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GENERAL-PURPOSE REQUIREMENTS CHECKLIST FOR IMPROVING THE COMPLETENESS OF A DESIGN SPECIFICATION

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1. Introduction

Two competences are crucial for achieving successful outcomes in innovation: the first one concerns all the decision-skills about "what to do" (or "doing the right thing"), the second one is about "how to do" (or "do the things right") [Lu 2009], [Labib 2004]. In other words, there is a double issue to be addressed in innovation context and related projects: effectiveness and efficiency [Gardner 2006].

To increase effectiveness and efficiency in design, methods and tools play a relevant role in enhancing the generation of outcomes of high-value for different stakeholders. Gero et al. [2012] compared unstructured/intuitive and structured design methods (respectively Brainstorming and TRIZ), concluding that the former proceeds through an unconstrained search for solutions, the latter focuses on problems to be addressed according to the objectives to be achieved. In these terms, the authors consider that systematic methods can support innovation projects more effectively and efficiently, because they aim at identifying goals and objectives before generating solutions, thus reducing trials and errors.

Several instruments exist to support the definition of requirements (whose entire set is called design specification) to be met by the design proposal. Roughly, they can be classified into two main categories. Some of them are suitable to be applied in different fields of application, but they are focused on a single specific objective. Design for X methods are a typical example of this category. On the other hand, there are domain-specific checklists (sometimes also formalized into standards), which address a wide range of requirements, but they are hardly applicable out of the specific context they have been built for. Overall, no instruments are available to completely overcome the dichotomy between versatility across multiple fields of application and exhaustiveness with respect to the different aspects to be addressed by the design task.

With the overall goal to contribute to the overcoming of such dichotomy, the authors have proposed an abstract-level checklist for requirements definition [Becattini et al. 2011], suitable for any field of application, but also to produce exhaustive lists of requirements. The overall research aims at producing a more versatile and effective alternative to populate a design specification; more into the detail, the specific objective of this work is about checking the applicability of this checklist and its potential capability to significantly increase the exhaustiveness of design specifications. This objective is expected to be particularly meaningful for new product development, i.e. when dealing with the definition of a set of requirements related to an innovative product.

Section 2 presents the role of requirements in the design process and the characteristics of a design specification. The section also presents the most known approaches for requirements identification and highlights their limitations in further details. Section 3 summarizes the overall logic followed by the authors in formulating criteria for the definition of system requirements. The fourth section presents a test to compare the capability of the proposed criteria to support the population of the design specification with a non-supported/intuitive approach, through an application to two products. The conclusions will sum up the main results achieved and present the opportunities for further development of this approach.

2. Requirements in the design process – role and tools for their identification

Regardless of the context or the conditions in which it may appear, a "situation" can be described as a state in which someone presents some discontent [Roozenburg 1995]. Capturing the demands underlying the situation is crucial to develop solutions capable of tackling the causes of discontentment.

Therefore, designing represent the process according to which different demands are satisfied as a result of the identification of solutions. This is the reason why innovation requires a search in a space of alternatives that, in turn, has to be constrained by both the goals to be achieved and the rules to be respected [Simon 1973]. In this reference, both the problem state and the goal state can be characterized by means of requirements. In the former, they assume their actual values, generating the situation of discontent. In the latter, they assume the target values to be achieved, so as to remove discontentment.

Moreover, the synthesis of technical systems requires boundaries for limiting the search for solutions. Such boundaries, as well, represent requirements to be satisfied. With this logic, it follows that they also drive the cognitive processes leading from the problem state to the goal state.

In this reference, the identification and the characterization of requirements for a technical system can improve the efficiency ("*do the things right*") of the whole design process by limiting the range of alternatives for solution concepts. Foremost such criteria can support the effectiveness ("*do the right thing*") of the design process by e.g.: recognizing which are the objectives to be achieved (analysis) with higher priorities; constituting a metrics for evaluating solutions (evaluation); driving design moves to appropriate directions (synthesis).

The hierarchy of aims and purposes by Roozenburg and Eekels [1995] provides further insights about such a role. *Goals* represent the target to be achieved in the form of future desired situations where discontent is not present anymore. *Objectives* (*Scaling* and *Non-Scaling)* are statements aiming at clarifying what to do in order to attain the goals. The latter category collects all the objectives that a design proposal can meet. These objectives are, thus, measurable (at least qualitatively). The other category, conversely, is its residual. Through Scaling Objectives, diverse design proposal can be ranked. This consideration leads to the definition of *Requirements* and *Wishes*. All the *Scaling Objectives* can be categorized as *Wishes* (also means to rank design proposals). *Requirements*, in turn, collect just the *Non-Scaling Objectives* that have to be met as a necessity, so as to distinguish good solutions from solutions to be discarded. Conversely, according to the Pahl and Beitz's [2007] vision, *Demands* and *Wishes* characterize requirements, respectively in compulsory and non-compulsory for the satisfaction of a *Goal.*

The importance of starting the development of the new solution with a well-populated design specification is stressed in both the abovementioned pillars of engineering design literature. Roozenburg and Eeekels [1995] also defined what characteristics this set of requirements should comply with, as follows:

- **Validity** – requirements should define the critera for assessingthe satisfaction of the design objectives;
- **Completeness** – requirements should cover all the potentially relevant objectives;
- **Operationality** – requirements should be measurable with reference to the objectives;
- **Non-redundancy** – requirements shouldn't be duplicated, if they have the same meaning;
- **Conciseness** – requirements should take into account all the relevant aspects, overlooking the non-relevant ones;
- **Practicability** - requirements satisfaction should be testable with available information.

According to such a logic, in both those references, checklists for supporting the integration of intuitively defined requirements are suggested. They effectively allow enlarging the design specification by triggering questions to the various stakeholders involved in the Product Development Process (PDP). They address different concepts along the product lifecycle, such as performances, maintenance, size and weight, … In this regard, the existing checklists do not address these characteristics, since both the one proposed by Pahl and Beitz and the Pugh's one presented in Roozenburg and Eekels simply do not allow, by themselves, to determine a design specification having the above mentioned characteristics. Designers or the facilitators in charge of extracting knowledge from domain experts have to deal with these issues by means of their own experience and skills. Instruments for supporting designers, or facilitators in the definition of a design specification with the abovementioned characteristics, will also support the PDP, so that it can be carried out with better effectiveness and efficiency.

Among the other means for supporting the management and definition of requirements, the Quality Function Deployment (QFD) method (e.g.: [Akao 2004]) addresses the issue of translating customer requirements into technical requirements. It is organized with a chart called House of Quality (HoQ) because of its shape resembling a house with a pitched roof. Moreover, QFD allows ranking customer requirements according to the perceived level of importance, to requirements and wishes as well as to more sophisticated classifications [Kano 1984], [Matzler 1998]. The main body of the House of Quality link Customer Attributes with Engineering Characteristics. This method, however, does not completely address the definition of technical requirements. It rather maps the relationships between customer and technical requirements, as a means to drive the PDP. Both types of requirements must be defined in advance and technical requirements, according to the prescriptions, should be evaluated in reference to the characteristics of the products developed and commercialized by competitors.

Existing technical standards and checklists, indeed, allow mapping a very wide range of requirements. The former are mostly focused on specific technical fields and, as a consequence, they result to be poorly adaptable to a various range of exigencies. Checklists, on the contrary, try to address this issue with a broader perspective, being more general and by taking into account different issues concerning the development of a product. However, their capabilities in defining a design specification do not necessarily pledge with the characteristics of completeness, validity, non-redundancy and conciseness as pointed out by Roozenburg and Eekels [1995].

From a different perspective, the "Design for X" guidelines address the needs of a wide range of technological domains, but they are mostly oriented towards the definition of best practices to design products, so as to satisfy one single meta-requirement (an objective) at a time, rather than a wide range of requirements as necessary in the development of artificial products that have to interact with a complex environment [Simon 1981]. So as to overcome the highlighted limitations, the authors have proposed an original set of criteria at a higher level of abstraction (than checklists) for the elicitation of knowledge from customers and stakeholders (Figure 1). The next chapter will summarize the overall logic underlying the criteria.

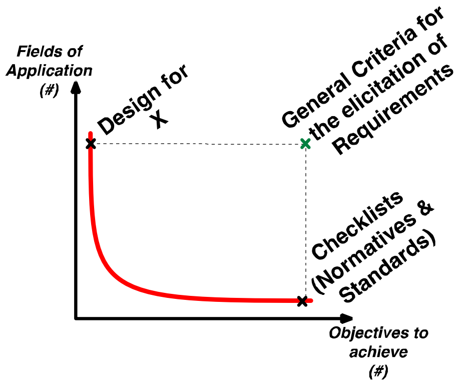

Figure 1. Scheme of current tools (black crosses) for requirements identification and the novel authors' proposal (green cross)

3. A recently developed set of criteria for the elicitation of requirements

Consistently with what has been introduced in section 1, the development of a set of criteria capable of eliciting knowledge elements from appropriate repositories (people and even sources of explicit knowledge) has to be carried out with direct reference to the innovation issues, as well as to the evolution and the development of technical systems in a “complete” and systematic way. In this sense, the author recognize in TRIZ, the Russian acronym for Theory of Inventive Problem Solving, a good opportunity. As the name says, it is a theory for solving design problems and its approach aims at avoiding design trade-offs: problems are tackled so that two conflicting requirements, Evaluation Parameters [Cavallucci and Khomenko 2007] in OTSM-TRIZ jargon, have to be both satisfied. In general terms, this theory is connected to innovation issues both because it concerns the solution of “inventive” design problems, but also because its concepts are grounded on the empirical results derived from the evolutionary analysis of a significant amount of patents, resulting in 8 so-called Laws of Engineering Systems Evolution [Cascini 2012]. TRIZ “law of ideality increase” has been chosen by the authors as the reference point from which to start the development of the criteria, since it defines three main objectives according to which technical systems evolve: (i) improvement of performances for carrying out *Useful Functions*; (ii) reduction of emerging side effects (*Harmful Functions*); (iii) slashing of costs (*Resources consumptions*) to be paid in order to make the technical solution exist and work. Moreover, they represent general, but mutually exclusive, classes and have been therefore chosen as the main reference classification for defining the requirements of technical systems.

Furthermore, it is important to define a common viewpoint for referencing the whole analysis so as to attain the characteristics of completeness, non-redundancy and conciseness. In this reference, the authors consider the EMS (acronym for Energy-Material-Signal) model a good candidate for setting the investigation. EMS is widely adopted for the representation of functions, as for Pahl and Beitz [2007] or Cross [2008]. It considers a function as a “black box” transforming flows, which are organized into three categories: energy, material and signal. Such a choice is motivated by the need of start characterizing the system under investigation according to its main useful function (in other words, its main purpose) being it related to the transformation of something that naturally wouldn’t change or, vice versa, to keep stable something who as the tendency to vary.

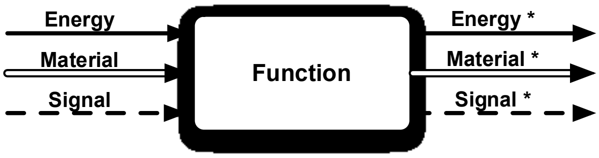

Figure 2. The Energy-Material-Signal model

According to the choices illustrated above, OTSM-TRIZ Evaluation Parameters represents requirements to characterize the Useful Function performed by TS, the effects of Harmful Functions as well as the need of Resources for the system to work. However, before going into the details of the criteria for the elicitation of system requirements, it is worth considering in which kind of domain (among Functions, Behaviour and Structures) the capabilities of a technology can be searched or determined.

With reference to the FBS framework proposed by Gero [1990], it appears evident that what concerns the delivery of Useful Functions pertains at a greater extent to the Function level, being it intended as the purpose of the technical system. On the contrary, the presence of side effects, as well as the need of resources, do not lie on the same level of FBS Function. They rather emerge considering what the system does in practice (Behaviour) and according to what compose the system (Structure), as a means to deliver the Function. This implies that requirements - concerning the capability of the system to both prevent the emergence of undesired side effects (Harmful Functions) and the limited consumption of Resources to make the system work - cannot just be exclusively considered in reference to the EMS model presented before.

Nonetheless, this issue is not contradicting the overall framework presented above as a reference to ensure a uniform analysis in terms of completeness, non-redundancy and conciseness. Indeed, the research for appropriate technologies to be implemented into technical systems has to be preliminarily carried out according to the Function they have to perform (e.g.: the methods reviewed by Cross [2008]). Then, once the several alternative and competing technologies have been identified and selected as promising for further development, according to their capability to carry out the function, it is necessary to reduce the range of alternatives. The comparison can be carried out according to (i) the capability to achieve the main useful function as required by the technical system; (ii) the extent of drawbacks potentially emerging by their introduction and (ii) the needed resources for system functioning.

For this reasons, system requirements concerning Useful Functions can be initially identified, as mentioned, in reference to the EMS model describing the transformation from inputs to outputs. Nonetheless, some of them can be determined also according to the capability of the selected technology to address diverse exigencies. Exigencies that also depend on the specific behaviour through which a function is carried out. On the contrary, the definition of requirements concerning the Harmful Functions and the Consumption of Resources should follow different criteria that take into account general features capable to describe the presence of side effects and reasons underlying costs.

In general terms, the requirements concerning Useful Functions have been divided into four sub-classes: Threshold Achievement, Adaptability, and Sensitivity to External Conditions as well as Controllability, as follows:

- **Threshold achievement:** requirements describing the capability to impact the object of the function with the expected extent**;**
- **Adaptability,** further subdivided into
    - **Versatility:** requirements characterizing the capability to adapt the behaviour of the technical system according to different operating conditions;
    - **Robustness:** requirements accounting the capability of the technical system to obtain the same (stable in values) desired outcome under varying inputs;
- **Sensitivity to external conditions:** requirements concerning the capability of the technical system in carrying out its function regardless of the conditions of the environment in which it is immersed;
- **Controllability:** requirements about the capability to set system characteristics and parameters so as to obtain a desired result according to user's will.

This subdivision allows all the potential facets, according to the EMS model, that may affect the delivery of a certain function to be mapped: the outcomes (outgoing arrows) are then evaluated according to the target to be achieved, the initial conditions of the flow (incoming arrows) to be transformed, the context in which this transformation occurs (environment in which the system works), as well as the capability to modify the target from inside the technical system upon request (the EMS black box itself).

Harmful Functions, on the contrary, appear in reference to the specific technology that gets used for a certain purpose (e.g.: cooling with a traditional vapour-compression cycle requires a compressor that produces noise. Peltier cells, on the contrary, allow the same function to be carried out, but they do not produce any noise). To this purpose, the requirements aiming at the prevention of harmful functions need to be elicited according to a slightly changed logic. The main reference is still represented by the Main Useful Function of the system, as the main objective to be achieved by the design proposal. Once the different competing technologies fulfilling such a purpose have been identified, the potential harmful interactions may occur among a finite set of entities, if described at a general level. Therefore, the criteria for the definition of the capability of technology in avoiding the emergence of Harmful Function are divided into three different but comprehensive sub-classes, considering negative impacts on:

- the object of the Main Useful Function (e.g. an undesired side effect caused by the same mechanism adopted to deliver the function or as its consequence);
- the system and subsystems integrity (e.g. an undesired side effect on the technical system as a whole or on its parts);
- the external environment (e.g. an undesired side effect that compromise some environmental conditions or damages some of the elements that pertains to the world in which the technology/technical system is immersed in).

According to this classification, it appears as almost impossible to determine in advance which are the potential effects occurring as a consequence of Harmful Functions. Nevertheless, their complete definition is also meaningless, since the same function (and its effects) can be considered as Useful and Harmful, depending on the contexts in which it emerged (e.g.: Eddy currents are undesired in a wide range of contexts, however they are also exploited purposefully in other applications, such as induction cooking).

At last, it is worth noticing that each system can be characterized according to the function(s) it delivers, meaning the changes that it carries out on *Energy*, *Material* and/or *Signal*. Before each system becomes a “system”, raw materials undergo the same modification of flows by other technical systems carrying out their own functions. It follows that every property or parameter of the different flows can contribute to represent typical facets of the system, according to the different level of detail selected. Such properties and parameters represent the reasons why some material is chosen against others for design; why some energy sources represents better opportunities than others and so forth.

Besides, each system, being it technical or natural, needs to exploit some resources for its existence. In other words, everything that exists needs at least some *Space* into which manifests itself and, if those entities play at least a dynamic act, they require also *Time*. These two dimensions represent the continuum into which all things are immersed, as taught in each Physics class.

According to this perspective, it is quite useful to characterize the kind of resources concerning the needs of the technical system in order to provide the benefits they have been designed for. Since both the time and the space dimensions represent a universal starting point into which things can be classified and EMS ontology (*Energy-Material-Signal*) has been used for defining the main function of the technical systems by the involved entities; the authors prpose to classify resources into the above mentioned 5 classes: resources of (i) space; (ii) of time, (iii) of information/signal; (iv) of material; (v) of energy). It is worth noticing that these two classifications may appear as not mutually exclusive, since all the flows can change during time and occupy some space (even zero is a value for describing room required). This is partially true, since changes occurring in the materials, energy or information may have also a role in slashing or increasing the consumption of space and time, but the effects of such changes are different and should go under different categories.

The above mentioned set of criteria has been already used in different contexts, such as the identification of relevant characteristics of manufacturing processes [Becattini et al. 2011] and the identification of requirements in a prototype for supporting the first stages of the PDP in a CAD system [Becattini and Cascini 2013]. Further details on the criteria are available in these two publications.

4. Design specification completeness – an experiment with the novel criteria

As briefly mentioned in the introduction, this paper presents the results of the first test aiming at verifying if the above presented criteria are applicable and provide benefits in supporting the definition of a more complete design specification. Indeed, it is almost impossible to state that a design specification is absolutely complete, because new demands from market or opportunities from technology development can always emerge and enrich it.

Therefore, the following experiment and the related analysis will focus on the difference between different groups of people who were asked to define a design specification for a specific product, expanding it as much as possible.

The authors carried out the test in an educational context so as to rely on a wide number of participants, thus having the chance of quantitatively evaluating the efficacy of the criteria in enlarging the individual perspective on requirements. In other words, the choice of testing the proposed approach in an educational environment derives from the need of relying on a wider amount of data with which it is possible to perform analysis of statistical significance.

More than 80 students participated to the tests. They all attended a Design Laboratory course, proposed by the industrial engineering school of Politecnico di Milano within the Bachelor of Science (MS-propaedeutic curriculum) in Mechanical Engineering. More into the details, two different but homogenous classes of the same course have been involved in the test, in order to have both a group whose individuals work with the support of the criteria and a control group, which was asked to identify requirements by means of no support except their personal intuition.

Moreover, the authors have considered that focusing on a single product may potentially produce biased results, according to the specific situation at hand. To this purpose, the test has focused on two products whose degree of complexity is markedly different:

- an iron, composed by a few components using a limited amount of working principles; and
- a laser printer, which is more complex, since it works with a greater number of components and by using a wider set of principles.

Each of the two groups has been asked to carry out an investigation on both the products. Each of the two groups has preliminarily defined requirements without any kind of support. Subsequently the groups have carried out the required identification by means of the criteria of section 3, suggested through a paper checklist. This choice has been driven by the need of avoiding the emergence of potential learning-by-doing effect, which may alter the results of the intuitive definition, if carried out after the assisted one. Table 1 summarizes the organization of the test in terms of support and subject of the investigation.

Table 1. Topics and approaches for the definition of requirements by the two groups of testers

	Subject of the intuitive investigation	***Subject of the criteria-assisted investigation***
Class #1	Iron	Laser Printer
Class #2	Laser Printer	Iron

The tests, both with and without support, have been carried out in the two classes with a hiatus of one week. For what concerns the distribution of the tests, since the testers are exclusively Italian students, the questionnaire containing the supporting criteria has been edited in their mother tongue, as a reasonable strategy to limit the perturbations due to language misunderstanding, which could have altered the collected results. More specifically, a set of detailed requests has been prepared to support the elicitation of requirements strictly following the sequence and the logic of the criteria, as proposed in Section 3. To ease the comprehension of the content of the questionnaire and the meaning of the criteria, each question has been matched with examples in the field of domestic washing machines, as presented in [Becattini et al. 2011]. Moreover, in order to set a common background for the analysis, the questionnaire begins by this statement (translation from Italian):

To systematically define the requirements of a product, it is suggested to properly define:

- *The object of the function (the entities which undergoes the functional transformation);*
- *Determine which characteristics or parameters of such object should be modified or kept to obtain a product that meets the needs; in other words, it is necessary to define which function the technical system carries out on the object.*

This statement is followed by the generic EMS model, as presented in Figure 2, which has to be filled according to the situation at hand, thus suggesting the testers to determine the main elements involved in the function of the system (e.g: “remove crease from clothes” for the iron and “transfer information on a papersheet” for the laser printer). Once such reference concepts have been defined, the background is set and the analysis for the elicitation of requirements can start.

Both the unsupported and the supported definition of requirements have been limited in a window of 45 minutes per each test.

Table 2. Results of the experiment, descriptive statistics (about number of requirements)

	Laser Printer		***Iron***	
	With criteria	***Just intuition***	***With criteria***	***Just intuition***
Average	45,18	17,00	40,83	15,11
Standard Deviation	10,53	6,01	9,12	4,41
Max value	68	27	60	32
min value	25	10	26	8
Sample Size	49	21	25	64

The preliminary examination of the results collected in Table 2 shows that, for both the iron and the laser printer, the average number of requirements (first row) defined by the support of the criteria is more than the double of the average of requirements identified without any support. Another remarkable result comes from the cross comparison between Max and min values (3rd and 4th rows): the higher number of requirements elicited without the support of criteria differs of just a few units from the minimum number of requirements elicited through the approach proposed in Section 3.

On this basis, the large number of requirements identified by means of criteria brings evidences in favour of their capability of populating a more complete design specification. Moreover, large descriptions of the design specification have occurred in case of many different testers, thus showing a certain repeatability of the results in term of numerosity. Furthermore, in order to determine if the improved completeness has been satisfied also in terms of statistics significance, it is proposed to test the effectiveness of the proposed criteria, under the null-hypothesis of equality between the average values, for both the tests carried out considering the Laser Printer and the Iron. The most suitable statistics to test this hypothesis is the t-statistics by Student, because of the poor knowledge about the population. The two mutually exclusive hypotheses under investigation are:

- *H_0: the difference in the average values depends on chance and the criteria do not provide any statistically significant contribution to the definition of requirements (H_0: $\mu_1 = \mu_2$)*
- *H_a: the difference in the average values depends on the treatment and therefore the criteria support the definition of new requirements (H_a: $\mu_2 > \mu_1$)*

To this reference, Table 2 shows that, due to the intrinsic variability of the presence of people at classes occurring in different days, the composition and the size of the sample vary, thus excluding the chance to carry out a paired t-test of Hypothesis.

The value of the test statistics has been calculated according to (1) and (2), since they are commonly adopted in cases where hypothesis testing has to be carried out between two samples pooled together, with a cumulative number of participants higher than 30 and under the assumption that the two standard deviations of the related populations are equal (as it can be assumed, considering the homogeneous distribution of students in the two classes). Specifically, the t-statistics is

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - d_0}{s_p \sqrt{1/n_1 + 1/n_2}} \tag{1}$$

where x are the observed average values for the distributions, d_0 is the hypothesized difference between the average values of the as for the null hypothesis ($d_0=\mu_1-\mu_2=0$) and s_p^2 (pooled variance) is calculated as follows:

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2} \tag{2}$$

For what concerns the Laser Printer, the degrees of freedom of the t-distribution correspond to 68 (49+21-2) and the value of test statistics is 11,46. It corresponds to a *p-valu*e = 7,64E-18, calculated for a one-tail distribution. Moreover, the test about the Iron is characterized by 87 degrees of freedom (25+64-2) and the related test statistics is 17,93, which corresponds to a p-value = 2,95E-31, still for a single-tail distribution. These results confirm what could be intuitively claimed looking at the results of Table 2: the very low value assumed by p-value means that the possibility that the criteria do not provide any effect on the result has a probability of being true practically null. It is, therefore, possible to claim that the criteria significantly support the identification of a higher number of requirements. Moreover, the relatively small differences between the laser printer and the iron show that the complexity of the products under investigation does not significantly affect the results of requirements identification supported by the criteria.

For what concerns completeness, however, it is worth to consider this parameter also in terms of an appropriate exploration of all the alternatives suggested by the criteria. To this purpose, subdividing the results according to the three main categories (Useful Functions, Harmful Functions and Consumption of Resources) the distribution changes according to what is presented in Table 3.

Even according to these results, it appears as evident that the criteria improve the exploration of the different facets concerning innovation.

Table 3. Summary of the results as proposed in Table 1. Details about the different categories under which the requirement can be classified

Product	*Approach for requirements definition*	*Requirements Characterization*	*Max*	*Min*	*Average*	*Standard Deviation*
Laser Printer	Criteria Assisted	Useful Functions	25	7	13,12	3,92
		Harmful Functions	27	3	12,06	4,62
		Resources consumption	30	11	19,59	5,75
	Intuitive definition	Useful Functions	8	1	4,10	2,05
		Harmful Functions	5	0	1,80	1,15
		Resources consumption	19	6	11,10	4,22
Iron	Criteria Assisted	Useful Functions	14	4	8,33	2,33
		Harmful Functions	24	9	13,54	3,67
		Resources consumption	28	8	18,96	5,20
	Intuitive definition	Useful Functions	18	0	1,75	2,45
		Harmful Functions	18	0	3,875	2,58
		Resources consumption	25	3	9,72	3,86

5. Conclusions

The present paper stems from the need of having more versatile means for better driving the definition of the technical objectives along a development processes, in order to carry out design tasks with improved effectiveness (to know what to do) and efficiency (to know how to do). The need of introducing new criteria for the definition of requirements at the beginning of, e.g., a Product Development Process is triggered by the limitations of already existing approaches that have been discussed, together with the role of requirements in design, in Section 2. To this purpose, a recently proposed set of criteria, which have been defined at a higher level of abstraction, is presented with the purpose of clarifying the contribution it can bring towards their more flexible adoption in different situations.

The overall research, this paper is part of, aims at providing a versatile and effective checklist for the definition of a more comprehensive design specification. This research work aimed at the investigation of the capabilities of such criteria to support designers in the definition of a more complete design specification, considering it as one of the keys to better drive the design process with reference to the overall objectives to be attained in order to satisfy new demands coming, for instance, from the market. This approach can impact the different stages of the design process by driving both the phases concerning the generation of new ideas (e.g.: conceptual and embodiment design) and the evaluation of design solution by providing adequate criteria for meaningful comparisons. The tests has been carried out on more than 80 subjects in an academic context. The testers (those who receive support by the criteria and the control group) were asked to define a design specification for two different products (an iron and a laser printer), so as to release from potential biases due to their intrinsically different complexity. The underlying assumption was that the students were adequately aware of the features and structure of an iron, while just marginally informed about the working principle of the laser printer (as it would happen while designing something new).

The experiments have shown, with a high statistical significance, that the general criteria here reported provide a strong contribution in populating design specifications with a more complete set of system requirements. Given the obtained results, the authors have planned to carry out paired tests (no control group) in the near future, with the purpose of verifying also the impact of the proposed criteria in teaching people to follow a systematic logic to elicit requirements, so as to also estimate the triggered effect due to learning-by-doing. Moreover the authors intend to perform further test to compare the performances of the presented approach with the competing ones (such as Pahl and Beitz's checklists) presented in the section 2, still with reference to their capabilities of broadening the perspective of designers, thus resulting in more complete and comprehensive design specifications.

References

Akao Y., "Quality Function Deployment: Integrating Customer Requirements Into Product Design", Productivity Press, 2004.

Altshuller, G. S., "Creativity as an Exact Science: The Theory of the Solution of Inventive Problems", Gordon and Breach Science Publishers, ISBN 0-677-21230-5, (original publication in Russian - 1979), 1984.

Becattini N., Cascini G., Petrali P., Pucciarini A., "Production processes modeling for identifying technology substitution opportunities", Published on the proceedings of the 11th TRIZ Future Conference 2011, Dublin–Ireland, 2nd-4th Nov, 2011.

Becattini, N., Cascini, G., "Mapping Causal Relationships and Conflicts among Design Parameters and System Requirements", Computer-Aided Design and Applications, 10(4), 2013.

Cascini, G., "TRIZ-based anticipatory design of future products and processes", Journal of Integrated Design & Process Science, 16(3), 2012, pp. 29-63.

Cavallucci, D., Khomenko, N., "From TRIZ to OTSM-TRIZ: addressing complexity challenges in inventive design", International Journal of Product Development, Inderscience, 4-21, 2007.

Cross, N., "Engineering Design Methods: Strategies for Product Design", Fourth edition, Chichester, John Wiley and Sons Ltd., 2008.

Gardner, P. L., Verma, V. K., Payne, B., "Balancing research vision and research management to achieve success in the 21st century", In Technology Management for the Global Future, 2006. PICMET 2006, IEEE, Vol. 1, July, 2006, pp. 99-108.

Gero, J. S., "Design prototypes: a knowledge representation schema for design", AI Magazine, Vol. 11, No. 4, 1990, pp. 26–36.

Gero, J. S., Jiang, H., Williams, C. B., "Design cognition differences when using structured and unstructured concept generation creativity techniques", in A Duffy, Y Nagai and T Taura (eds), Design Creativity 2012, The Design Society, 2012, pp. 3-12.

Kano, N., Seraku, N., Takahashi F., Tsuji S., "Attractive quality and must-be quality" (in Japanese). Journal of the Japanese Society for Quality Control 14 (2), 1984, pp. 39-48.

Labib, A. W., "A decision analysis model for maintenance policy selection using a CMMS", Journal of Quality in Maintenance Engineering, 10(3), 2004, pp. 191-202.

Lu, S. C., "Collective rationality of group decisions in collaborative engineering", International Journal of Collaborative Engineering, 1(1), 2009, pp. 38-74.

Matzler, K., Hintertuber, H. H., "How to make product development projects more successful by integrating Kano's model of customer satisfaction into quality function deployment", Elsevier Science Ltd., Technovation, 18(1), 1998, pp. 25–38.

Pahl, G., Beitz, W., Feldhusen, J., Grote, K. H., "Engineering Design: a systematic Approach", 3rd Edition, Translation from German by Wallace K., Blessing L. (eds.) , Springer-Verlag, London, 2007.

Roozenburg, N. F. M., Eekels, J., "Product Design: Fundamentals and Methods", Wiley, Chicester, New York, ISBN:0471943517, 1995.

Simon, H. A., "The Sciences of the Artificial", (2nd ed.), MIT Press, Cambridge, MA, 1981.

Simon, H. A., "The structure of ill structured problems, Artificial Intelligence", Elsevier, Vol. 4, Issues 3-4, Winter, 1973, pp. 181-201.

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