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AXIOMATIC DESIGN AS A CONSULTANCY TOOL IN PRODUCT DESIGN

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ABSTRACT

The practice of innovation and technological advising demands from consultancy companies the ability to propose consistent solutions to their customers' challenges. This paper explores the use of Axiomatic Design as a consultancy tool by Altran group, and how the unequivocal definition of optimal design given by the axioms constitutes a high-value for strategic decisions. More specifically, from the methodological research carried on in collaboration with the School of Aeronautics of Universidad Politécnica de Madrid, this work presents how Axiomatic Design has been used to advise Altran clients in innovation and improvement challenges, focusing on the lessons learnt by applying it to product design. Additionally, the discussion presents the main difficulties and benefits found on the aforementioned applications.

Keywords: Axiomatic Design, consultancy, decision making, product design.

1 INTRODUCTION

Practicing consultancy requires from advising firms not only the analytical description of customers' challenges, but the appropriate rationale that justifies the decision making. According to each consultancy scenario -strategic, operational, innovative, technological etc.- customers' challenges are formulated in specific terms that are natural to each of the aforementioned contexts, and that more adequately represent customers' challenge definition.

When speaking about strategic consultancy in the framework of technological problems, (this paper considers technological problems the ones in which the application of practical science to obtain a specific product is required) the comprehension of the physical laws governing the problem definition results critical, even when the challenge drive is to answer to strategic considerations, for instance, the design and development of a new product. In technological environments (field where Altran Consulting Group is focused on), according to the authors' opinion, the strategic management analysis should not be decoupled and separately understood from the technical analysis: strategic, technical and users' insights should be considered in the challenge definition.

When combining technological and strategic advising, most of the activities are oriented to respond to one of the main concerns of companies: "how can we gain competitive advantage?" Although innovation is used as a common answer to it, the real challenge surfaces when the world of innovation has to be translated and implemented into the operational world. Unfortunately, very often both worlds are developed separately in many companies. As a consequence, when companies try to bring to their operational world some of the disruptive ideas that are generated thanks to the efforts put into creative activities, they realize that the constraints and own rules of operations severely condition or even avoid such implementation.

Furthermore, the word innovation is sometimes misunderstood and applied to any activity pertaining to engineering or to the high tech domain, independently from the nature of the activity. Consequently, many of the so-called innovation activities do not have any innovative motivation, but they correspond to general engineering developments.

As depicted by the iterative process presented by Suh [Suh, 1990], Figure 1 shows how analysis is used as a guarantee to achieve a valid solution to the design problem. As it is exposed, to gain competitive advantage in such step of the design process is difficult. Indeed, the more the number of iterations required to achieve a valid solution, the less the possibility to synthetize disruptive ideas to revolutionary products. When the efforts are put exclusively in analysis, the design problems become optimization problems rather than innovation ones.

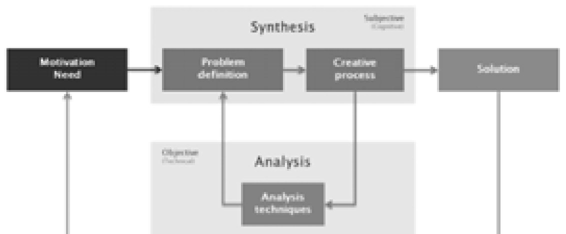

Figure 1 The design process as a feedback system, based on Suh [Suh, 1990].

In such context, the innovation success passes through the ability to synthesize and analytically select only the good ideas during the preliminary stages of design [Suh, 1990]. However, one of the most common misunderstandings in the industry is that analytical techniques should be used to validate products, prototypes etc., but for validating neither ideas nor concepts. In addition, in most companies, the following question surfaces: how to promote innovation by diminishing the technological risk? If the key milestones to achieve disruptive innovation and to gain competitive advantage are the preliminary synthesis steps of design, where the product is still not defined… how can we analyze the idea rather that the product? At this point the selection of a design process that adequately merges different technological approaches results critical [Benavides, 2012].

In this sense, the ideas in this paper were born due to the Axiomatic Design theory. The methodology used in the practical cases solved by the company is based on Suh's Axiomatic Design [Suh 1990 and Suh 2001], and has been adapted to Altran's particular context through the experience and through the collaboration with the School of Aeronautics (ETSIA) at the Universidad Politécnica de Madrid (UPM), where it was studied how to convert the Axiomatic Design framework into a systematic procedure that could be implemented with other design theories in technological advising. In any case, the experience gained by Altran answering to these questions will be presented trying to keep as much as possible the perspective of the use of Axiomatic Design in different fields of application. Additionally, it will be presented how the definition of a theoretical optimum design helps clients to position their products in front of their competitors, while understanding the inner constraints or requirements that condition the achievement of the optimal design.

This paper is structured as follows: in the next section a justification of why Axiomatic Design was considered by Altran the optimal tool to answer to the aforementioned questions is presented. Further, a set of lessons learnt in product design will be exposed. Finally, important ideas and difficulties are discussed, previous to collect the main conclusions.

2 THE CHOICE FOR AXIOMATIC DESIGN

The early stages of design (particularly in innovation problems) are generally characterized by a lack of precise information. Key questions have to be answered in these phases: What are the main needs that should condition the first levels of the design hierarchy? What are going to be the main critical points of the solution? Which one is the best solution to the design problem? How costs can be surfaced from the very early decisions? How can the same methodological approach guide the whole product lifecycle? Figure 2 collects some of the questions around the product definition during the preliminary design.

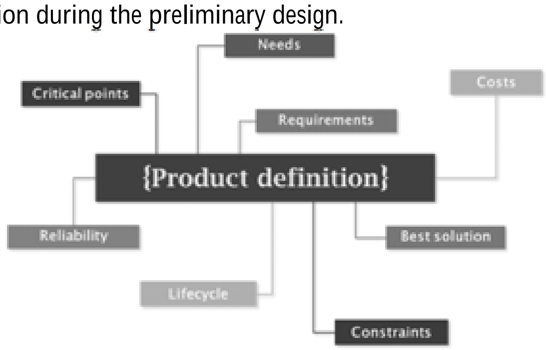

Figure 2 Context in the early stages of design.

Generally, the relations between FRs, DPs and constraints that achieve the optimal design are answered thanks to analytical tools. Nonetheless, as Figure 3 illustrates, even if the number of available tools and the knowledge about design increases, the impact of the design decisions taken during the analysis, prototyping or redesign phase is significantly restricted by the design decisions that have been adopted during the conceptual phase. According to Suh mapping and zigzagging processes [Suh, 1990] "what used to be design parameters at a higher level of the design parameter hierarchy may become constraints at a lower level of the design parameter hierarchy", the number of degrees of freedom decreases as the design process advances. Actually, the main decisions affecting cost and freedom to achieve disruptive products have been already taken during the early stages: analysis, by itself, may not guarantee innovation. For that reason, one of the most challenging questions for engineers is to get a rationale that justifies the "physical" design decisions while the amount of quantitative information is still marginal.

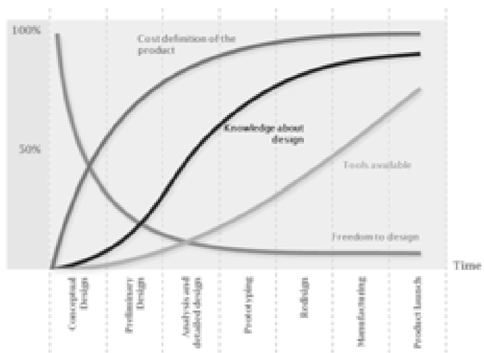

Figure 3 Trends in the design process

In this context, Axiomatic Design is extremely valuable because it permits to establish the optimal relations between FRs, DPs and constraints, even if the amount of available information is still vague or not precisely defined.

As a consultancy tool, it is very important to notice that one of the most important steps of Suh's methodology [Suh, 1990] is the appropriate definition of the design problem. Once the design problem has been appropriately stated, Axiomatic Design identifies the best design solution to the challenge.

Thanks to the establishment of design hierarchy levels throughout zigzagging in four domains (Customer, Functional, Physical and Process), [Suh, 1990, 2001], Axiomatic Design gives understanding of the whole conceptual product lifecycle until the product is ready to be launched (including brand positioning and value proposal). One of the key assets in this aspect is that Axiomatic Design establishes a common vocabulary for the four design domains. This represents a key point that tremendously facilitates concurrent engineering which in general is difficult to accomplish when the collaboration between different departments is strongly conditioned by different decision making criteria and design principles. Furthermore, the formulation of the design problem and of the characteristic intervals for FRs, DPs and PVs from a multi-domain perspective permits to guide the whole design process, and to establish the main relations that are critical to understand the customer challenge from a global perspective [for further information on the implementation of acceptance interval in Axiomatic Design, please, refer to Benavides, 2012]. Actually, the knowledge of these relations, even if the design process turns over a detailed optimization where Axiomatic Design may not be applied, is crucial to orientate it and to support understanding of some results that cannot be understood only from a detailed perspective. The zigzagging combined with mapping process achieves simultaneously the functional and the physical design, which is one of the key points to understand the solutions to the customer challenge.

Another main reason for choosing Axiomatic Design is that the unique and unambiguous definition of the best design (thanks to the two axioms) complements other methodologies. Indeed, even if the design process is not strictly guided by the mapping or zigzagging processes but by other methodologies such as functional analysis, Lean, TRIZ, Model Based System Engineering, Pugh Total Design, Decision Multi-criteria Matrices, reliability-based design, etc., the axioms constitute an excellent tool to validate the design decisions that are taking throughout the process, indicating if the configurations achieved with the use of any other design methodologies violate the axioms, and consequently, generate poor designs.

Table 1 collects some of the Axiomatic Design characteristics and relates them to main value drivers that a consultant company takes into account.

Table 1 Decalogue Axiomatic Design - Value

AXIOMATIC DESIGN	VALUE
Universal methodology	Multi-sectorial applicability
Design over the need	Sustainability
Robust Design	Quality
High standard theory	Talent
Product and manufacturing design	Concurrent engineering: counselling in all the design steps
Relatively new theory	Innovation leadership
Unambiguous definition of best design	Complement for other methodologies
The best solution is described because of the relations between FRs, DPs and constraints	Robust methodology for gaining competitive advantage from the very early stages of the design process[1]
Identifies the best solution in the conceptual design	Competitive advantage from the early stages
Permits innovation, and improvement	Widespread approach
Optimizes the design process FRs – DPs	Efficiency added to efficacy: development
identifying critical points	costs reduction

[1] Nakao [Nakao, 2011] reviews how appropriate strategies in the selection of FRs and DPs definition guides to superb products.

3 LESSONS LEARNT IN PRODUCT DESIGN

The following section depicts some of the lessons learnt when applying Axiomatic Design as a consultancy tool in the field of product design. It is divided into three subsections compiling the experiences gained in the analysis and improvement of existing products and in the development of new ones. Each subsection will treat some methodological aspects, some of the main difficulties found, and finally, some of the main benefits obtained.

3.1 IMPROVEMENT OF AN EXISTING PRODUCT

From the methodological perspective, Suh [Suh 1990, and Suh 2001] presents how the same methodological approach can be used for the analysis of existing products and for the development of new ones. In the first case, the design equation is built from the description of the existing product by means of the relations between FRs and DPs; whereas in the second case, the design equation is built thanks to the creative process that identifies the appropriate DPs that satisfy the minimum set of FRs. In this sense, the translation of the functions of the product in terms of FRs is not the consequence of the creative process mapping from the Customer Domain into the Functional Domain. In general, as a first approach, the first set of functions and solutions to them are established by the product owner who depicts the different functions and constraints, while describing the physical parts satisfying them. From the rigorous perspective of the theory, this design equation may not be axiomatic, and this is one of the key aspects to begin the improvement.

Unfortunately the reformulation of the design problem is very often forgotten. However, its reformulation with rigor can conduct to extremely valuable improvements. Some of the following questions can be useful for the practitioner in order to reformulate the design problem and identify potential improvements:

- Is the design challenge unambiguously stated and the existing solution an adequate answer to it?
- Is the set of functionalities given by the client minimum and independent?
- Are the system and input constraints clearly identified as separate entities than FRs?
- Are acceptance intervals for FRs and variation intervals for DPs clearly stated?
- Can the set of functionalities be reformulated into design levels with a clear correspondence to the physical domain?
- Even if a FR seems unnecessary… which is its importance related to the final client satisfaction?

In general, the value proportioned to the final solution coming exclusively from the reformulation of the design problem is tremendous and in general unexpected from the client. Although it seems a minor activity, it may suggest deep changes in the way that customers face their challenges. A methodological approach can be found in [Rodriguez, 2013].

Once the design problem is reformulated from the Axiomatic Design perspective (i.e. the problem definition is clearly stated), the set of FRs is independent, hierarchical and minimum in each design level, the acceptance and variation intervals are well identified and the constraints formulated. Starting at this point, the procedure turns into the study of the design equation [Suh, 1990] by means of the compliance with the two axioms. Once the design problem is properly reformulated and the design equation written, the elimination of off-diagonal dependencies and the minimization of the information content will detect the potential list of improvements [Suh, 1990 and Suh 2001].

3.1.1 MAJOR DIFFICULTIES

Further are presented some of the major difficulties that have been found in the analysis of existent solutions:

To identify the real design challenge: even if it appears as a simple task, to identify the real design challenge requires in general some iterations with the product owner. In the analysis of existing products, two challenges have to be considered. The first one corresponds to define the main customer's need to which the product answers. The second one describes the kind of improvement the design problem has to face, and consequently, establishes the framework that delimitates the degrees of freedom for the improvement analysis.

Number of FRs: very often, because the product is already existent and defined in detail, the number of functionalities given by the product owner is high. This aspect makes considerably difficult the initial steps of the analysis. In one hand the solution may be perfectly described. On the other hand, most of the functional requirements pertain to low levels of the design hierarchy, and very often, they are not the most relevant for the conceptual improvement of the existing solution.

Hierarchy levels: if the product owner has not clearly established design levels during the design of the product, grasping the functional requirements into design hierarchies may result into a difficult task. This is particularly critical because, according to Axiomatic Design, the next level of the hierarchy level cannot be defined until the DPs of the previous level have been defined [Suh, 1990], which behave as constraints to the next level. Depending on the number of FRs and DPs, the obtaining of the hierarchy levels for an existing solution may result difficult. It is important to notice, that as design decisions behave as restrictions to the next design levels, dependencies pertaining to the first levels of hierarchies are the most critical and in general, the root of the main deficiencies of the product. So the ability to identify the minimum set of FRs of the first design levels in existing products is crucial to succeed in their improvement.

Make FRs independent: when the solution exists and the FRs have not been defined by the designer as the minimum set of independent functions per design level, to find the minimum number of independent FRs can surface the existence of inadequate or "useless" FRs. This assumption can imply a completely new perspective on the product, which in a redesign for improvement may not be possible.

Client reaction to very simple but straightforward questions: when technological counselling, very simple questions may require the answer from the most experienced engineer. Asking about which are the dependencies between the different DPs and FRs, and their weight as terms of the design matrix, is very often a question that the customer has not thought about. The counsellor applying Axiomatic Design must understand that this question, even if for him is simple, requires a deep understanding of the product analysed, and commonly, not only from the technical perspective but from the strategic one too. Additionally, the consultant must be aware of the fact that this way of thinking could be completely new for the customer and not necessary easy for him.

Identification of the laws of physics: in many design problems, the transfer function (as a generalization of the design equation [Benavides, 2012]) is obtained from the formulation of the laws of physics. However, very often the aforementioned laws are not fully known by the designer (they are based on experience; can be implemented in a simulation software that uses them implicitly; some products imitate proved existing solutions, etc.). Because of the effort and resources consumed in analytical tools and optimization, this is not always critical. Nonetheless, from the Axiomatic Design perspective, the knowledge of these laws may result in the knowledge of the available DPs and their importance.

To give an appropriate consideration to the constraints: constraints are not always properly formulated (misunderstood as FRs, of less importance, lately introduced in the conceptual process, incomplete…). When analysing an existing solution, the constraints to the design problem are difficult to detect, particularly, when the analysis is done much later that the design was done. The constraints study is critical not only from the design problem formulation, but also to understand the potential margin of improvement the solution has. Very often, acceptance and variation intervals, DPs and FRs are frozen because of constraints that cannot be removed even if they are conditioning the achievement of the optimal design. Benavides [2012] gives a practical definition of constraints and the way of differentiating them from FRs.

3.1.2 MAIN BENEFITS

Some of the main benefits obtained are:

Drastic reduction of the time required for product redesign: thanks to the reformulation of the design problem and the analysis of the compliance of the two axioms, the potential improvements are immediately identified without the consumption of a huge amount of iterative analytical tools or models.

Justification of the key improvements detected: Axiomatic Design adds not only efficiency in the identification of critical points. Moreover, based on its rationale, it permits a clear justification of the decisions that have to be taken, which is absolutely necessary in a technological advising context.

Understanding of the main constraints that limit the improvement: in many cases, some constraints cannot be easily eliminated (for example, constraints coming from strategic positioning of a corporation, contract with providers…). In this context, it is critical to identify them in order to comprehend why a certain improvement cannot be adopted.

Easier understanding of Information Axiom: Information content is in general difficult to calculate. Very often, the quantitative formulation of Axiom 2 makes difficult its application during qualitative solving, particularly, when the available information is still vague. However, in improvement design, Axiom 2 is easier understood as “maximize the probability of success of satisfying a FR” [Suh, 1990] because the functionality of the solution can be check-out. Indeed, during improvement analysis design teams immediately perceive how complex design decisions decrease the probability of success.

Deeper knowledge on the solution: it is astonishing how product owners increase their knowledge on their products after applying Axiomatic Design in a redesign process. Suddenly, a huge amount of relations between functions, constraints and design parameters are surfaced and justified, and the product is understood from a global perspective. In this context they are able to take better decisions through the whole life cycle of the product.

Positive impact in the four domains: even if the improvement analysis is carried out only on two domains, for instance between FRs and DPs, the obligatory mapping process surfaces important relations between CNs and PVs, particularly, when the redefinition of the acceptance and variation intervals of FRs and DPs.

A valuable complement to other methodologies: here it is important to notice that the nature of the information given by Axiomatic Design is substantially different to the one furnished for example by optimization. Whereas numerical analysis or multipurpose optimizations give accurate results for defined variables, Axiomatic Design gives understanding of the relations between the main variables of the design problem. Consequently, it introduces a criterion to properly define the detailed analytical problem, once the best improvements have been selected: with the use of Axiomatic Design, the number of tentative improvements diminishes.

3.2 NEW PRODUCT DEVELOPMENT

Methodologically **speaking**, Suh [Suh 1990 and Suh 2001] establishes the basic steps to conduct the design process through the four domains. One of the main and most important differences with the situation described in improvement design is that in the development of new products, the designer defines the set of FRs when mapping from the Customer Domain. His creativity is not only put in the search of design solutions, but it is first of all oriented to fully understand the Voice of Customer and to properly formulate the design problem. The definition of the design challenge is again critical and very often requires several iterations with the design team. An adequate challenge definition should deeply contain the main user insights detected during the exploration of the Customer Domain, and consequently, must orientate the design effort to the satisfaction of the main expectations of the product customers without containing any preconceived solution. Once the challenge definition is properly settled, the translation of CNs into FRs and constraints for the first level of hierarchy can be easily achieved. Once the set of minimal independent FRs and constraints are settled, and the acceptance intervals defined, the designer has to identify the most accurate DPs that satisfy the set of FRs. According to the nature of the design problem, the DPs can derive from various fields, for instance, from the laws of physics if the transfer function is known, or from the best practices in the context of Lean and operational excellence context etc. Once the list of DPs is surfaced, the most appropriate in terms of compliance with the two axioms have to be selected. Suh [Suh, 1990] and Benavides [Benavides, 2012] expose techniques to properly select the DPs.

The following sentences may help the practitioner to succeed in this step:

- Is the definition of the design challenge implicitly defining a preconceived solution?
- In order to find the first level of the design hierarchy… which of the CNs is essential to answer to the design challenge?
- From all the CNs detected, which of them reveal the same concept?
- Several needs can be translated into a single function with an appropriate acceptance interval?
- Some of the constraints identified can be included into a FR in terms of its acceptance interval?
- Which of the CNs is essential for the functionality of the product and which pertain to aesthetics or other perceptive attributes?
- Once the essential CNs are detected… which is the minimum set of FRs satisfying them?
- From the set of DPs identified… which of them make the design problem more linear?
- Some of the constraints identified can be included into a DP in terms of its variation interval?

3.2.1 MAJOR DIFFICULTIES

Some of the main difficulties found in applying Axiomatic Design to the obtaining of new products are listed below:

Communicate the importance of the challenge definition: the critical nature of this step (as exposed in the improvement design) is not always well understood. However it is essential, even more, in innovative challenges. From the authors' experience, it is worth to iterate with the design teams until a real innovation challenge is formulated, even if they consider it useless in the beginning. Otherwise, the whole design process can turned into the description of a preconceived or existing solution.

Give importance to acceptance and variation intervals: as Axiomatic Design is very often used from a qualitative point of view, the design intervals are frequently forgotten. However, their definition is crucial to trace throughout the domains of the design process how the FRs and DPs must vary in order to satisfy CNs and FRs respectively. (Acceptance and variation intervals are implicitly involved in the Second Axiom by Suh [1990, 2001]; and they are explicitly included in the First Axiom by Benavides [2012]). The definition of those intervals can elucidate the probability to succeed in the optimal solution to the design challenge.

Give importance to constraints and differentiate them from FRs: the basic product specifications not always distinguish between requirements and constraints. Consequently, it is important to communicate to the design team how, from Axiomatic Design perspective, constraints do not have the same value as FRs, and hence, how to differentiate both concepts.

Difficulty to understand Information Axiom as a guide for designing: most commonly, Axiom 1 is well understood by design teams as a design guideline to encompass the creative process in the ideation of new products. However, Axiom 2 it is not. As presented by Suh [Suh, 1990], Axiom 2 permits to select between two uncoupled designs. However, very often the information required to be able to apply it is available during the early stages of design, nor the distribution of the probability function associated to the different FRs. Additionally, design teams are not always familiar with the appropriate definition of system range and design range [Suh, 1990]. In this context, it is important to incorporate qualitative conclusions derived from the Information Axiom that can accompany the creative design process, as physical integration, wide tolerances or the use of symmetries [Suh, 1990 and 2001] and Benavides [Benavides, 2012].

New concept of FRs: in Axiomatic Design the rigor in the definition of FRs is critical to succeed in the whole design process. Thomson [Thomson, 2013] collects some of the major errors in the definition of FRs. From the counselling perspective, the design process should not go on until the whole design team has interiorized the concepts of direct independency between FRs [Benavides, 2012] and neutral solution environment [Suh, 1990]. The rigor and the importance of it is not always easy to communicate, particularly, when the design team has to reformulate the basic specifications of the design product, and moreover, change the way they have been approaching requirements definition.

Zigzag mapping: in Axiomatic Design the appropriate definition of each design level is critical because it contains the minimum set of FRs and DPs that freeze a conceptual solution in each step of the design process. Consequently, the design team has to simultaneously do the functional design and the architectural design. One cannot be understood without the other, and the design axioms could not be applied. This way of proceeding is very often new for the design teams; not necessarily the mapping and the search for a solution to each function (QFD already presented it), but the rigor needed to properly apply Axiomatic Design and obtain the maximum benefit of it.

Applying it to systems engineering: a typical characteristic of system engineering is the amount of FRs it deals with. Although the use of Axiomatic Design in this context is presented and systematized by Suh [Suh, 2001], according to the authors' experience its application still remains difficult from the practical perspective. In one hand, traditionally in systems engineering all the requirements are first postulated, and subsequently, the architecture is built up. On the other hand, the application of the Independence Axiom requires the set of requirements were related to the systems' architecture. Consequently, in order to apply Axiomatic Design in this context, systems engineers must deeply change their ways of designing. First of all, defining exclusively functions in a neutral environment which means to formulate requirements with a design perspective and not only from a validation and verification point of view. Later, selecting the minimum number of FRs per design level and identify the adequate modules of the architecture. Therefore, even if the use of Axiomatic Design in systems engineering adds value and keeps complexity at minimum levels [Lu, 2009], its practical application requires a deep transformation in the way engineers design systems, which is not always achievable or desired.

3.2.2 MAIN BENEFITS

As a continuation of the difficulties encountered, some of the most relevant benefits of the application of Axiomatic Design to the design of new products are described:

Functional and physical designs are achieved simultaneously: although it is an imperative from the methodological perspective, it constitutes an extremely valuable approach for the design of new products. Because the set of FRs cannot be defined until the previous level of DPs is frozen, the number of useless FRs is minimum. Consequently, the complexity generated by a big amount of FRs can be controlled and maintained at its minimum level. Moreover, this way of guiding the obtaining of the final solution, permits to clearly trace the set of CNs, FRs, constraints and DPs throughout the whole process. This aspect is of a high importance when changes have to be done and demand going back to higher levels of the design hierarchy.

Trade-offs are minimized: selecting the best design configuration with the use of the design axioms minimizes the use of pondered matrices and other subjective techniques. Once the design problem is conveniently formulated, the design principles unequivocally identify the best solution. Trade-offs between pros and cons are not necessary (or marginal), and consequently, the number of subjective and not rationalized design decisions is minimal.

Strategic and technical positioning: from the strategic point of view, the design axioms identify the best solution to a particular design problem. As the context may be similar for different competitors, Axiomatic Design points the optimal solution. Consequently, when solving any design challenge in a competitive environment, the theory permits to identify how far are competitors from the optimal solution, how far is the proposed solution from that optimal, and in case the optimal could not be reached, which are the main restrictions that impede its consecution. Axiomatic products are strategically better positioned because technically speaking they approach the best conceptual solution.

Identification of technological limits and strategic R&D lines: because Axiomatic Design identifies the most critical dependencies, it naturally identifies which are the technological limits of the conceived solutions. To surpass these limits, strategic R&D lines have to be defined. The solving of a critical dependency or of a technological limit results in gaining competitive advantage.

A common vocabulary for concurrent engineering: one of the main difficulties to implement concurrent engineering in corporations is the lack of a common semantic that facilitates the communication between the multidisciplinary design teams. Axiomatic Design principles establish a common vocabulary and common criteria that are valid for all the domains of the design process. To have an unambiguous definition of the best design with a common vocabulary is a key milestone to be able to implement concurrent or multidisciplinary engineering.

Achievement of innovation with minimum technological risk: the systematic use of the design axioms conceptually validates the potential design solutions. The compliance with the design principles from the very early stages of the design process facilitates the selection of the best ideas in each level of the design hierarchy. Solutions are consequently validated before investing resources in their development, and innovation is guaranteed minimizing the technological risk generated by the development of inadequate designs.

A natural complement for other methodologies: as it has been stated in improvement design, the axiomatic design principles are a natural complement to other design methodologies or industry practices. In the context of new product development, it is particularly interesting the combination of Axiomatic Design with theories dealing with the product value proposition. For instance Suh [Suh, 1990] explains the combination with QFD as an excellent tool to translate CNs into FRs and consequently, identifying the critical functionalities of the product in order to maximize customers satisfaction. Another interesting combination is the use of Axiomatic Design for enriching classical benchmarking. In such cases, the design principles permit to plainly identify the reasons that make the different industry actors be more competitive from a conceptual design perspective. Identifying these reasons is of high value for defining corporate strategies. Related to benchmarking, it has to be noticed how powerful is the synergy between Axiomatic Design and business model generators, such as Business Model Canvas [Osterwalder, 2010]. In this context, Axiomatic Design helps to define and explain the value proposition of products, the reasons of their competitive advantage, and moreover, the relation with customer needs. Finally, it is important to comment an additional connection with methodologies oriented to motivate creativity, such as Synectics. In general, these methodologies are excellent to potentiate inventive and to generate disruptive innovations. However, they define a role in the creative process (sometimes called the owner of the design challenge) who selects among all the ideas generated the ones he or she considers the best to solve the challenge. Combining Axiomatic Design with creative methodologies results in an excellent design tool for synthetizing and selecting the best disruptive innovations.

4 CONLCUSIONS

In this article, a basic review of the lessons learnt applying Axiomatic Design as a consultancy tool has been presented. First of all, it has been justified why Axiomatic Design constitutes an excellent methodology for technological advising. Afterwards, some of the key points that surface when facing improvement and innovative designs were presented. As a result, Axiomatic Design, thanks to the unequivocal definition of the best design according to Suh principles, permits to select exclusively the best design configurations for the early stages of design. Furthermore, it justifies the decision making, it simultaneously achieves strategic and technological product placement, it permits to face different challenges with a single methodology, it facilitates multidisciplinary engineering while incorporating a common vocabulary, it promotes innovations with the minimal technological risk, and it surfaces the critical points that may reduce the value of the conceived or improved solutions.

As a result, Axiomatic Design as postulated by Suh is an optimal tool for counselling, in order to gain competitive advantage from the very early stages of product definition or improvement.

5 REFERENCES

[1] Benavides E.M., *Advanced Engineering Design: An integrated Approach*, Cambridge Woodhead publishing, 2012. ISBN 0-85709-093-3

[2] Lu S.C.Y, Suh N.P *Complexity in design of technical systems* CIRP Annals - Manufacturing Technology (157-160), 2009

[3] Nakao M., Nakagawa S., *A superb industrial design has special FRs or DPs that go beyond the customer's imagination,* Proceedings 6th International Conference on Axiomatic Design, ICAD 2011, Daejon, March 30-31, 2011

[4] Osterwalder A. Pigneur Y.: *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers.* Wiley, 2010. ISBN 0-81-2653367-6

[5] Rodriguez J.B, Benavides E.M, *The vacuum cleaner as a case study for teaching conceptual design,* Proceedings 7th International Conference on Axiomatic Design, ICAD 2013, Worcester, June 27-28, 2013

[6] Suh N. P., *Axiomatic Design: Advances and Applications*, New York: Oxford University Press, 2001. ISBN 0-19-513466-7

[7] Suh N.P., *The Principles of Design*, New York: Oxford University Press, 1990. ISBN 0-19-504345-6

[8] Thomson, M.K, *A classification of procedural errors in the definition of functional requirements in axiomatic design theory*. Proceedings 7th International Conference on Axiomatic Design, ICAD 2013, Worcester, June 27-28, 2013