy to manage	Resources consumption	Energy	2	3	2
6	Life	Prevent disaffection	Harmful effects	System	1	3	1
7	Beauty treatments	Gratifies customer	Auxiliary		1	2	2

Table 7
Matrix of the pair-wise comparisons of attributes based on the scale proposed in Table 4.

Attribute ID	2	3	4	5	6	7
1	1/3	1/5	1	3	3	1/3
2	1	1/3	1	5	5	1/3
3	3	1	3	5	7	1
4	1	1/3	1	5	7	1
5	1/5	1/5	1/5	1	5	1/7
6	1/5	1/7	1/7	1/5	1	1/7

4.2. Second part of the procedure: assisting concept selection

After connections between attributes and domains have been identified, it is possible to assess the effect on customer's life of a solution that does not satisfy some attributes. This analysis can involve conceptual solutions or real solutions, as presented in the illustrative example.

In Phase V and Phase VI, Solutions A, B, and C briefly described above, were compared. Firstly, the development team judged the attribute fulfillment (f) provided by each solution (s) using a 1−3 scale: the list is reported in the right side of Table 6. Then, relative solution contributions to a domain satisfaction were calculated according to Equation (3).

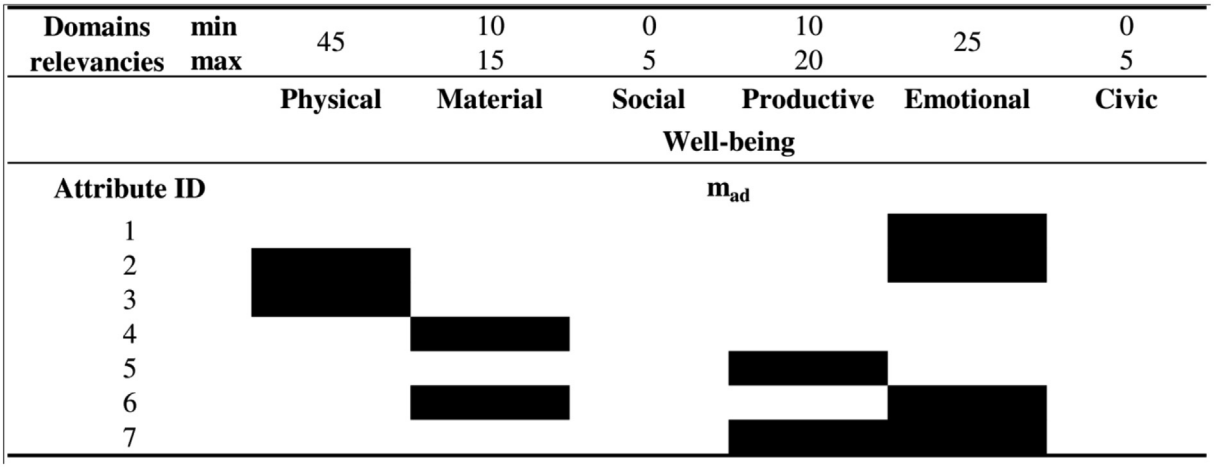
The radar plot in Fig. 5 offers a general picture of the domains satisfaction provided by each solution. It is worth noting that both Civic and Social well-being are completely satisfied by all three solutions only because the product does not affect these domains. In this plot, the effects of low performance are directly connected with negative impacts in customer's QoL: gaps between solutions are highlighted in terms of their final effect. In addition, referring to the matching realized in Phase III, it is possible to move back in the procedure in order to identify attributes that need more attention. For example, focusing on the Physical well-being domain, which is the most relevant one, it is suggested to better understand the dynamics related to the two attributes: “water distribution on skin and favor bubble effect” and “secure to health and favor substance flows”. Similar arguments could be followed for the remaining domains or for other solutions, in order to help the definition of improvement or new products.

4.3. Results

During the illustrative case elaboration, the procedure appeared smooth in spite of the time consumed by the development team for understanding domains during first approach. The final diagram demonstrated its capability to provide indications and to describe the consequences of different levels within the fulfillment of attributes by each solution.

The discussion between experts at the end of the first part of the procedure highlighted that the proposed rankings better reflected the description provided by Marketing Department on benefits

Table 8
Matches between attributes and domains of quality of life (m_{ad}s). In the top of the table, ranges assigned by the development team to domains relevancies are reported.



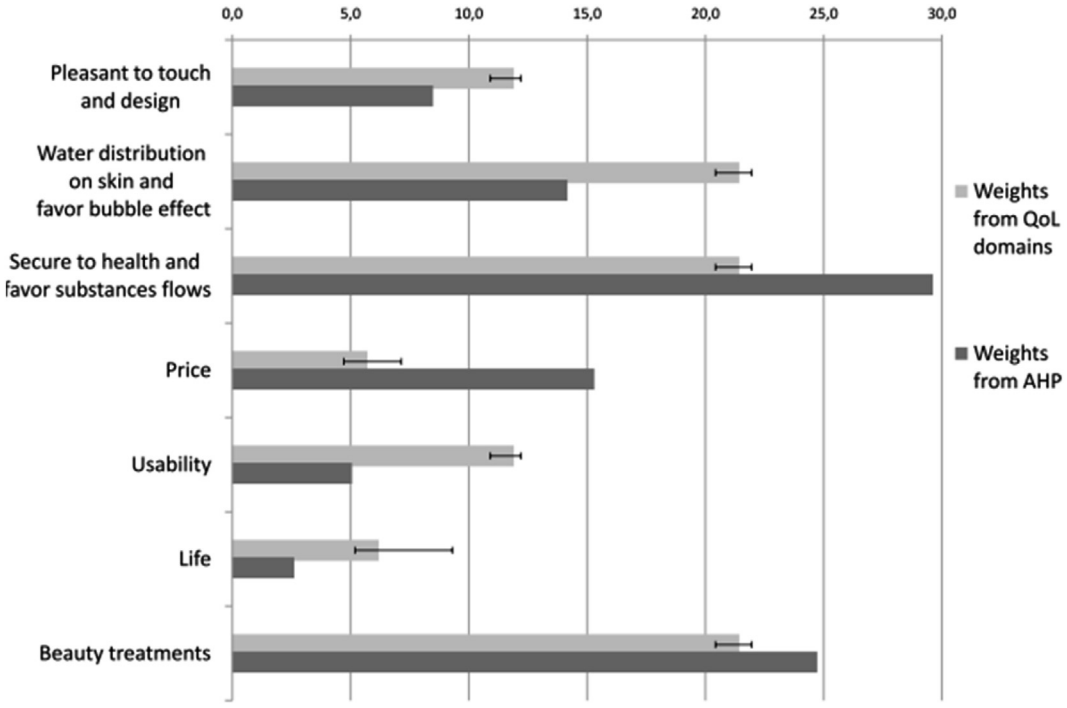


Fig. 4. Outputs of the first phases: a new ranking based on quality of life compared to the traditional ranking.

expected by customers than by the initial ranking. However, the experts stigmatized the suggestion related to the attribute "price" because on the contrary, they were inclined to increase the weight derived from the analytic hierarchy process. However, the price gaps between solutions seem to indicate that customers do not mind prices so much, because they are ready to pay more for new features.

Moreover, it was shared the opinion that differences with the initial ranking especially derive from an interpretation of attributes that is strongly biased by the current solutions. In other terms, attributes often depict current solution features rather than customers' real desires: these findings confirm the usefulness of an approach that drives the development team to consider final benefits.

Experts particularly appreciated the radar plot produced by the second part of the procedure. It is important to notice that the simultaneous accent on different domains of quality of life allows the development team to have a better understanding of the final consequences of their solutions. This aspect is important not only for the desire to improve satisfaction, but also to prevent unwanted side effects whenever the development team unintentionally neglects some undervalued aspects just because the focus is on sustainability interpreted as reduced resources consumption. In fact, the improvement of resources efficiency often causes rebound

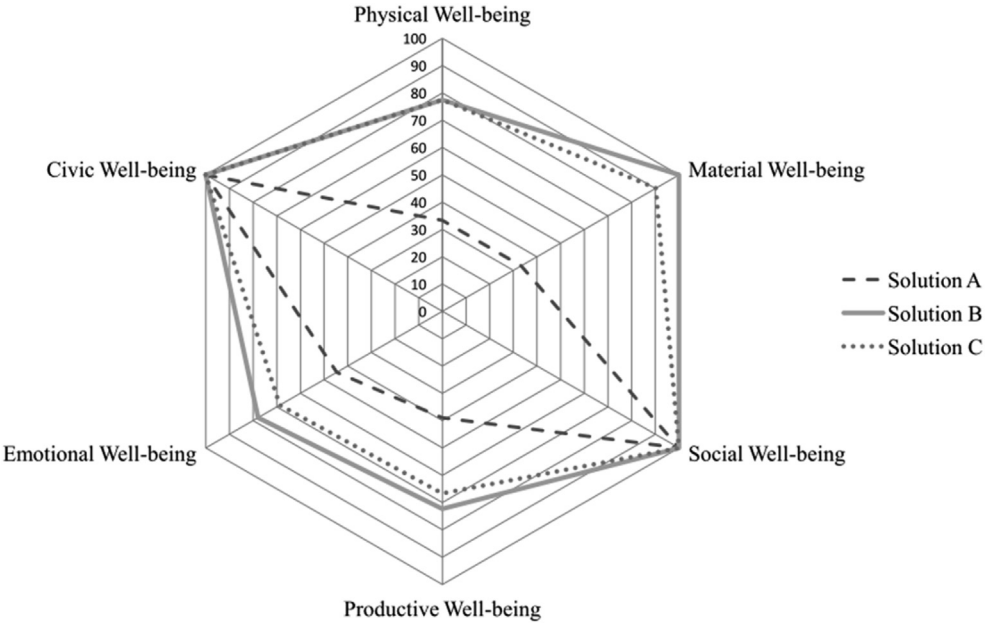


Fig. 5. The lack of satisfaction for each domain due to unfulfilled attributes by the three solutions.

effects because savings encourage customers to consume more in order to reach a higher level of satisfaction: this procedure can have an important role for guiding improvements in satisfaction and limiting consumptions.

The illustrative case provided evidence that this approach could not be applied to any product or service, because some of them are not directly involved with customer satisfaction, but they exploit functions auxiliary to the overall function, e.g. a system that exploits a sub function according to the model of Pahl et al. (2007). For example, the current procedure is not able to assess the contribution of a component of a system that is considered by customers as a unique product because it is not possible to define the contribution of the components. This limitation could be addressed in future works.

Eventually, the application indicated that product development can benefit from a deeper understanding of the final contribution of each attribute: the development team can identify and correct misleading interpretations of product characteristics that cause unnecessary resources consumptions, while different solutions can be selected for their final benefits, instead of for a comparison based on functionalities.

5. Conclusion and discussions

The paper desires to contribute to Eco-Efficiency and to Design for Sustainability introducing a debate on the effectiveness of goods and services with respect to the impact in customers' lives. The exploratory application has proved that the product development team is able to link inputs with their final results evaluated within the quality of life paradigm. This capacity allows for a wider and probably more interesting application. This paper proposes to investigate the role of QoL in the comparison of different solutions or scenarios. The authors believe that QoL domains can serve as basis for the comparison of dissimilar products, services or product-service systems and for focusing on the final effects on customers' lives that the designer will be able to channel resources.

On the other hand, the first applications of this exploratory procedure reveal that the results are significantly influenced by domain relevancies and by the attribution of a binary value for describing the connections between attributes and domains. The direct involvement of a fellow researcher facilitated the development of the illustrative case, because the other members of the team were free to ask for clarifications and considered him as a reference point. Notwithstanding the procedure appeared sufficiently smooth for being applied also without this guidance. In any case, before a large-scale application, the procedure needs to be implemented in other intended applications in order to assess its usability and its applicability. According to the methodology that has guided this research activity, a final evaluation requires the carrying out of a second descriptive study.

Before that, further works are essential in order to validate the relation between attributes and QoL and to systematically define the domain relevancies. While in the prescriptive study reported above it was assumed that relevancies of domains were established by the development team, it clearly emerges the importance of an interdisciplinary involvement in defining their method of calculation. Although such an activity could be based on statistical data on expenditure, the authors suggest the involvement of experts and policy makers.

Although some additional works are required, it is expected that this approach will be increasingly useful in the future, when efficient improvements will be more and more complicated by conflicting expectations of technical improvements. Further resources savings can be driven by a strategy that intends to maximize the ratio between final benefits in customers' lives and impacts.

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