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DESIGN FOR INNOVATION

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1. Introduction

A good title for a conference paper should usually be self-explanatory, but this does not probably apply to this paper, because of the hyperinflated usage of the term "innovation" that is included. So, an introduction is needed to clarify the meaning of the title and to discuss the problem of designing products and product-services in order to lead to innovation in its proper sense.

The starting point for the discussion is – of course – the meaning of the term "innovation", for which a number of definitions can be found. In common usage, innovation simply means "something new", it can thus be applied to any technical novelty. Therefore, designing and innovating are close to being synonyms, with "design for innovation" being a tautology. Dictionaries (e.g. the Merriam Webster) add something by defining innovation as "the introduction of something new". The Innovation Management literature goes deeper in defining what this "introduction" means. According to Schilling [2008], innovation is "the commercial exploitation of an invention". So, following this widely accepted definition, innovating means designing something (let's call it a widget) that will not only work from a technical point of view, but will also make business sense. In turn, and in its simplest form, this implies that innovation occurs when an economic actor will be able to cover his costs by selling a given volume of widgets at a given price and that, on the side of demand, a number of economic actors will be willing to buy that same volume of widgets at that price, and still gain some utility out of it.

Should we limit ourselves to this simple model, there would be nothing very new, since literature in the fields of Design, Product Development, etc. has over the years developed a number of methods aimed at helping designers make this happen, i.e. identifying user needs and translating them into technical requirements, while defining target prices and costs. Among these methods one can list Design-To-Cost and Target Costing, Value Analysis and Value Engineering, and Quality Function Deployment, etc. Recent contributions to literature also provide interesting attempts to create bridges between these methods and integrate them e.g. [Zhang et al. 2011].

However, in most instances, the innovation process is considerably more complicated than simply making sure that a single buyer and a seller will find mutual benefit from a transaction, so that the former will buy the widget from the latter. In fact, after the purchasing decision, the widget must be actually put to use (i.e., *adopted*) in order to deliver its benefits, and this process may also necessitate learning by the user, thus requiring an expenditure of time and effort.

Furthermore, the sale of the expected volume of widgets is not instantaneous, but typically follows a *diffusion* process [Mahajan et al. 2000]. In this other process, at any point in time, the actors who have not adopted widgets yet are usually influenced by the actors who have successfully done so, either because of direct "word of mouth", or because of simple observation of the benefits.

Finally, products and services are seldom aimed to a single actor [Cantamessa 2011]. While buyers and users are not necessarily the same person, the actor(s) that will ultimately benefit from the widget might be different from either the buyer or the user. Buyers can also be influenced by other stakeholders, such as installers or vendors. In some cases, the relationship between user and beneficiary is relatively straightforward to identify. In other cases this is not true and one may use the economic term *externality* [Laffont 2008], that represents the phenomenon by which a transaction between a buyer and a seller impacts either positively or negatively on someone who is external (i.e., an outsider not taking part) to the transaction.

A few examples may clarify these concepts. In the case of buses for public transport, the buyer is the purchasing office of the transport authority, the users are the bus drivers (but one might also include maintenance crews in this category) and the direct beneficiaries are the passengers. However, there are also "outsider" beneficiaries involved too, such as citizens being affected by the emissions of the vehicle, or passers-by that may be impacted (quite literally in fact) by the degree of pedestrian impact performance of the bus. In the case of medical devices for hospital use, the buyer is the hospital's purchasing office, the users are the medical staff, the direct beneficiaries are the patients, and the outsider beneficiaries may include patients' relatives. Finally, when deciding on the equipment to be installed during the renovation of a house, some members of the family will be buyers, users and beneficiaries, other members (e.g. small children) will only be beneficiaries, and also installers will have a key role as users and sometimes as buyers too.

The implication of this discussion is that, in order to have a successful innovation (i.e., to actually make commercial impact), the product or service has to be designed having in mind all the phases that make up the innovation process and the specific decisions taken by the actors that take part in each phase. Failing to do so, and neglecting any one of these phases, can actually kill the innovation process even in the case of products with good potential. For instance, it may lead to designing products that might be used, but will never really be, if they are not purchased first. Or, to products that will be purchased, but then will not be properly used, maybe because users are concerned by potentially negative externalities that might occur to someone else.

The concept of "Design for Innovation" can therefore be separated in four core components that we can define as "Design for Purchasing" (by buyers), "Design for Adoption" (by users), "Design for Impact" (on the beneficiary) and Design for Externalities (on outsiders). In studying each of these "Design For" components, one must also consider that actors involved do not act in isolation from the others. So, Design for Innovation does not only require to understand the individual perspective of each actor, but also the influences that are reciprocally cast among the set of actors and – potentially – the conflicts occurring between their needs .

The paper has the objective of proposing a first structuring of this problem and a methodology – loosely derived from QFD – to tackle it. It develops and structures the preliminary empirical findings by Shluzas et al. [2011], who presented a case study on identifying and managing value in a multiple-stakeholder environment. The main contribution, that sets the current paper apart from previous literature on requirements capture, is the multi-component and multi-actorial perspective. For instance, Roder and Birkhofer [2011] propose the use of requirements clusters in order to manage complex situations, but do not attempt to cover a multiple-user perspective. Other authors propose to use Value Analysis on the overall product life cycle. However, their perspective is more general and is concerned with the phases of design, manufacture and use of products, rather than on the specific elements that make up the innovation-adoption-diffusion processes.

The purpose of the paper is a preliminary theoretical contribution and the authors are aware that the potential of the proposed approach is only partially demonstrated; however, this paper should be considered as a first step to the development of a more comprehensive model for representing the complex issues which arise designing for innovation.

The following Section 2 of the paper reviews an approach for defining needs and requirements in design. Section 3 proposes a structured model of the "Design for Innovation" problem that extends the concepts discussed in Section 2 to the case of the four components and to the related actor network. Section 4 then proposes a method for tackling the Design for Innovation problem and a simple example is proposed in Section 5.

2. Needs and requirement in design

Marketing literature has been suggesting for some time that the definition of design requirements cannot be made without listening to the "Voice of the Customer", in order to understand customer needs. Actually, the "customer need" concept has been quickly broadened because of the important role of emotions and psychological issues. Many recent contributions have stressed the importance of considering the wider "customer behaviour" concept, specifically taking into account personal experiences [Nicolas and Aurisicchio 2011], [Kim and Hwang 2011].

Besides Needs, Requirements are "structured and formalized information about a product" and "consist of a metric and a value" e.g. [Ericson et al. 2009]. Requirements are the translation of needs into an engineering specification, i.e. a set of technical constraints such that it is possible to assess whether they are satisfied in a given context. That distinction considers the customer information about desires and aims to be translated into representations of needs and formalized into requirements.

In Engineering Design these two concepts are operatively tackled day by day. However, a proper distinction between needs and requirements actually does not really exist. Ericson et al. [2009] investigate this issue and bring some contribution to highlight their distinction. Vermaas and Dorst [2007], for instance, analyze how the "physicochemical description of an artefact" should be converted by designers into usable information, emphasizing that the design process must cover more activities than a translations of some requirements into a functional specification.

Unfortunately, the information that the customer is able to provide is elusive, and, if the expressions are not sufficiently analyzed and categorized, they can mislead the development team. This happens because customers may have difficulties in articulating their needs, due to "functional fixedness", which makes them ask only for what they presume they can get. Moreover, market researchers often ask the wrong questions, or focus on picturing the 'average customer', limiting the opportunities for meaningful innovation [Weber 2008]. Besides, requirements must be arranged in the form of structured and formalized information about a product, the so called "product design specification", which constitutes the reference for the further steps in developing the product. A proper product design specification allows assessing at each stage of the development cycle if the new product satisfies what the customer needs and is willing to purchase.

A proposal that clearly distinguishes Needs and Requirements as distinct elements in design is enunciated in Cascini et al. [2010].

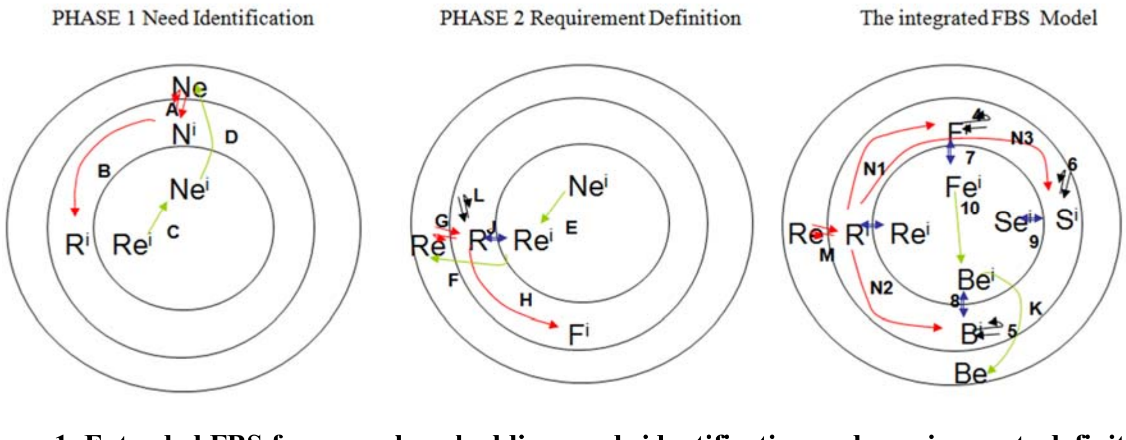

Figure 1. Extended FBS framework embedding needs identification and requirements definition

In the "extended FBS model" they formally introduce two new types of variables, i.e. Needs and Requirements, and "situate" them into Gero & Kannengiesser *External World* (composed of representations outside the designer or design agent), *Interpreted World* (built up inside the designer or design agent in terms of sensory experiences, percepts and concepts) and *Expected World* (effects of actions predicted according to current goals and interpretations of the current state of the world). By analyzing the cognitive processes determining the transformations of those new types of variables within these three worlds, the extended FBS model postulates Needs Identification and Requirement

Definition as diverse phases, part of the design process. The introduced two phases and the extended model are shown in Figure 1.

Regarding tools and methods for needs identification and requirements definition, a number of approaches have been proposed in literature and are implemented in industry.

Needs identification comprises two main classes: needs derived from customers' inputs (both explicit and tacit) and those postulated by the designer according to his experience and to the consolidated know-how in that domain. The former, in particular, includes the information that the customer is able to provide (e.g. through interviews and surveys), and what can be extracted by the observation of users' behaviour with existing artefacts. It is worth noting that there is a general trend in product development to develop methods for including ever more user input in the design process. Among them, Value centered approaches and User/Human centered methods e.g. [Redstrom 2006], [Miaskiewicz and Kozar 2011], User Experience based methods [for a review, Nicolas et al. 2011] and approaches that include the users' "life space" including cultural aspects and usage contexts [Kim and Hwang 2011].

This quite prolific scientific discussion about methods to identify needs is complemented by an even larger literature about requirements definition. However, all these approaches and techniques are focused on the "use" phase and, indeed, "the user" is the unique target of the designer. So, the following section will extend the model outlined above, in order to deal with all the facets of the innovation process and take into account the roles and the actors that take part to each phase.

3. Beyond use situations and the multi-actor context

In general, it is possible to imagine three situations beyond "use": purchasing, delivering benefits and creating further impact or externalities. The proposed set of situations is not exhaustive, but we feel that it represents a good balance between simplicity and representativeness. Of course, and as already mentioned, each further "beyond use" situation leads to the need of including more stakeholder roles, and namely buyers, users, beneficiaries and outsiders. For certain products, some actors may collapse in the same role.

Each of the stakeholders involved operates based on a set of specific needs. These needs can derive from the actor itself (native needs) or can result by influences cast among actors (reported needs). The influence cast by an actor on another actor can lead to a reported need if that need would not have been considered if the influence had been missing. Conversely, the influence can modify the importance or the perception that an actor assigns to a native need.

Some needs are well known to everyone, either because they are obvious, or elicited by external entities (e.g. regulatory institutions), or because they reflect common sense or general interest. Referring to the medical devices example, it is obvious to assume that – all the rest being equal - hospital management will prefer a product that minimizes discomfort to the patient even without receiving direct influence from patients themselves. However, the importance that management will attach to this need may be altered if patients do cast such an influence (e.g. through a patients-rights association) or if by purchasing a less invasive device the hospital might be able to attract more patients. For the designer that is developing the medical device, the ability to understand and proactively work on these influences is integral to defining the product and its go-to-market strategy.

This multi-actor context is sketched in Figure 2. Two consequences for designers result. The former is that designers must consider a wider set of needs as the basis for the requirement definition. Requirements must be the "balanced expression" of stakeholder needs. This implies that also the extended FBS model as proposed in Cascini et al. [2010] has to be further broadened and a needs identification phase for each actor involved (hence one circle for each actor) has to be considered. As shown in Figure 3, circles can intersect differently in relation to the way with which needs are shared among different actors. If some needs are common, they must fall in the same intersection set. The circle intersection modalities and the analysis of the related cognitive processes are surely worthy of a deeper investigation, but this issue will not be discussed here.

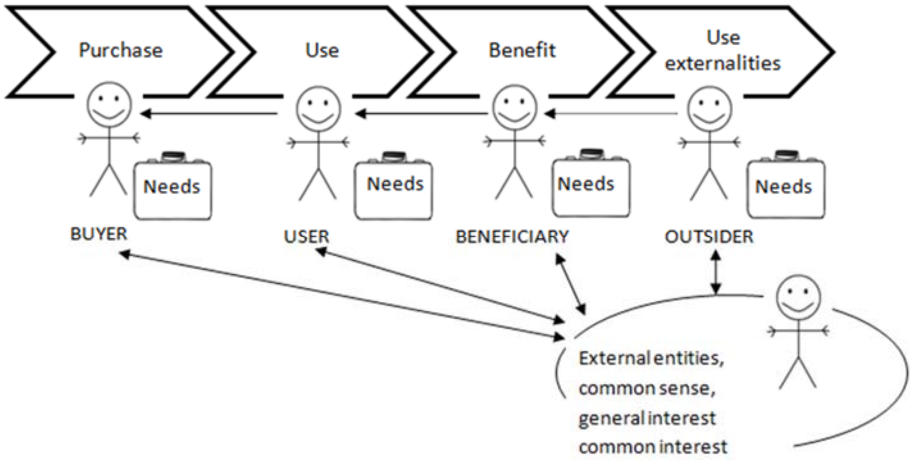

Figure 2. The multi actor context of beyond use situations

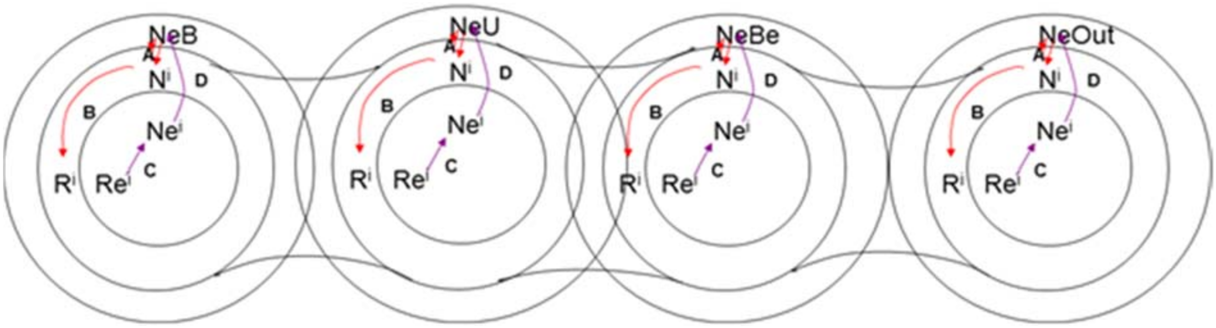

Figure 3. Situating the needs of several stakeholders in the extended FBS model

The latter consequence is that designers must investigate the mutual influences among the actors and their impact on Needs. As mentioned above, that implies that "Reported Needs" must be considered beyond "Native" ones. The Reported Needs result from the explicit and implicit influences an actor is subjected to. This is the reason why in Figure 3 the expected and interpreted worlds of the diverse actors merge together. If actors reciprocally influence to each other, they can be influenced in their needs and designers analyzing these influences can construct new needs that are the result of an "interpreted or expected impact" of the influences on the actor needs. From now, needs, which would have not been considered if the influence had been missing, are taken into account, as well the importance of a need for an actor can increase or decrease because his experiential context. These elements have impact on the centrality of a specific need in the design and consequently on the weight designers can attribute in the requirement definition phase (such as for instance with QFD).
The influences between actors will be studied by using Social Network Analysis for communication flows, and Actor Network Analysis for representing actor roles and negotiation situations. The use of these approaches in Engineering Design is not very common, with Wadell and Norell Bergendahl [2011] being one notable exception.

4. From needs to requirements: how to manage multi-stakeholder contexts

Among the Actor Network Analysis methods, the approach here proposed for the analysis of inter-actorial influence is inspired by MASAM (Multi-issue Actor Strategy Analysis Model) [Bendahan et. al. 2004], an evolution of MACTOR by Godet. Both are formalized multiple-issue actor analysis methods, usually applied to strategy analysis and negotiation problems. Indeed, the same authors of MASAM suggest that the method can be successfully applied to a variety of situations involving many actors and issues. The assumption here behind the adoption of the MASAM model is that this tools can be useful to represent inter-actorial influences on needs as a basis for the definition of multi-actorial requirements.

In MASAM, these relations are described with the constructs "position", "salience", "clout" and "influence". Given a certain *issue*, the preferred outcomes which, if realized, would best suit the actor's objectives, can be defined as the *position* of the relevant actor on the issues. The position indicates the direction towards which an actor is willing to exert influence over an issue. In this study the issue represents just the Need. In general, the $Position_{i,j}$ of Actor i on Need j is set along a continuum between two extreme values that can be normalized in the interval [-1, 1].
Moreover, relevant actors normally have to give priorities to their positions on each issue. This priority can be estimated as the degree of *salience*. Salience represents the relative importance of the realization of the favourable outcome with respect to the actor's overall objectives. The $Salience_{i,j}$ of actor i on issue j (i.e. the priorities of a need for different actors and the loss of utility when the design outcome is different from one's need) is set along a linear continuum between 0 and 1; a salience of 0 means that the actor has absolutely no interest in the need, whereas the value 1 represents the strongest salience of the need.
Hence, defined as J the set of issues (i.e. needs), J_i represents the set of the needs j typical of actor i (i.e. the native needs) and $\overline{J_i}$ the complementary set of needs j of actor i that are not native, but reported (Fig. 4).

$$J_i \subset J \quad J_i = native \tag{1}$$

$$\overline{J_i} \subset J \quad \overline{J_i} = reported \tag{2}$$

Consequently, is it possible to define:

$$position_{i,j} = pos_{i,j} \subset [-1; 1] \tag{3}$$

$$salience_{i,j} = sal_{i,j} \subset [0; 1] \tag{4}$$

Position and salience together can completely define the thought of actor i on need j. Actors that consider a certain need i as equally salient can have opposite position on them. Those will be the negotiation cases to be managed.

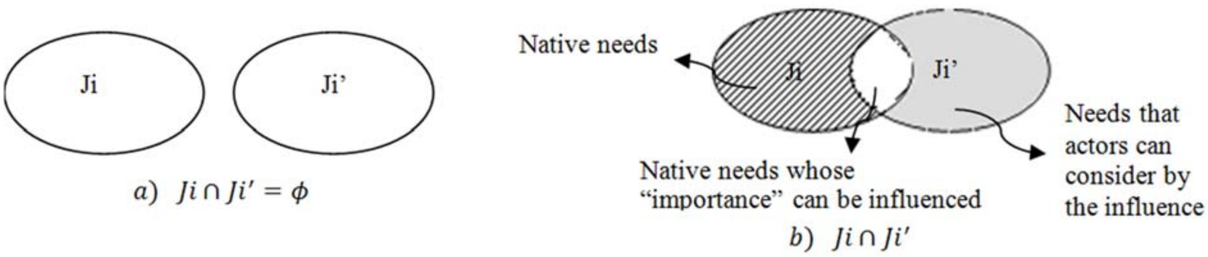

Figure 4. Set of influence on needs

Actors have the ability to influence other actors, affecting their thoughts and behaviour. This can be expressed into a percentage of $Influence_{i,i'}$ of actor i on actor i'. The influence can be exerted either through the importance attributed to native needs or through needs, originally not native, that after the influence become issues also for the actor i'. Moreover, some native needs can be common to more actors, or be related to each other (i.e. commonality or dependence), and consequently the influence can result in an increased or decreased importance associated by the actor i on his native issue j. These represent the intersection between the two set of needs, Ji and Ji'. This means, for instance, that if there exists a coincidence between the goals of actors i and i', satisfying the need of the actor i' is helpful to the satisfaction of the need of the actor i. On the other hand, a direct intended influence of the actor i on the actor i' can have as result that a native need of i becomes a need also for i'.
Taking into account all these elements, it is possible to move the focus from the native needs to the reported ones and to define, both in case a and in case b, the importance an actor i attributes to issue j, $Importance_{i,j}$:

a)

$$imp_{i,j} = \begin{cases} pos_{i,j} * sal_{i,j} & \forall j \in J_i \\ \sum\limits_{i' \neq i;\, \forall j \in J_{i'}} pos_{i,j} * sal_{i,j} * influence_{i',i} & i' \neq i;\ \forall j \in \bar{J}_i \end{cases}$$

b)

$$imp_{i,j} = \begin{cases} pos_{i,j} * sal_{i,j} & \forall j \in J_i - (J_i \cap J_{i'})\ \forall i' \neq i \\ \sum\limits_{i' \neq i;\, \forall j \in J_{i'}} pos_{i,j} * sal_{i,j} * influence_{i',i} & i' \neq i;\ \forall j \in \bar{J}_i \\ pos_{i,j} * sal_{i,j} + \sum\limits_{i' \neq i;\, \forall j \in Ji \cap Ji'} pos_{i,j} * sal_{i,j} * influence_{i',i} & i' \neq i;\ \forall j \in (J_i \cap J_{i'}) \end{cases}$$

MASAM also considers indirect influences among actors. In tackling the current application, we consider that introducing indirect influences would make the study pointlessly complicated and would not add enough value.

The next step is the analysis of each need for each stakeholder, evaluating the way with which each actor can influence native needs or give rise to reported needs. Figure 5 shows the table that can be used to this aim, representing the influence of native needs on reported needs, by distinguishing the actors they are related to: the first row and the first column list the native and the reported needs respectively, clustered by actors according to the classification depicted in Figure 2. The former are also associated to the salience the actor gives to the need. Each distinct matrix cell represents the single contribution, in term of influence, by which an actor passes from his initial set of native needs to his final set of reported ones.

- green cells represent the influence due to connections among needs (e.g. commonality, dependence, etc.)
- grey cells are related to direct intended influences between two actors (i.e. not native needs, that after the influence become considered issues);
- white cells constitute the self-influence of an actor on himself, thus assuming the value 1.

Reading the table by rows we obtain the $Importance_{i,j.}$ Considering the column of the reported needs, each reported need for all the actors is considered. It is important to highlight that conflicts among actors in their needs perform their effect firstly in the increased or decreased $Importance_{i,j.}$

So, the resulting matrix allows to define, per each actor involved, a set of native and reported needs that can be fed into corresponding actor-specific QFD matrices. It is important to remember that it would be misleading to try and "average out" this result into a single QFD matrix. This because, as previously mentioned, the innovation process is based on a number of phases that must "all" be complied with. Of course, it is likely that tradeoffs will emerge, since actors might have conflicting needs (e.g., cost for the buyer and ease of use for the user). The company developing the product would be wrong to make a product that satisfies the needs of one actor only, since the likely result would be a usable product that will never be purchased, or a purchased product that will never be used. Similarly, it would be a mistake to make a product that "costs a bit less and is a bit harder to use", since the likely result would be no sales and no usage at all. Instead, having formalized this conflict should either lead to more significant innovation in the product ("*we really must find a solution so that the product is cheaper AND easier to use*") or in the go-to-market strategy ("*how can we make the product easy to use AND make the buyer aware of the benefits*?", or "*how can we make the product cheap AND direct some of the benefits on the user so that he will not be against it*"?).

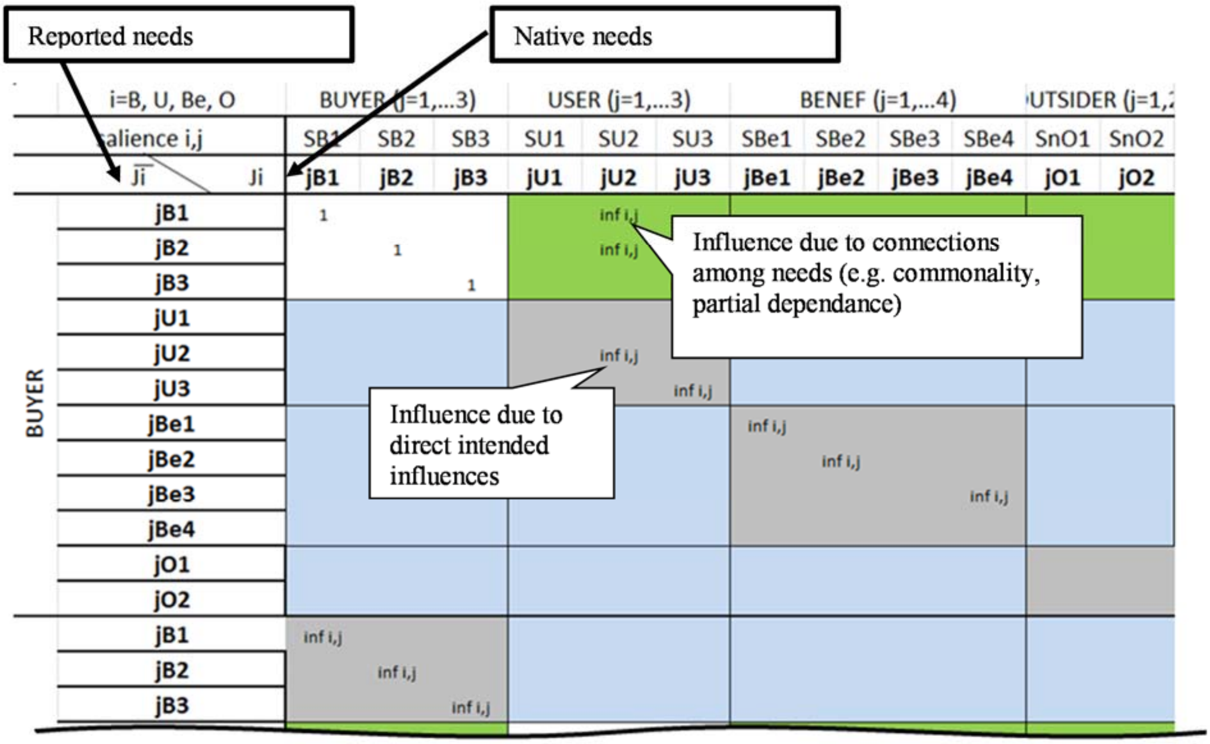

Figure 5. Influence analysis of needs

5. Exemplary influences of needs for a school drawing desk

Presenting a detailed case study with a complete representation of actors, needs and influences among them related to a given product or service would go beyond the scope of the paper, as well the space limitation. Besides, it is useful to introduce a simple example, as a clarification of the proposed classification of influences between needs.

The exemplary product here considered is a school drawing desk. A furniture company, willing to introduce some innovation in this field, should take into account the needs of the multiple actors connected to the life of the school drawing desk.

With reference to the above-mentioned classification, the following actors can be recognized:

- Purchase: school head or a school purchasing board;
- User: pupils;
- Direct Beneficiary: pupils (indirectly, further beneficiary appear, as parents will be interested about the posture of their kids at school);
- Use Externalities: school caretakers, cleaning personnel, teachers etc.

Each of these actors is characterized by a number of native needs, such as:

- School head: prestigious appearance, safety;
- Pupils: ergonomics, possibility to hide papers with suggestions and answers;
- School caretakers: ease of displacement, possibility to stack in a pile, reparability;
- Cleaning personnel: ease of displacement, ease of cleaning;
- Teachers: possibility to arrange the classroom with a different layout, possibility to use the desks for different kinds of activities, ease of monitoring students work.

Among these native needs, ease of displacement is a common need (green cells in Figure 5) for school caretakers and cleaning personnel, even if for complementary reasons and there might be a partial influence among their importance.

Moreover, some reported needs might appear: for instance, the school head might be influenced by teachers about the possibility to have desks supporting different configurations and by the school caretakers about their stackability (gray cells in Figure 5).

Some needs reflect conflicting goals of these actors, e.g. the ease of monitoring students work requested by the teachers, clearly goes against the pupils desire to hide tests solutions; besides, the latter is not expected to influence anyhow the buyer's decision.
However, some conflicts are worthy of being identified and properly mapped, because a design solution capable to overcome such conflicting needs would result in a valuable innovation. The proposed influence analysis allows mapping potentially conflicting needs, such as the possibility to use the desks for different kinds of activities (e.g. by changing the slope of the desk) having an inverse relationship with the desk safety (e.g. the mechanisms might be the cause of injuries during manoeuvres) and with the ease of cleaning (e.g. being some parts of the mechanism difficult to reach).
The assessment of those reciprocal influences is essential for further taking into account conflictual needs and for the identification of innovative design solutions. The application of the proposed MASAM-based analysis to the whole set of requirements and the related quantitative outcomes are here omitted because of their marginal contribution to the main theoretical purpose of this paper.
The authors are conscious that the proposed example just partially demonstrates the potential of the proposed approach; howerver the validation process to assess its practical usability, benefits and limitations is a long process, still taking place in more extensive industrial case studies.

6. Conclusions

The present paper aims at contributing to the growing scientific discussion about needs identification and requirements specification by introducing an explicit representation of product and service stakeholders, meant as all the actors who are involved in the product/service life from the purchasing phase to each stage of use and disposal.
While many scholars debate about the importance to consider the multi-faceted aspects of needs, as well some attempts exist to define design specifications with multi-stakeholders lists of requirements, there are still no models supporting a holistic representation of needs and their mutual relationships. Neglecting the impact of multi-actorial contexts and influence elements on Need identification and Requirement Definition, can actually kill the innovation process even in the case of products with good potential. On the contrary, mapping needs and formulating requirements with a robust and comprehensive approach can be essential for adoption and diffusion processes, being it related to a product or to a service, from mass production to made-to-order businesses.
While studying the extension of the situated FBS framework to the interactions with different "external worlds" (i.e. related to different stakeholders), the authors have here pointed out the necessity to properly map the reciprocal influences that those actors might have on each other. The essential motivation is to introduce, in a model usable by designers, the aspects that are relevant to making a new product or service something that effectively leads to innovation.
The paper proposes an approach, inspired by the MASAM model, for representing inter-actorial influences on needs. Besides, the influence matrix can be directly connected to a QFD analysis of needs and requirements as a means to properly rank product and service priorities, still taking into account the expectations of all the actors who will interact with it.
The proposed trivial example, related to a school drawing desk, clarifies such classification. The authors are aware that it just incompletely demonstrates the potential of the proposed approach; however, this paper should be considered as a first contribution to the development of a more comprehensive model for representing the complex issues which arise while defining the target of an innovative design task. As a first direction of development, the authors are validating the approach in industrial case studies to assess its practical usability, benefits and limitations. The idea is, on one hand, investigating the processes occurring in the Needs Identification phase while considering a multi-stakeholder perspective (Figure 3) in order to identify relevant patterns and peculiarities. Besides, on the other hand, it can be powerful to investigate the use of this matrix as a means to identify conflicts between actors needs to be leveraged as a hint to guide the generation of innovative solutions with higher probability of market success: in fact, a quantitative model allows defining the criteria to negotiate a compromise solutions, as well as to highlight the possibility to overcome the conflict itself with the introduction of a more radical innovation.

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