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Smart object design:

Objectomy, a new design approach analysis

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Abstract

The word “design”, it is both a noun and a verb and it can refer either to the product or to the process. In this paper, design represents a process, part of the wider development process, that allows the designer achieve design solution(s) of a problem. Designing smart objects is a particularly challenging and complex process because they encompass the physical and digital worlds. Designers can rely on design approaches, methods, technique, tools to leads their works, but in the specific case of smart object, except for some attempts, the literature does not show an extensive spectrum of options.

This document starts from this premises and, through an extensive literature review, aims at creating the fundamentals for an analysis of current design methods. The result is framework is structured by the identification of three macro-activity of and a selection of design variables involved in the design process. The intersection between design methods analyzed through the literature review and the variables taken into consideration shows the potential uses of each design methods in navigating the design process. This framework is as such implemented with the analysis of the most relevant design methods involved in the design of smart object. The framework represents a relatively simple tool for analyzing different design approaches and highlights potentiality and limitations in supporting the various design macro-activities.

The second part of the paper, is dedicated to a new design method, specifically created to deal with the design of smart objects, called “Objectomy”. Objectomy is derived from the Chris Bangle design philosophy, and it consists in projecting yourself to the mind of the object, to understand its essence and meaning. The approach is defined and described in its principles and working process. Finally, Objectomy is inserted within the framework created in the first part

of the paper, to make a systematic analysis of the approach, and comparing it with the already-existing design methods. Furthermore, the documents shown in two real case of application of Objectomy, how this new way of thinking can lead the designer to questioning the design problem and to discover unexpected design solution.

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Life is 20% what happens to you and 80% how you react to it

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Introduction

The problem

Today, designer job is a challenging activity, but to be a "good" designer is playing a different game. More specifically, designers that must deal with the world of digital artefacts, that enable innovative service, they have to deal with complex processes, in which the degree of complexity increases day-by-day. Technology evolves faster than that the learning process on how to use it, and designing an object, service, or system of either of them requires a holistic approach. To this end, it is fundamental to use tools and technique that allow to deal with that complexity, i.e., design methods (approaches).

From the '70s, the world is becoming more and more digitalized, digital artefacts are permeating our life, and enormous amount of data are collected every day. All these aspects lead to the establishment of the *data-driven design paradigm* (Cantamessa, 2020). This "digital" transformation has consequences in the world and consequentially the design is being impacted as well. In the last year, many studies have proposed alternative approaches to support digital artefact design, but they rarely focus on smart objects, therefore, the analysis is usually limited to a "rearrangement" of existing methods and tools used for digital services or for designing non-smart artefacts.

Beyond that, a new approach, based on Chris Bangle's design philosophy, analyses the meaning of object and the relationship created with the human. The approach is called "Objectomy", and it has been used in the conceptual phase of innovative projects, to help the designer in identify himself with the object. For these products, that are interactive for their intrinsic nature, the design is a complex process that requires new guidelines, practices and tools, suited to match the dynamism of the context in which they will be used. The premises behind Objectomy seems to be sufficiently consistent for an analytic study as design approach, that can help in innovative project about smart object, from problem analysis, to generate new idea and defining the system's architecture.

The aim of this work

The aim of this paper is to create a framework to systematically analyse a collection of methods used in the design process, in relation with design variables, in order to highlight which are the actual limitations of the methodologies in supporting the design process of smart objects.

The same framework has been used to study the new design approach, Objectomy. This analysis aims at being a conceptual comparison of current design methods, commonly used in the industry and Objectomy approach. This part of the work wants to represent the starting point of a new approach to design, as a theorical base for future research, and providing new guidelines in the design of smart object.

The methodology

The paper is mainly based on literature review. One section of the research works has been dedicated to collect information about smart objects, that helped to come up with a definition and a classification of the capabilities, that distinguish them from non-smart objects. Another sections has focused on the design process, and the identifications of the main activities that allow to achieve a solution proposal of a design problem and on define the variables which the design thinking deals with during the process. Then, the main part of literature review has been dedicated at identifying relevant design methods, that have been selected by influential text about Design Science and Design Methods. Consequentially, design methods have been classified according to design activities they support, and the relationships between design methods and variables is analysed.

The rest of the time has been spent analysing Objectomy approach. During the research, the various interviews and discussions with Chris Bangle have been important, to gathering the design philosophy in order to define design principles and practices of Objectomy. Once Objectomy approach has been defined, it has been put in relation with the framework created, in order to understand its positioning in regards to other design approaches.

In the end, two examples have been selected and studied in order to underline Objectomy approach's application in real use cases, in order to identify its potentiality and limitations.

Structure of the document

The paper is made of four chapters, excluding the introduction and conclusion.

The first chapter focuses on the contextualization of the main problem and the introduction of the two main concepts on which the paper is built on: the notion of design method and the concept of smart object. The chapter opens with the presentation of the problem and its origin in the digitalization. It continues with the definition of smart object and its characteristics, and it ends with on introduction on design methodology, through the definition of design process and related activities and variables.

The second chapter is dedicated to the literature review, and it composed of three parts. The first part concerns the smart object definition and starting from the concept of digital artefact. The second part focuses on a collection of design methods, available in academic literature review, classified according to the design activity each one of them supports. Finally, the third part analyses each design methods in relation with set of design variables, that are common in most design processes of smart object.

The third chapter introduces a new design approach, called Objectomy. Starting from the description of the CBA Design Philosophy, on which Objectomy is based on, to arrive to define the approaches characteristic. Then, in analogy with other design approaches previously considered, Objectomy is analysed in relation with the preselected design variables and activities.

The fourth chapter contains two design projects (the kitchen of the future, megacity vehicle concept), in which Objectomy was used as different approach to design problem. The two examples are here analysed as case study, to evaluate the contribution of Objectomy as an alternative and complementary support to design of new smart object.

The conclusion summarizes the salient aspects of the work. In the end, it provides the useful based for further research on design methods to support smart object design.

The fourth chapter is focused on Objectomy approach application on a project conducted in Chris Bangle Associates, in order to highlight the peculiarities and the potentiality of this new approach to a real design problem.

1. Design Methodology and Smart Object

1.1 Problem contextualization

During the last years, digitalization drove the transformation or substitution of many analogue artefacts into digital artefacts. According to Oxford dictionary, Digitalization is: "The process of changing data into a digital form that can be easily read and processed by a computer" (Oxford Dictionary, 2021). This change is enabled by digital technologies, and it has consequences not only on designers, both at individual level and as part of the team, but it has also implications on the development process. (Cantamessa, 2020). As obvious consequence, design process has been affected as well, leading to an adaptation of the current, and implementation of new, design methods.

Despite the methods implemented in designing digital artefacts, some of them appear very useful and desirable at a first look, but then limitations and counter-intuitive aspects jump to the eye of the users during the functioning. Meanwhile others, even though they look less functional on paper, manage to create a "smooth" and "natural" interaction between the user and the object, so that, in the end, they allow to better satisfy the user's needs, and more then often surprise the user with unexpected features.

For the scope of this paper, the term designer refers to both industrial designer and engineering designer. Considering all the previous premises, designers must deal with many common challenges (W.S. Green, 1999):

1) **The technology-driven approach and the management of a multidisciplinary process**. Most design approaches claim to be based on a user-

centred philosophy, but many times a machine-centred design is put in place instead. This is probably emphasized by a difference in knowledge between the participants to the product development who are technically oriented, and non-technical users. Designers have the tendency to implement more and more functions, rather than to think about a more natural relationship between the user and the object. As Donald A. Norman states "Sloppy thinking about the concepts and tactics often leads to sloppiness in design. And sloppiness in design translates into confusion for users" (D. Norman, 1998). The feature creep is a natural tendency of designers and these over-stimuli given to the user, leads to user confusion. During the conceptual phases of the new product development process, designers have to collaborate with new functional roles, such as data scientists, software engineers and sociologists.

2) **The character of smart product with their technical limitations.** The physical product and the user interface are disintegrated, and form no longer follows functions. The UI is limited in comparison to the vast number of functions, and this leads to confusion and useless complexity for the user. Furthermore, if the paying user of the product or service does not understand how to use, or he/she is confused by, the product, his/her willingness to pay might be reduced or he/she can decide not to buy the product/service. (Atasoy, 2017). In designing electronic products, so either smart object, we are stuck in a world in which the hardware and the software have the same life cycle (Cantamessa, 2021), and the object is designed as isolated, but instead are connected, have social relationship with physical and virtual world and its functions need to be framed and compatible in an ecosystem (Bangle, 2010)

3) **The heterogeneous user group of these products.** The user of smart product is wider spectrum of user because smart product usually are consumer durables. To satisfy all the customer, given the programmability of digital components allow designers to adopt a design philosophy that embraces incompleteness and continuous improvement, digitised (tangible) product may also become incomplete and open-ended. In other terms “Design is never done” quotes Google (Vitali, Arquilla, 2019), that consists in make a step back and leave the user define the way in which the product will satisfy their needs. (Lyyra,2016)

Designers, who want to manage these challenges must considers different points of views, to explore not only the expected, but also the unexpected outcome; considering the subject of the project both stand alone and as element of the infrastructure/system, leading to a new type of product architecture. (Y. Yoo, 2010). Part of the unexpected outcome comes from the “current” product and the way in which the user interacts with him, but part of it is related to the characteristic interactive nature of the digital artefact. “Technology should be embedded in our society in a way that is not perceived, and it has to reduce the cognitive load of the user”, technology should be and “intelligent social glue” (Bangle, 2010)

1.2 Smart Object

There is no unique definition of what a “smart object” is, but the term is usually used to indicate object with the capabilities to capture and process data, with a certain degree of autonomy and with an adaptive behaviour. This generates a object-to-human interactions and a communication flow with user, environments and other product and systems (Vitali, 2019). Smart object, smart things, intelligent objects, are just some of the phrases to referred to a class of digital artefacts, with particular “abilities”, since in 2002, Wong (Wong et al, 2002) introduced the notion of “intelligent product”, to describe physical product with associated properties, that allow it to achieve some elements of behaviour, typical of an intelligent being. An intelligent product can be defined by the following characteristic: possess a unique identity, can communicate effectively with its environment, can retain data about itself, deploys a language to display its features, production requirements, etc. and it is capable of participating in or making decisions relevant to its own destiny. In the recent literature there are many authors that tried to make a common definition and classification of smart object, in particular refereeing to their "abilities", i.e., capabilities. T.S. Lopez (Lopez, 2011) defined smart object as a physical product empowered with digital technologies, that enabling new features: programmability, communicability, memorability, sensitivity, traceability, and associability. M.E.P Hernandez (Hernandez, 2014) states that "a smart object is a physical object with enhanced digital capabilities, at least identification, communication, retention and energy-harvesting .Smart objects are derived from non-smart object and maintain these objects original essence. Smart object is type of smart thing and include not only devices but regular objects". Stefan Raff (Raff et al., 2020) from an extensive literature review derived 16-capabilites to defined smart product, that can be synthetised in four macro-capabilities: digital, connected, responsive, intelligent. For the scope of this paper, smart object will be considered as follows:

"A Smart Object is a physical object, with enhanced digital capabilities, that possess an identity, can collect and elaborate data, can communicate with other objects, with humans and with the environment and is able to participate in decision making processes"

1.3 Design Methodology

A preparatory introduction to talk about design methodology, it is to analyses the historical relationship between design and science. Two important references in time are 1920s, with a research focus on scientific design products, and 1960s with a focus on scientific design process (Cross, 2001). From Le Corbusier, who wrote about the house as a "machine for living: The use of the house consists of a regular sequence of definite functions"; to "Design Methods Movement" in London, that was created with the aim of base the design process on objectivity and rationality. From this perspective, there is a peak with Hebert Simon and its book "Science of Artificial", in which he descried science of design as a discipline to teach in the university. He distinguished (Simon, 1988): the natural sciences are focused with "how things are", while design is concerned with "how things ought to be", with devising artifacts to attain goals.

Reached this point, due to the complexity of the engineering and industrial design activity, and the impossibility to support the design process only with intuitive methods, design and science become strongly linked one to other, and it made sense to do some distinctions:

- *Scientific Design*: it is the scientific approach, like decision theory and operational research applied to design, i.e., rigorous application of concepts derived by different discipline to support design activities
- *Science of Design*: Design as a phenomenon to be studied scientifically
- *Design Science*: Scientific advancement in design, i.e., developing of scientifically based methods and tools to improve design actions.

The following work can be considered in the fields of Design Science and Innovation Management, it is focused on design methodology, and new approach to support the problem-solving process.

1.3.1 Design process

"Anything around us other than nature was designed by humans,
and even nature has been redesigned by us"

(Simon, The Sciences of the Artificial, 1969)

The design process, also according to H. Simon, it is one of the most important human activity, it will probably distinguish ourselves from animals, and he was so fascinated from it, that he decided to how it take place and basically find out an answer to the following question: “How does designer think?”

Design is one of the most interesting activities that influences all the area of the human life, using science knowledge and special experience, it provides the preparatory steps for realisation of solutions ideas. At the base of the designer activities there is Decision Making process. Even if this activity concern different domains, from Economics and Strategic Management to Organization Theory and Knowledge Management, Herbert Simon (Simon, 1996) proposed a model that encompasses all these domains, he identified a three stages process for his rational decision-making model:

1. Intelligence, that consists in data and information needed to clarify the problem
2. Design, that represent the ideation and development of different alternative
3. Choice, represented by the evaluation and selection of the alternative previously generated.

From the previous consideration, it is obvious that this model and the Decision-Making literature, define problem-solving and design as the main activities in any decision process. More specifically, the connection between the Decision Making and Design arise from many articles in Design Literature.

There have been many attempts to create a framework or scheme of the design process, and in general these are represented by a sequence of activities, less or more detailed. Industry uses the term ‘design process’ to mean one of two things: the generic, high-level approach each design project would follow, or the set of activities that actually happen.

Furthermore, these activities are supported in their execution by a vast number of alternative design methods.

Design methods are related to cultural tradition. From the XX-Century, with the first research about Design, two school of thought evolved: Engineering Design (ED) and Industrial Design (ID), related to specific technical fields and design processes.

On the one hand, Engineering Design is mainly functional driven: it consists of an iterative, systematic and relative precise process that leads to the definition of the product's functionality and because of that the form. Historically, Engineers are identified by De Camp (De Camp, 1963) as: "These are the men (today we would say women) who, down the long centuries, have learned to exploit the properties of matter and the sources of power for the benefit of mankind". Engineering design has been defined as the process thanks to which a need or various needs are satisfied by a solution that becomes an actuality or product (K. M. Kim & K.P. Lee, 2010). In the process, a system, a component, or a process are ideated to meet the desired needs, and generally this process is progressively precise, systematic, mechanical, and usually mathematical. Engineering designers usually solve design problems related to functionality, they are mainly focused on technical devices and systems. They are focused on how the components (physical or virtual) perform their functions and how these components work together to accomplish the overall function of the product system. This is defined by Ulrich and Eppinger as the "layout design" (Ulrich & Eppinger 2008).

On the other hand, Industrial design (that include Graphic Design, Product Design, Car Design, etc…) is mainly meaning driven it consists of the creative act of determining and defining a product's form and features, relatively unpredictable and spontaneous. Industrial designers initially merely refined form, shape, and colours according to the customer needs; then, their role become wider and wider, up to today, when the industrial designer is fundamental for the whole user's experience around the product or service. From the purchasing moment to the end of the life cycle, industrial designers have to refine the aesthetic appeal, user interactions, design meaning to the user, upon a personal and even social perspective.

In other terms, while engineering designers are concerned about actualizing functions, working out performance and architecture, industrial designer are focused on user experience, aesthetics, ergonomics, user interface and meaning.

The aim of the artifacts should not only fulfil the technical functions, but also aesthetically satisfy the user. In many products the aesthetics are as important as the technical functionality, and this is especially true for mass products that users meet in their everyday life. For this kind of products, the attention is put not only on aesthetics and use but also on prestige, fashion, and lifestyle. Quite obviously, all the requirements about, function, safety, use, and economy should be met as well. That said, the aim of industrial design, that seats in the middle between engineering and art, it that of creating a product that engages and appeals customers, while the aim of engineering design, is that of addressing mainly function and safety issues, but both they have to deal with ergonomics and visual issues, and they have been supported by similar or same tools and methods.

1.3.2 Design activities

Despite the cultural tradition you chose, design process can be considered as a set of activities, that designers follow to solve design problem and to reach the design solution. In order to identify the main design activities, it has been necessary do a literature review on the main book on design method and methodology, also design research and science, the selected ones for a deep analysis are listed in (table 1).

Author	Paper	Year
Herbert Simon	The sciences of the artificial	1966
Chris J. Jones	Design Methods: Seeds of Human Features	1970
Stempfle J. & Badke-Schaub P.	Thinking in design teams-an analysis of team communication	2002
Pahl and Beitz	Engineering Design: A Systematic approach	2007
Bryan Lawson	How Designer Think: The Process Demystified	2005
Nigel Cross	Engineering Design Methods: Strategies for Product Design	2008
Karl T. Ulrich & Steven D. Eppinger, 2015	Product Design and Development	2015

Table 1. List of paper analysed for design method research

Obviously, the starting point is H. Simon, who dedicated big part of his research to understand the behaviour of human, more specifically “designers”. To summarize the essence of his masterpiece Science of Artificial, the task of an adaptive organism is understanding the differences between the current state and a desired state and then find the correlation to delete these differences, in other term a means-end analysis. For Simon, problem solving is design, is tinkering with artefacts (Simon, 1966). He basically opened design research to the phycology and cognitive science.

B. Lawson, (Lawson, 2005) made a lot of study about the “way of thinking” in design. He analysed many design processes, and he criticized the idea that these happen sequentially. Of course, he defined a series of activities, such as analysis, synthesis, and evaluation, but the order they happen can be different. It seems more likely that the design is a process in which problem and solution emerge together, thanks to a repetitive negotiation between analysis, synthesis, and evaluation. In other words, the design process does not indicate any starting and finishing point or direction of the flow from one activity to another activity.

Nigel Cross, (Cross, 2008) proposed a four-stage model of the design process, as illustrated in the (figure 1). The process starts with the exploration of the "ill-defined problem". In second step, designers try to identify the significance of generating solution in the early process. In the third step, the initial solution conjectures are subject to analysis against the goals, constraints, and criteria of the design brief i.e., evaluation. This step can go well or not, if it is not, the initial conjecture needs to be rethinking. The last step is the communication of a design solution.

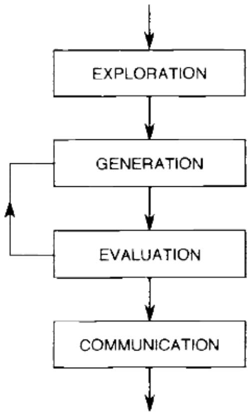

Figure 1. Model of design process. Cross N. 2008

According to Stempfle and Shaub (Stempfle J. & Badke-Schaub P., 2002), the question is relevant for both research and practice in design. Design-problem are complex problems and designing as specific area of problem solving implies that the goal space and the solution space must be overlap in the optimum way, in other terms the solution shall meet all the relevant requirements. Thinking in design can be seen as a cognitive process that consists in four types of cognitive operations, that are necessary to deal with any kind of problem space:

- *Generation*
- *Exploration*

- *Comparison*
- *Selection*

The first two serving to widen a problem space and the last two to narrow a problem space. In this regard, Chris Jones approached the topic from a reasoning point of view, design process can be breakdown into three stages (C. Jones, 1970):

- *Divergence* consists in the act of extending the boundary of the design situation to have large enough the search space in which to seek a solution
- *Transformation* consists into an imposition, upon the results of a divergent search, a pattern that is precise enough to permit convergence to the single design that must eventually be decided upon and fixed in every detail. Now the problem get structure into sub problems
- *Convergence* consists in reducing the secondary uncertainties progressively until only one of many possible designs is left

A more complex model, problem-focused has been proposed by (Pahl and Beitz, 2007). This model consists of four main design stages:

- *Clarification of the task* is the collection of information about the requirements and the constraints that will determine the solution
- *Conceptual design* consists of the function structures, and looking for solution and combine into concepts variants
- *Embodiment design* consists in the activity of the designer of determination of layout and forms of a technical product or system, considering the technical and economic considerations.
- *Detail design* is the review of form, dimensions, surface properties, material specification, technical and economic feasibility, preparatory to manufacturing.

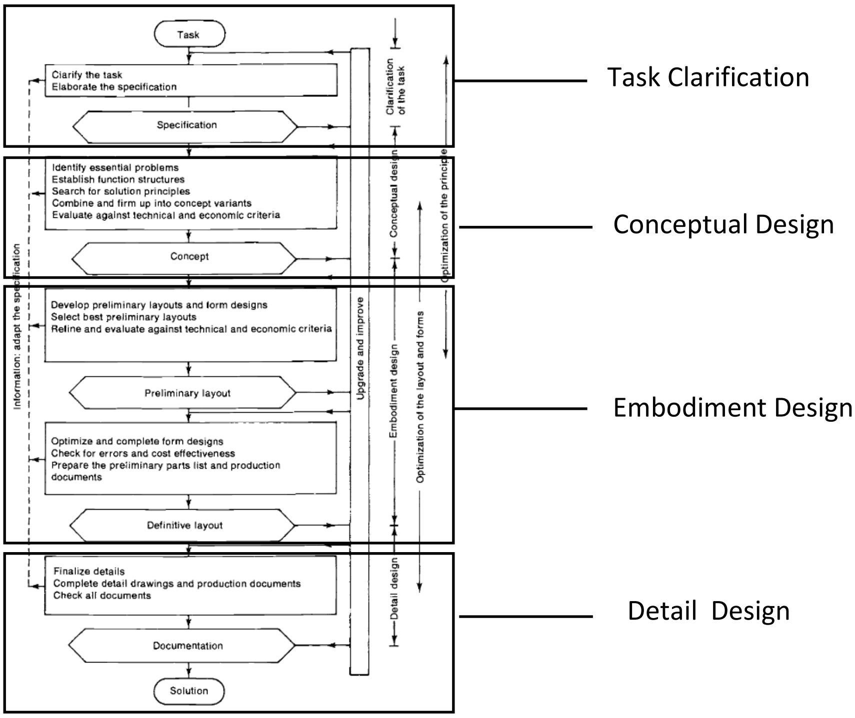

Figure 2. Model of design problem-focused process, simplified version in the left side. Pahl & Beitz 2007

The more detailed structure of this general approach to design is subdivided in seven stages. The output of the stage before is the input of the next stage, and the output of the first stage is particularly important and constantly reviewed. Despite of that, each stage does not follow rigorously the other stage, each stage can be recursively reviewed, in order to do optimization.

According to (Ulrich & Eppinger, 2008), the concept generation start with the clarification of the problem, i.e., it consists of developing a general understanding and then breaking down the problem into subproblem, the so-called *problem decomposition*.

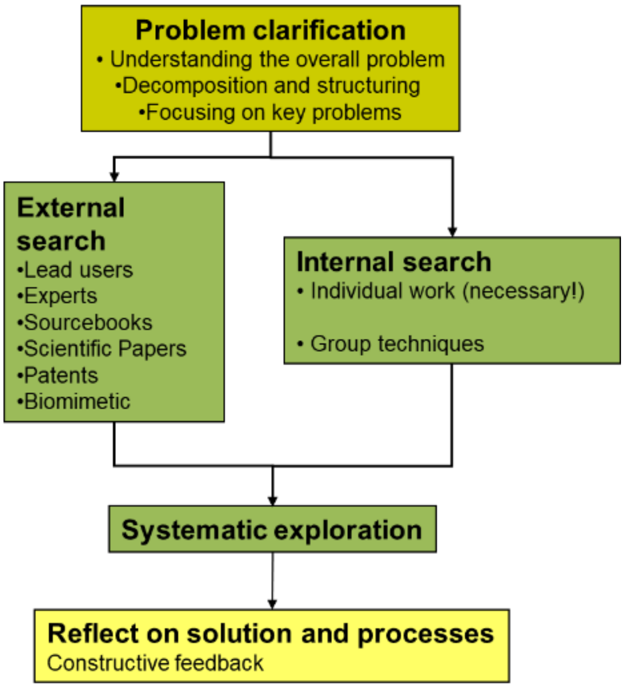

Figure 3. Concept development process model. Ulrich & Eppinger, 2008

The aim of this part is to highlight the critical subproblems and create a solution for them. The second step is the external search, mainly based on information gathering process with the aim to find solution to both overall problem and subproblem, and can be done with different source of information: lead user interview, consult expert, search patents, etc… The third step is the internal search, and it consists in the use of individual or team knowledge to generate solution concepts and can be done with different hints and methods. The fourth step is the systematic exploration of the collection of solution proposal to subproblems, by organizing and synthesizing them. The fifth step is the reflection on solution and processes, and even if it is the last step, it should be done over the entire process recursively, and it consists in identify opportunities for improvement in subsequent iterations or future projects.

From the different authors' contributions, a general framework of the design process is derived. This is done, by a synthesis of the the different authors' views, regardless of the context of design. The design process can be considered as three main macro-activities:

- **Design task clarification** (*Problem formulation/definition, in which design requirements are established*)
- **Idea generation** (*Idea/Concept Generation, in which potential solutions are found through ideation*)
- **Idea selection** (*Idea/Concept Selection, after the strengths and weakness of the possible alternatives are compared*)

It is clear, that the framework is a simplified version of the process, that usually happens in reality, indeed, as indicated by the circular blue arrows, each activity or the whole sequence can be repeated many times, in order to go from the Design Brief to the Design Proposal. Despite that, this simplified version of the design process into three macro-activities, as illustrated in (figure 4) it is what generally

occurs in a design project. Each macro-activity represents a series of sub-activities that need to be considered before moving to the next activities. These activities can be seen as decision making processe.

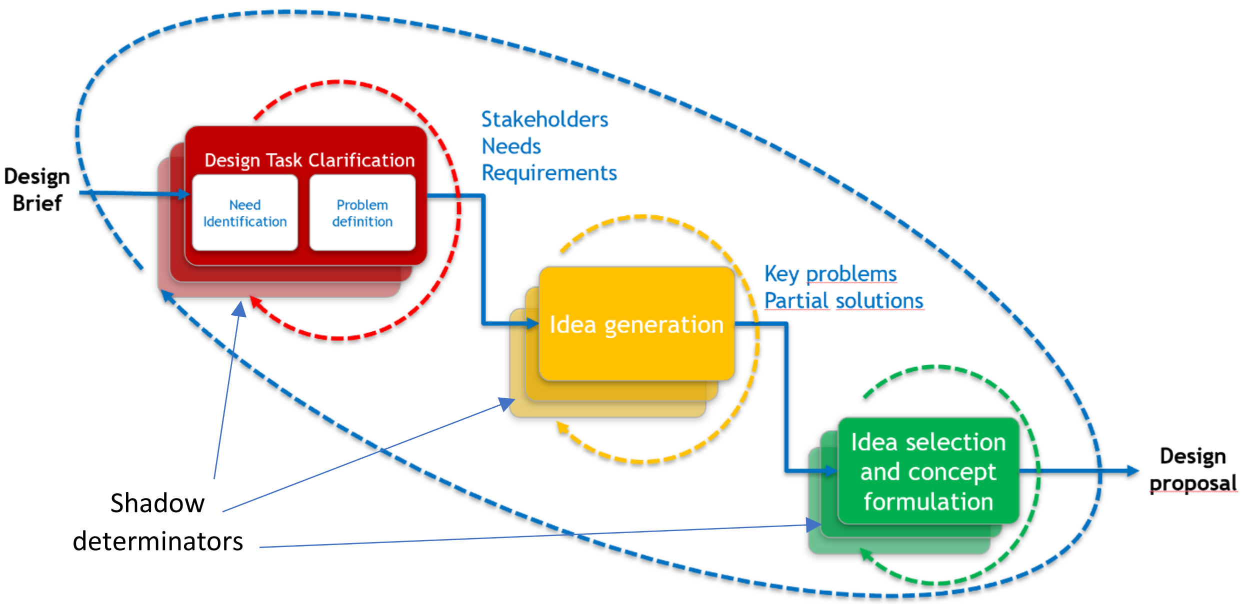

Figure 4. Simplified design process model. Innovation management & Product development lecture

The connection between Design and Decision Process is not so simple, the Design (according to Simon "Design" phase) process is a reiterative sequences of numerous design decisions (Montagna, 2011). In Chris Bangle Associates we call this iterative decision-making process, the "Shadow Determinators" (Chris Bangle, 2020), the series of small decision behind the main design process that allow to go on with the development, and this small decision are driven by different methods, . The shadow determinators are the unspoken, unsaid, unrealized, non-aware influences that drive the decision process. Often, this is the medium in which the design occurs, medium is equal to corporate culture, tacit knowledge, choice of processes, team makeup, etc...

The Design Task Clarification consists in Need Identification and Problem clarification, and generally it starts from the Design Brief and the result of this process is a requirement list. This document represents the specification against which the outcome of design project can be evaluated. The first is a process itself and can be done with different methods, with the aim to understand customers' needs and to effectively communicate them to the development team; with a special attention to the "latent needs", which are difficult to the customers to articulate and unaddressed by existing product. (Karl T. Ulrich & Steven D. Eppinger, 2015). The second has the aim of understanding the overall problem, decomposing, and structuring and focusing on the essential problems (Pahl & Beitz 2007)

The Idea generation or Concept Generation activity includes a mix of External Search and Internal Search, and Systematic Exploration (Ulrich and Eppinger, 2015), with the aim of generating concept solution (product, service or system). A concept is an approximate description of the meaning, technology, working principle and form of a solution proposal to the pre-identified problem (as shape for the physical part, experience for non-physical part). The External Search is basically an information gathering process in order to enlarge the search scope, done with the aim of finding existing solutions to the pre-defined problem. The Internal Search consists in a mix of personal and team knowledge and creativity that allows to generate solution concept (Ulrich and Eppinger, 2015). The Systematic Exploration is a navigation through the space of possibilities, i.e., the concept solutions or partial concept solutions generated with the Internal and External Search, to do a synthesis/recombination process of them and obtain a list of candidate solution concepts for the last selection activity.

The Idea Selection and Concept Formulation consists in in the selection procedure, a two-step procedure, that can be named concept scoring and concept selection. The first step consists in the "elimination", since the large number of solution proposal, unsuitable solution is eliminated. The second step consists in the "preference", i.e., the evaluation of the "best" solution concepts (Pahl and Beitz, 2007), that is formulated as Design Proposal.

For the rest of the paper, it will be used this schema of design process for the main activities involved in the design process. For each of these activities, there are different methods, from both the school of thought ID and ED, support and control the execution of the task, illustrated in (figure 5).

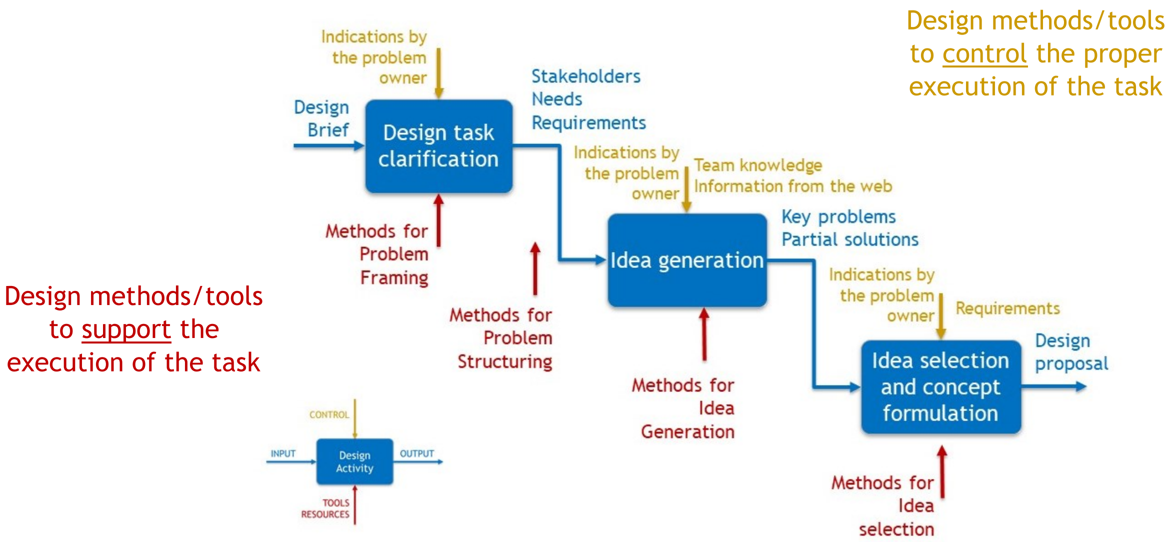

Figure 5. Design process with details about design methods. Innovation Management and Product development Polytechnique of Turin

1.3.2 Design variables

Despite the design method chosen, from literature there is evidence that design activities work and rework on a bundle of common criteria, that in this paper we decided to call "design variables". The following analysis has the purpose to highlight some of main design variables commonly accepted and use in the academy and industry world.

Functions-Behaviour-Structure

Pahl and Beitz (G. Pahl, W. Beitz, 2007) proposed: a technical artifact can be seen as systems connected to the environment by means of input and outputs, and a system can be divided in subsystems and what belongs to a system is determined by the system boundaries. The viewpoint used to divide the system depends on the intended purpose of the division, for example the functional point of view, it is used to identify or describe the functional relationship. To solve to solve a technical problem, we need a system with

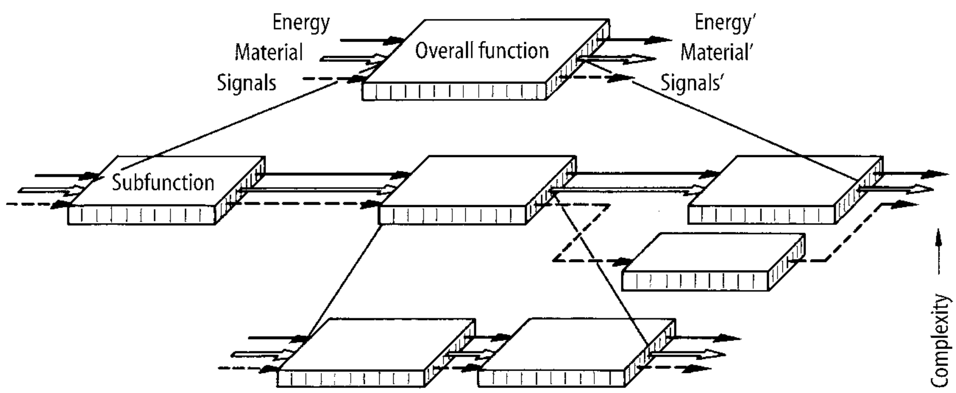

Figure 6. Establishing a function structure by breaking down an overall function into subfunction. Pahl & Beitz 2007

a clear and easily reproduced relationship between inputs and outputs. Such relationships must always be planned that is, designed to meet a specification. For the purpose of describing and solving design problems, it is useful to apply the term *function* to an intended input/output relationship of a system whose purpose is to perform a task. The *overall function* can be divided directly into identifiable subfunctions corresponding to subtasks. The meaningful and compatible combination into an overall function produces a so-called *function structure*.

Function can be defined in general as activities, effects, goals and constraints, and the functions define the behaviour of artifacts, i.e., task, activities, characteristics (Pahl and Beitz, 2007).

A different perspective it is proposed by J. Gero, that assumed the *"Design activity can be now characterized as a goal-oriented, constrained, decision-making, exploration, and learning activity" (J. Gero, 1990).* The purpose of design is to transform *functions* (F) (a set of functions) into a *design description* (D) in such way that the artefact being described can produce these functions. However, no direct transformation can achieve this result. The design description represents the artefact's element and their relationships, it is labelled *structure* (S). And the transformation that can happen are S to D and F to S. But no direct transformation between function and structure exists. Function has been defined in another context as the relation between the goal of a human user and the behaviour of the system (Bobrow, 1984). The behaviour B can be view in two ways: first, the behaviour of the structure Bs (a set of behaviour), which directly derivable from structure; second, the expected behaviour Be (a set of Be), they provide the syntax by which the semantics represented by function can be achieved. Shown below the Function-Behaviour-Structure (FBS) framework.

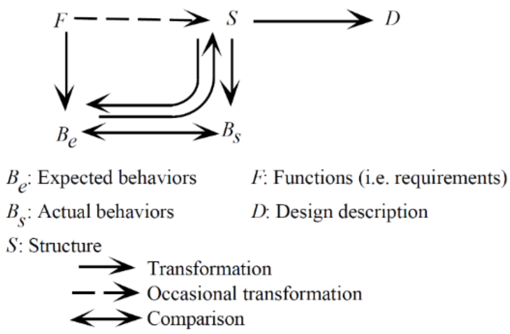

Figure 7. Function-Behaviour-Structure model. J. Gero 1990

The premise of the theory behind the FBS model is, that the designer is not able to define the function of a structure is, without first conceive the behaviour of the structure. And the direct reasoning from function to structure is not possible, if the designer does not determine the behaviour first that fulfil the function (Birkhofer, 2011)

The FBS framework has been extended by J. Gero himself, thanks to the insights derived be the application of cognitive science and empirical design research, into situated FBS framework. In which the knowledge of the design agent is grounded in its experience and its interactions with a multiple interacting environment.

The basis for Gero's FBS framework is formed by three classes of variables that describe different aspects of the object:

- *Function variables*: describe the teleology of the object, i.e. what it is for.
- *Behaviour variables*: *describe the attributes that are derived or* expected to be derived from the structure (S) variables of the object, i.e. what it does.
- *Structure variables*: *describe the components of the object and their relationships, i.e. what it is.*

The designer defines connections between function, behaviour, and structure of a design an object through experience, more precisely the designer ascribes function to behaviour and derive behaviour from structure. Situatedness and constructive memory thus provide the conceptual bases for grounding the knowledge of an agent in the situation being constructed by its interactions with the environment.

The expansion of the original FBS framework can be viewed as the adaptation of the viewpoint of an external observer of the design agent, more specifically this external observer has knowledge about the agent's construction, interpretation, focussing and action processes, which together make up the agent's situatedness. (J. Gero, 2004).

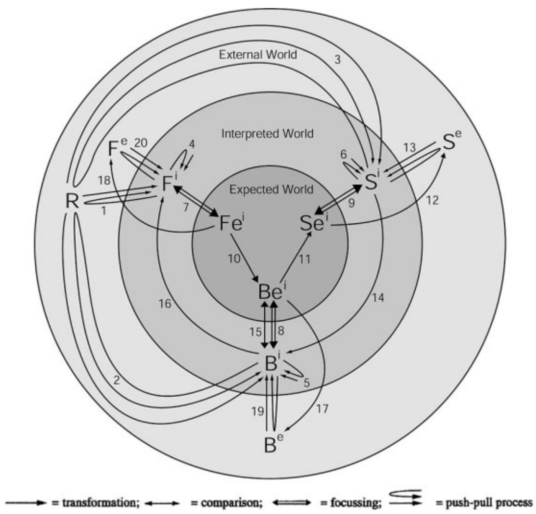

Figure 8. Function-Behaviour-Structure model. J. Gero 1990

This framework provides a new foundation for the development of intelligent agent-based design systems.

With digitalization, and digital artefact, in particular smart object, there is clear evidence in literature of increasing attention on the Agents-Based Models (ABM) and Multi Agents System (MAS) to understand and eventually design new smart object, as an agent that interact with other agents. The higher is the level of autonomy, the more important is its ability of agents to reason and act socially, and to do that it needs to have an internal representation of the other agents. One of the most important contribute is given by J. Gero and U. Kannengiesser, they adapt the FBS view to the situated social interaction within an open MAS environment.

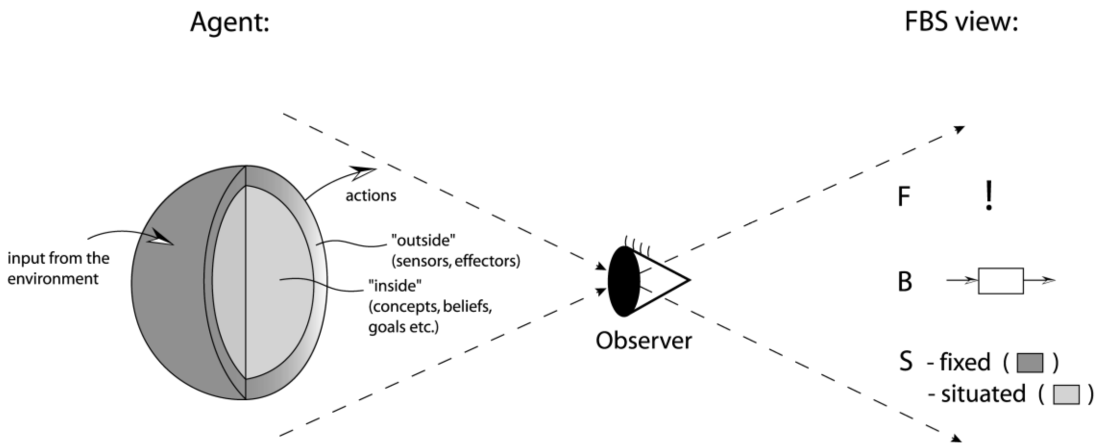

Figure 9. An FBS view of an agent. Gero 2006

Considering as starting point the FBS view of object, that allow the agents to understand and interact with objects, also the processes can be seen with the FBS view, in other terms a particular class of "object" include agents, the FBS view of agents. As illustrated in (figure 9) in this case, the function is the purpose that an observers ascribe to its behaviour, that usually refers to the agent's role in some environment. The agent's behaviour is how the agent act in a set of given conditions, the agent is considered with the "black-box" or "input-output" view. The structure of agent is the complex part, and it can be distinguished in two:

- *Fixed* refers to those components or processes that are given by design and are not subject to important changes. Generally, those components are "visible" such as sensors and effectors of the agents. This part of the structure is called "fixed structure" (Sf)
- *Situated* refers to those internal representations or processes that are generated by the agent's interaction with the environment. Generally, this part can be interpreted as bundle of concepts, goal, constraints, beliefs etc. This part of the structure is called "situated structure" (Ss)

The structure is the most complex properties of the agent, and the way by which is instantiated depend on the observer. Three main types of observers are the designer of the agent (object), other agents with which there is an interaction and the agent itself. This consideration leads to the concept of "situated structure" (Ss), i.e., the instantiation of structure depends on the perspective of observer, different context and purposes shape this perspective. Traditionally, designing activities (agent's interactions) is focused on fixed structure (Sf) of an object or an agent, social interactions commonly deals with the generating or *modify an agent's situated structure (Ss).* But both kind of interactions relay on some kind of structure (S) and aim at generating a behaviour (B)

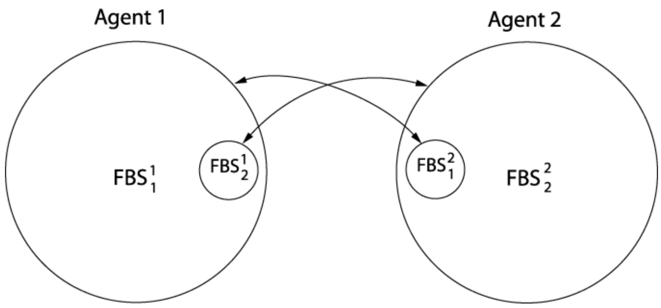

Figure 10. Pairs of matching FBS models that establish the common ground of two agents. Gero 2006

that is to bring about a function (F). Thus, FBS schema has been developed for all interactive contexts, and it is used in the context of socially interacting situated agents, it is called situated FBS framework. The (figure 10) illustrate an example of two agent system interaction in which each agents has to create an FBS model of the other agents and its own FBS model to interact each other. (Gero, 2006)

Affordance

Most of the design methodologies currently applied are inspired to the philosophy of Human-Centered Design, (HCD) that are not a precise set of methods but assumes that innovation should start by getting close to the users and observing their activities (D. A. Norman, 1988). In other terms it consists in developing solutions by involving the human perspective in all the steps of the process:

Human-centred design is an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs, and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility, and sustainability; and counteracts possible adverse effects of use on human health, safety and performance. ISO 9241-210:2019(E)

One of the most deeply studied part of HCD is Human-Computer Interface (HCI), which is strongly related to the concepts of Affordance. The word Affordance was coined by the psychologist James Gibson, in (1977), to refer to "the actionable properties between the world and an actor (a person or animal)". For Gibson affordances represents the perception, originated by senses, that the user has from the relationship created between him/her and the object inside an environment, these relationships exist naturally. Through its affordance, the object "offers what it does because of what it is" (Gibson, 1977)

D. Norman reinterpreted the Gibson's concepts of affordances in the Engineering Design context. Form the studies of the perception that object communicate to actor is possible to define an intuitive product architecture from the usability point of view. The reinterpreted concept of affordance from D. Norman:

"An affordance is a relationship between the properties of an object and the capabilities of the agent to determine just how the object could possibly be used"

(Norman, 1988)

From this definition, Norman proposed two variations of the affordance:

- *Real Affordance* is referred to the real properties of affordance
- *Perceived Affordance* is referred to the perceived properties, that can be not real, and it determines the usability of the object.

The interactions of the object with the humans determines its affordances, but human can perceive the affordances of the objects through the senses before the action. The course from perception to action seems a direct one, implying an ease of learning desirable for artifacts. In general, an artifact is easy to use when the perceived affordances fit its intended use. The concept of affordance implies that a natural intuitive human-object interaction is "good design".

That said, Affordances exists whether they are perceived or not, for this reason (Gaver, 1991) systematically analyzes the relationship between affordances and perceptual

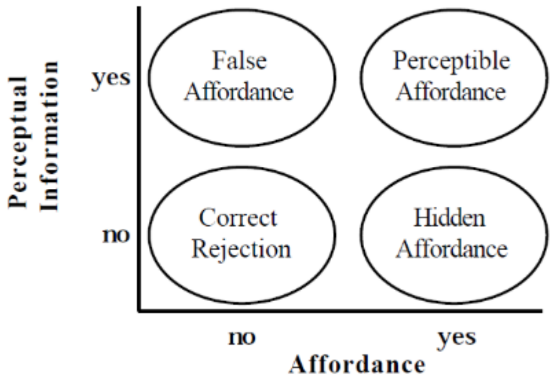

Figure 11. Classification of affordances accordingly to the informational context. Gaver 1991

information about affordances. He distinguished four possible combinations of the presences or absence of affordances, on one side, and the presence or absence of information about affordances, on the other side, as illustrated in the (figure 11):

- *False Affordance* if the information suggests a nonexistent affordance

- *Perceptible Affordance* if perceptual information suggests an existent affordance
- *Correct Rejection* if there is no affordance or nor any perceptual information suggesting it
- *Hidden Affordance* if there is no available information for an existent affordance.

Making affordances perceptible is one approach to designing easily used systems. From the previous considerations emerges the accessibility of informational context is the key to interpreting the affordance. This becomes important with interactive technologies, as smart object. The accessibility to information happens by the interface of the object, in other words, the affordance of the smart object is manifested by the user's perception who is interacting with the interface. Here we are going into the so called "Perception design", in which the designer is focused on the studies of perceptual system, i.e., perception the object communicated to the user. The actual perception of affordances is in part determined by the observer's culture, social setting experience and intentions. (Norman, 1988)

Digital Affordance

For designer of interactive technologies, the concepts signified the promise of exploiting the power of perception to make everyday things more intuitive and in general, more usable. With digital artifact and so also with smart object, the concept of affordance is related to a much broader information context, and it is difficult to perceive all the affordances from the digital artefact only, but you need to consider also the affordances associates to the service that the artifact enables. The concept of affordance results reductive to support the activities of designer, to overcome this problem, some researchers introduced the concept of "Digital

Affordance". Digital artifact's shape is independent of the function, and it has multiple relational aspects, and it has some affordances associates to the artifact and some associates to the digital system. The affordances are defined with the idea of support the user in doing specific action, and the contact with the user happen throughout the sense perception: sight, hearing, smell, touch and taste. In the case of digital artefact, the sensory stimuli are generated by the output of the artifact itself. (Perpignano, 2020)

Architecture

According to (Ulrich, Eppinger, 2015) a product can be thought of both functional and physical terms. The functional elements of product are the transformations and operations that contribute to the overall performance of the product. They usually are represented in schematic form than are described more in detail with technologies, components, or physical working principles.

The physical elements of a product are the parts, components and subassemblies that implements the product's functions. The physical elements of a product are typically organized into bigger building blocks, that can be called chunks.

"Said that, the product architecture is a scheme by which the functional elements of a product are arranged into physical chunks and by which chunks interact."

The product architecture can be:

- *Modular*, when chunks implement one or a few functional elements in their entirely and the interaction between chunks are well defined and generally fundamental to the primary functions of the product

- *Integral,* when functional elements of the product are implemented using more than one chunk, a single chunk implements many functional elements

The most integral architecture will often be designed with the highest performance in mind, while the most modular architecture is the one in which each functional element of the product is implemented by exactly one physical chunk and in which there are a few well-defined interactions between the chunks

The architecture is a relative property of the product architecture, the product is rarely only integral or modular. The modular architecture comprises three types: slot-based, bus-based and sectional-based, the difference between these types of relay on the way of the interactions between chunks are organized.

Modular Layered Architecture

The rapid miniaturization of computer and communication hardware, combined with their increasing processing power, storage capacity, communication bandwidth and more effective power management have made it possible to pervasively digitalized previously non-digital artefacts, in which hardware and function were strongly coupled. Digitalized product can now be flexibly re-programmed and re-purposed with very low cost (Faulkner & Runde 2010; Kallinikos et al. 2010). The separation of hardware and function has great implication on the product architecture. However, the product architecture explained above, results incomplete to explain the architecture of digital artefact, as smart object. Yoo Y. (Yoo Y. 2012) introduced the concept of "modular layered architecture", that is the results of a temporary link between single elements in different layers. The modular layered architecture is dynamic and flexible, qualities enabled by the modularity, granularity and by the standardized interface of digital artefact. The layered modular architecture is similar to the traditional modular architecture, but it differs in a specific aspect, it is product-agnostic in contrary to the traditional one that is product-specific (Ulrich, 1995).

2. Literature Review and Analysis

2.1 Smart Object literature review

The literature review has been conducted by analysing various papers dealing with the subject of Smart Object, focusing on keywords such as: "Smart Object Design", "Smart Product", "Smart Object Classification", "Connected Product", "Smart Connected Product", "Intelligent Product" "Internet of Things" "Digital Artefact". The main journal resources taken into consideration have been: Design Society, International Journal of Engineering Science, Journal of Engineering Design, Journal of Mechanic Design, Journal of Artificial Intelligence for Engineering Design, Analysis and Manufacturing, Institute of Electrical and Electronics Engineers Journal of Product Innovation Management. In the paper Smart Object are considered as a category of "Digital Artifact", the starting point of the following analysis on smart objects has been a brief description of the differences between a digital and a non-digital artifact (traditional artifact). The list of paper identified for the analysis are list in chronological order in table 2:

Author	Paper	Year
Yoo, Y.	Digitalization and Innovation	2010
Kortuem, G. K. & Kawsar F.	Smart Object as Building Blocks for the Internet of Things	2010
López, T.S., Ranasinghe, D.C., Patkai, B. et al.	Taxonomy, technology and applications of smart objects	2011
Yoo, Y., Boland, R.J., Lyytinen, K., and Majchrzak, A.	Organizing for Innovation in the Digitalized World	2012
Hernández, M.E., & Reiff-Marganiec, S.	Classifying Smart Objects using capabilities	2014
Vitali I. & Arquilla V. & Rifino I.	Design for Meaning of Smart Connected Products	2019
Raff, S., Wentzel, D. and Obwegeser, N.	Smart Products: Conceptual Review, Synthesis, and Research Directions	2020

Table 2. List of papers about smart object

2.1.1 Introduction

Starting from the (Simon, 1996) definition of artefacts, as both material and immaterial objects that are man-made for sub-sequent use to accomplish certain goals by performing certain functions. In other term, designer transforms raw material into a particular from to accomplish a potential function. Digitalization of these artefacts, started with representation, then increasingly tools and forms of organizing (as mediated by these tools and representation), affords new forms of materiality to them, ultimately making them more generative than their analogue counterparts. This new kind of artefacts are called "digital artefacts", in which the digitalization of the physical world exploits unforeseen material properties to previously non-digital, industrial age, product process (Yoo Y., 2012). Yoo Y. has identified four aspects that characterized the digital artefacts:

- *Binary structure of information*, all the information can be expressed throughout a series of bit
- *Microprocessors and software are based on the Von Neumann architecture*
- *The digital technology is immaterial*, the digital information and the software are codified in a binary array
- *Autoreferential nature*, each new artefacts or technology becomes the based on which make progression

The combination of these characteristic is what made the digital artefact generative and suitable for evolution. The homogenization of data and the re-programmability of digital technology drive to separation between physical device and service, and separation between contents and network. These two separations lead to the rise of a new architecture, layered modular architecture. A digital product with a layered modular architecture is a result of temporary biding of individual components in different layers.

2.1.2 Smart Object definition and capabilities

Smart Products have become a tangible reality, and they have contributed to the disruption of traditional market in the new era, the era of Internet of Things (IoT) and technologized marketing and innovation. Despite the lack of consensus in a common definition of "smart product", it is important also distinguish it from the related aspects such as service and functions, that they render or related concept such as IoT in which they operate. In this regard, it is important remember that a smart product, is a "product", with its materiality, i.e., it is a cyber-physical device that not only has software-based digital capabilities, but also a physical nature (Vitali et al.,2019).

Starting from the point of view G. Kortuem and F. Kawsar (Kortuem et al, 2010) considers Smart Object as building blocks of Internet of Things, and they define smart object as: "autonomous physical/digital objects augmented with sensing, processing, and network capabilities. Smart Objects carry chunks of application logic that let them make sense of their local situation and interact with human users. They also deeply analysed three dimensions that have to do with the design of smart object:

- *Awareness* is the ability of understanding events and human activities occur-ring in the physical world
- Representation refers to application and programming abstraction
- Interaction is the ability to communicate with the user with input, output, control and feedback

By the iterative exploration of these three dimensions, Kortuem and Kawsar a classification for smart objects: Activity-aware object, Policy-aware object and Process-aware object (table 3)

Table 1. Summary of smart-object types.

	Awareness	Representation	Interaction	Augmentation	Example application
Activity-aware object	Activities and usage	Aggregation function	None	Time, state (on/off), vibration	Pay-per-use
Policy-aware object	Domain-specific policies	Rules	Accumulated historical data, threshold warnings	Time, vibration, state, proximity	Health and safety
Process-aware object	Work processes (that is, sequence and timing of activities and events)	Context-driven workflow model	Context-aware task guidance and alerts	Time, location, proximity, vibration, state	Active work guidance

Table 3. Summary of Smart Object type. Kortuem et al. 2010

Tomas Lopez et al. (Lopez et al. 2011) consider a smart object: "any object or product that is by way of embedded technologies, aware of its environment and state, and it may have the ability to make its own decision about itself and its uses, communicate state of information, and achieve actuation under its own control. The classification is based on how many the following characteristics, the smart object possesses:

- "I", "Identity", the object possesses a unique identity and the capability to store relevant data
- "S", "Sensing", the object is able to define its physical condition and its situated environment
- "A", "Actuation", the object is able to send actuation commands to others object or system
- "D", "Decision", the object is able to make decision on its own destiny, based on available information, the decision can imply some kind of actuation or control
- "N", "Network", the object is able reach or retrieve information by using wired or wireless communications, to improve its functionality

Marco Hernandez et al. (Hernandez, 2014) conducted intensive research about the ontology of the term smart object, illustrated in the (figure 12) with the aim of identifying the commonality on definition and on classification model of smart object.

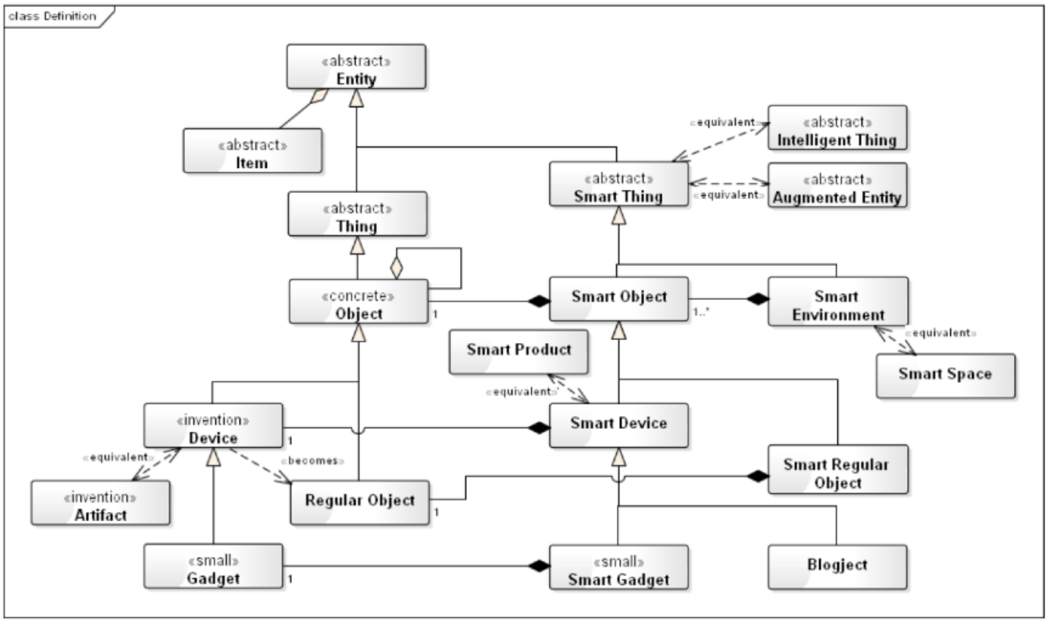

Figure 12. Ontology of the terms Smart Object. Hernandez, 2014

The main highlights of the study are:

- Non-smart artifact can be transformed in smart object by adding digital features, i.e., they become part of the IoT
- Terms as intelligent and smart can be used as equivalent
- Smart things definition includes not anly object but also environment containing smart object
- There are many points of view by which smart object can seen

Hernandez also provides a definition of smart object: "*A smart object is a physical object with enhanced digital capabilities including, at least, identification, communication, retention and energy-harvesting. Smart objects are derived from non-smart objects and maintain these objects original essence. Smart objects are* *a type of smart things and include not only devices but regular objects".* Assuming this definition, he establishes a classification model, based two sets of capabilities. On one hand, the core capabilities, that define the essential ability that a smart object must have to be define smart:

- *Digital Identification* is the ability to access information and to define the object identity in a digital context. This enables the capability of the object to identify itself to other object, systems, and humans.
- *Retention* is the ability of the object to store information about itself or environment, on a local or remote memory
- *Communication* is the essential ability to exchange information with other objects or users
- *Energy-harvesting* is the ability to catch the demanded energy to accomplish its task.

On the other hand, form core capabilities and for the object's purpose, lifetime, design or technical or financial optional capabilities are derived, and they are illustrated in (figure 13):

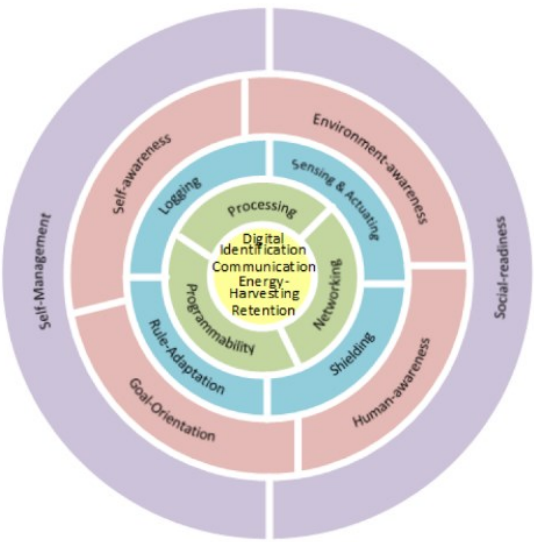

Figure 13. Smart Object Capabilities

From extensive systematic literature review conducted by Stefan Raff (Raff, 2020) defining criteria of smart product that they were grouped in 16 capabilities. The capabilities-based criteria were synthesized, in order to derive a comprehensive conceptual framework for smart product, they are organized in four different product archetypes:

1. Digital (*IT Equipped, Data Storage, Data Processing and Analysis, Data Provision and Transmission*)
2. Connected (*Unique Identification, Networking and Connectivity, Communication and Information Exchange, Interaction and Cooperation*)
3. Responsive (*Sensing, Real-Time Context awareness, Reactivity and Adaptability Automated actuation, Functionality and Customization*)
4. Intelligent (*Reasoning and Decision-Making, Autonomy and Self-Management, Proactivity*)

These archetypes are organized in a hierarchical logic where a product need to fulfil all essential criteria of one archetype, before moving to the next one. So, these are not only defining criteria of smart products, but also a framework that distinguish 4 different bundles of cyber-physical arrangements, as illustrated in the following (figure 14).

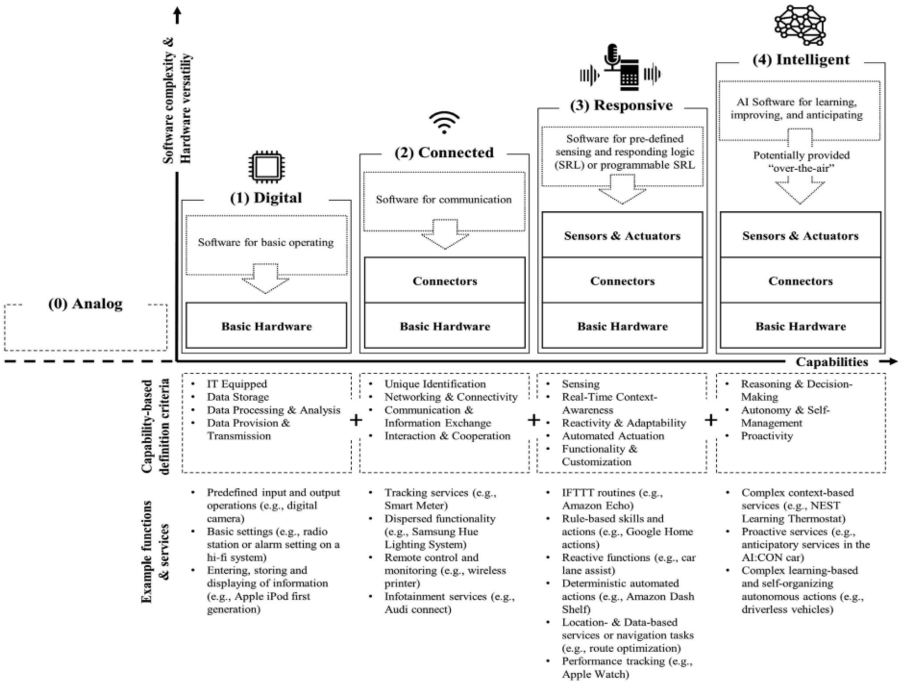

Figure 14. Framework of Smart Product Archetypes. Raff et al, 2020

In other terms this table represent an interdisciplinary framework that distinguishes different types of smart products based on the complexity of their hardware and software. This framework can be seen also as useful definition of domain for related concepts as IoT, IoE or smart services.

Probably, the complex nature, together with the possibility of studying these objects from a multitude of perspectives, it makes difficult to find a common agreement. However, for the scope of the paper, it is useful to achieve a definition of Smart Object. Form the above collection of different authors' contributions, it is interesting to notice that even if there is not a shared definition of the concept, there is a common acceptance of the term Smart Object. Furthermore, most of the authors base their own definition and classification of Smart objects on their "capabilities". Some of these capabilities are proposed many times, for this reason a comparative analysis between the authors has been done, with the aim of highlights some commonalities. This analysis is illustrated in the following (table 4), each column represents an author, and on the rows, there are the capabilities.

As it is possible to see, four chunks can be identified, according to the definition proposed by authors:

Kortuem, G. K. & Kawsar F.	López, T.S., Ranasinghe, D.C., Patkai, B. et al.	Hernández, M.E., & Reiff-Marganiec, S.	Raff, S., Wentzel, D. and Obwegeser, N.
Awareness	Identity	Digital Identification	Digital
Representation	Sensing	Retention	Connected
Interaction	Actuation	Communication	Responsive
	Decision	Energy-Harvesting	Intelligent
	Network		

Table 4. Smart Object Capabilities comparison and analysis

1. Digital, Digital Identification, Identity
2. Awareness, Sensing, Retention, Responsive
3. Network, Communication, Connected, Interaction, Actuation
4. Representation, Decision, Intelligent

For this document, a new definition of smart object has been proposed, considering the precedent cited definition and the results of the comparative analysis of the capabilities above. The proposal, that has been used for the rest of the research, is the following:

"A Smart Object is a physical object, with enhanced digital capabilities, that possess an identity, can collect and elaborate data, can interact with other objects, humans, environment, and is able to participate in decision making processes"

2.1.3 Smart Object Design

According to Gartner *"Digital experience is no longer limited to the domain of born-digital companies or outlier enterprises in specific industries*." Designers are now designing products that are increasingly reliant on a myriad of tangible and intangible interdependencies. Smart object is one category of this product, with a dual nature, cyber-physical, or "phygital" nature (Vitali 2019), that consists in the ability to blend the physical and the digital worlds togethers. In analogic artefact the shape is expressive, thought its affordance, the object "offers what it does because of what it is" (Gibson, 1977) and communicate how it could be used, and consequently the interactions. In electronic products, such as smart object, the link between shape and functions is often lost. These products are able to perform a multitude of functions, and most of them or even all are not highlighted by the form of the artifact. Due to their dual nature, smart objects can be interacted with a physical and digital way, this blurs the lines between product and service and the user environment companies need an integrated design view "end-to-end" (Breschi et al, 2017). The object become a mean between the user and the company, and the company can interact directly with the user and sometimes also reverse. The nature of the product-consumer relationship changes dramatically and after the delivery a continuous data analysis and user feedback process happen (Vitali, 2016). Furthermore, it emphasizes the fact that objects are not "static", but dynamics entity, that may evolve from one level to the next, by hardware or software upgrade, from a connected product to a responsive product or even an intelligent product. From this framework emerges also that smart product may never be "finished", in other terms the process of design never truly ends. For all the reason above, designing smart object represents a challenge for every designer, and the support of design methods and approaches can be a useful tool, to assume the right mindset and to have a holistic view over the whole design problem.

2.2 Design methods literature review

Design methodology has its origin in the 19th century in Germany, and it was developed on findings from scientific and pragmatic approaches to design, and for a long time, it was focused on the design of objects.

At the end of the 1980s, with mechatronics, electronic, and then with software, the design work become more interdisciplinary and complex. “The focus of design research shifted from the “object” to the “system”, and currently the area of object has been widened to adaptronic and intelligent system that recognise and evaluate their surrounding independently and adapt their behaviour in a goal-oriented and autonomous way”. (Birkhofer, 2011).

Design Methodology was created with the purpose to overcome the conception of design as an art, or at least extend it with rational model based and methods based on a framework of natural sciences. (Birkhofer, 2011). Traditionally design methodology’s aim is to support design work, especially in industrial companies, but also to allow teaching and training of design. Design methodology is a concrete series of action for design artifact that derives its knowledge from design science and cognitive phycology and from practical experience in different domain (Pahl & Beitz, 2007)

Most of the design research on the topic, make evidence on the constant interaction between the systematic procedure, based on scientific work and knowledge, and a creative thought and action, based on the experience and intuition of the designer. Usually, method that rely more on the systematic procedure fit better in the engineering design school of thought, while the ones that rely more on creativity are linked to industrial design. Aside of this dualism, the design methodology has the purpose of support the designer along the design process, going from the design problem to a solution. In the field of literature, all the theories, model, techniques, and methods applied to improve the aspects of design practices are encompassed by the term "design methodology", (Cross, 1993) which its primary concern is:

> *"…the study of how designers work and think, the establishment of appropriate structures for the design process; the development and application of new design methods, techniques and procedures; and reflection on the nature and extent of design knowledge and its application to design problems."*
>
> *(Cross, 1984)*

There are a vast number or research and studies on the topic, but despite that "the is no 'silver bullet' method which can be universally applied to achieve process improvement" (J. Clarkson, 2005). Furthermore, the design process is a high complex socio-technical activity, that requires a multidisciplinary approach and a broader range of skills, such us marketing, resource management, cognitive science etc… The choice of the method or a group of method to use in a project or in a company is strictly link to integration of methods between each other, tools and resource, and also to the phase of the project. Design methods are valuable for three reasons (K. Ulrich, S. Eppinger, 2015):

- The decision process become more transparent, allowing participants to understand decision making.
- Allow to designers to sets milestones in design process.
- Allow to keep track of information and create a record of decision-making process for future reference or education.

This chapter reviews several methods that are proposed by literature or are used in the industry, that are specifically link to the conceptual design phase of the design process. The tool used for literature review are Google Scholar and Scopus; and the key words are *"design method", "design methodology", "conceptual design"* and *"design science".* The methods identified are distinguished by the phase they are supporting. The methods listed below are intended for use by engineers and designer, to support the execution of each design activities identified in the previous chapter.

2.2.1 Design method to support task clarification

The process of identifying customer *needs* is a process itself inside the design process, to be understood implies a clear distinction between *customer needs* and *product specification*. Needs are mostly not related to the concept we will decide to develop and are expressed in the "language of the customer". On the other hand, specifications are related to the concepts that will selected and they must reflect the customer needs. Designer refers to customer needs also with customer attributes and customer requirements. It is important also recall the concept of *latent needs,* those are not largely identified by customers, and are not yet satisfied by existing product. (K. Ulrich, Eppinger, 2015). Usually this process is done, having a predefine direction, that is also called design brief or mission statement. The method to support design task clarification, that are selected for the scope of this paper are listed below, in (table 5).

Method for design task clarification	
1	Interview
2	Focus group
3	Observing product in use
4	Functional analysis

5	Performance specification
6	Objective’s tree
7	Mental-Conceptual maps
8	Meta-design
9	Quality Functional Deployment
10	Computational thinking
11	Design for Innovation

Table 5. List of methods to support design task clarification

Interview

One or more participant of design process discusses needs with a single customer. The modality how the interview is done are variable, but usually are done in the customers’ environment. (Ulrich & Eppinger, 2015)

Focus group

Similarly to the interview, but with a group of 8 to 12 customers and a moderator that facilitates the discussion. Most of the time the moderator is a market researcher, but he can be also a participant of the design process. (Ulrich & Eppinger, 2015)

Observing product in use

Consist in watching the customers using an existing product or perform a task for which a new product is intended. Observation can be passive, or implies a interactions between customers and member of the product development team. This method can be done also online, with online observation of the user interactions or simpler with a web-based survey. (Ulrich & Eppinger, 2015)

Functional analysis

Functional analysis is a tool for design process used to explore new concepts and define their architecture. Functional analysis is commonly used in conceptual design, to solve a technical problem, by a graphical representation of as block diagram of "functions",

i.e., "*the intended input/output relationship of a system whose purpose is to perform a task.*"

Function trees assume that a product can be defined by a hierarchy of functions, starting from the "overall functions", that represent the high-level task, that can be divide in "sub-functions" corresponding to subtask. The meaningful combination of overall and sub-function generates the "function structure", that illustrate alternative path to fulfilling higher level functions. Here defining the inputs and the output of the black box the designer can define the system boundaries, that is used to define the function of the product or device.

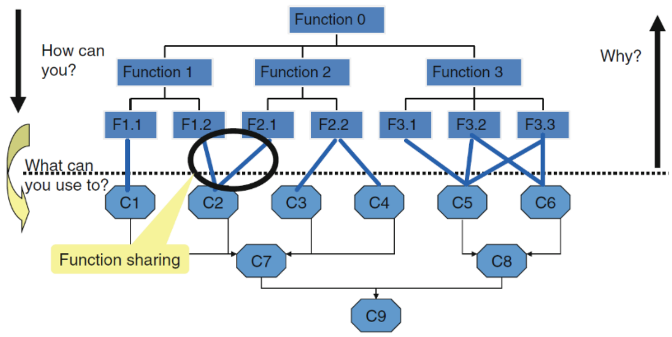

Figure 15. Functional tree example. Pahl & Beitz 2007

From the top-down point of view the functions path answers to the questions "how can you?", from the bottom-up point of view the questions would be "why do you?". Below the dotted line in (figure 15), the components or physical process able to fulfil the function that answer to the question "what can you use to?"

Functional Analysis System Technique (FAST) can be considered an expansion, in which the functional analysis is done by diagrams. This method does not imply a hierarchical illustration of the functions, but a transformation process, with the definition of the system boundaries. Each block of the diagram is not a component but a functional element. These diagrams can be developed in different ways one of these is the Rodenacker diagrams. The type of relationship between the boxes can be varies energy material and signal and also the function can be "main" or "auxiliary", the first one serves the overall function directly, the second ones contribute indirectly. (Pahl & Beitz, 2007)

Performance specification

Performance specification is a method to support the definition of design problems, with the intent of leaving a certain amount of freedom to the designer in order to achieve a satisfactory design solution. The performance specification method defines the required performance and the required product, i.e., the method supports the definition of the performance that the design solution must achieve and not the components to which these performances are achieved. The first step is to establish the appropriate level of generality, to do that we consider:

- Product alternatives
- Product types
- Product features

From the topmost general, to the bottom more specific. That said, the second step is to decide the level of generality, that will determine the either the broadening or a narrowing of the concepts or the design brief. This is usually done by a negotiation between the client, or the company management or the costumer and the designer. Third step consists in setting attributes of the product or machine has to be decided, attributes can be things like comfort, portability, durability key features, speed, cost, etc… An important consideration to keep in mind in doing this step is that performance attribute should be independent of any specific solution (performance-based rather solution-based statement allow to avoid the unnecessary restrictive solution concepts). Fourth and last step, stating succinct and precise performance requirements for each attribute, when it is possible specifications should be quantifiable and inside a limited range.

Objective's tree

Objective tree method consists in a schematic and simple format for statement of objectives, which is as clear as possible between client and designer, or different member of the team. It is a diagram that illustrate the different objectives, how they are related to each other and the hierarchical scheme of objectives and sub-objectives. The starting point usually is the "brief statement", or alternatively the client leave freedom to the designer in doing design proposal. The design objectives may be called client requirements, user needs or product purpose, and part of them are direct consequences of the design brief, and part of them are consequence of the rethinking of the designer, clients. These methods can be very useful tool to classify the users need, primary, secondary and tertiary needs. (Cross, 2005)

Mental-Conceptual maps

Concept maps are tools used for organizing and representing knowledge, they usually enclose concepts or propositions in circles or boxes, and lines between two concepts are relationships between concepts or proposition. Concepts are defined as "*perceived regularity in events or objects, or records of events or object designated by a label";* propositions are "*statements about soe object or events in the universe, either naturally occurred or constructed";* and proposition contain two or more concepts connected to form meaningful statement. In other terms, a concepts map is a graphical reprsentartion of the relationship among terms

The concepts are organized in a hierarchical way, with the most inclusive, most general at the top, and the most specific on the bottom. Concept map is a tool for facilitation of creative thinking, inspired to the learning process of children, which allow to better organize knowledge for problem framing. (Novak, J. D. & A. J. Cañas, 2006).

Meta-design

The aim of Meta-design is to define the "why" of the project from different point of view of user, of the market, and of the company itself, in other terms, it is a phase of meaning creation. For this reason, it can be considered a method to help the task clarification, in particular the problem definition starting from the initial design brief (Fischer, G. & Giaccardi, E. 2006).

Quality Function Deployment

Quality Function Deployment (QFD) is a method developed by Yoji Akao, 1966 in Japan for new product development under the domain of the Total Quality Control. Yoji Akao defined the QFD as:

"Method to transform qualitative user demands into quantitative parameters, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process".

QFD method assumes that the person who buys or who has most influences in the buying decision for a product is the most important factors in determining the commercial success of the product. (Cross, 2005) Indeed, QFD's aim is to assure satisfaction and value to the customer or stakeholder with new or existing products by designing the requirements that are important for them.

Formally, QFD starts with the customer needs identification, often called "the voice of the customer", that are not subject to reinterpretation. Then determining the relative importance of the attributes, many techniques can be used, normally the percentage weight is used. Then benchmarking, the evaluation of attributes of competitor product and the design's team own product (if it exist) against the customer requirements. Designing a matrix of product attributes on row and engineering characteristic (measurables) on columns and define the relationships by a symbol or numbers. and into engineering characteristic for a product or service, so it can be considered is a customer-oriented approach to new product development. Throughout the "house of quality", the roof of the matrix, identify the interactions between the engineering characteristic. As last step set the targets to be achieved by the own product, by using competitor product and trial customers.

Computational Thinking

Computational thinking has been defined by (Wing, 2016) "*involves solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science*". In other terms the designer must think like a computer scientist, that requires multiple levels of abstractions. Computational thinking consists in using abstraction and decomposition when you are dealing with a large and complex task or a large and complex system. It is an appropriate representation for a problem and hierarchical decomposition in order to make it tractable. This method seems to be more and more important with digital area in which everything is digitalized and ubiquitous computing. This method supports the conceptualization, not programming in the way that human think, not computer think, to do a better problem clarification and problem modelling. (Wing, 2006) The main elements of CT are:

- Abstraction is the core of the method, it makes problem or systems easier to analyse and reanalyses, it consists in a process of elevation of the artefact concepts, without unnecessary detail and reducing the number of variables in order in order to be more understandable.

- Problem decomposition, it is also called "divide and conquer" and this phase consist in destructing the problem in smaller and more understandable part
- Algorithmic Thinking is the process of is a scheme of organized step that when "it lets run" they should solve the original problem
- Automation is the configuration of formed algorithms over computer technologies that can reiterate on other problem
- Generalization is the adaptation of fomulated solution or algorithm to other variables or problem (S. Kılıçarslan & F. Kürşat, 2019)

Meta-design

Meta-design is an approach to understand technologies, market and user in order to determine product and service, that have value. This approach is focused on opening up solution space rather than complete solution, because of users' situation and needs cannot fully predicted, in other term when the problem is ill-defined and change over the time. Traditional approach has two phases: *design time* and *use time,* the first one implies no user involvement and designers create a complete system, "world-as-imagined". With Metadesign approach system are not completely designed before to use, it consists in developing a socio-technical environment, in which the user can create solution by his own. Gaccardi and Fisher said that: *Metadesign is a unique design approach concerned with opening up solution spaces rather than complete solutions (hence the prefix meta), and aimed at creating social and technical infrastructures in which new forms of collaborative design can take place (Giaccardi, 2008).*

Metadesign create open systems, the user can modify the contents and functionality as he use the system to solve the problems. Open system implies redistributing design activities between the two main phases, and encompasses "multidimensional design space" following three planes:

- *Designing Design,* it implies anticipatory methods and techniques, metadesigner has to predict most of the users' needs and inoculate good "seed"
- *Designing Together,* it implies participative methods and techniques, metadesigner has to play a fluid ruole as collaborators in design process

Designing the in-between, It implies effective methods and technique, it consists in the use of mediators to support sensorial and emotional responses of the users

Design for Innovation

Cantamessa suggests (Cantamessa et al, 2013) that actors involved in the purchasing and the use of products do not act in isolation from the other actors, but they are reciprocally influenced and the designers that are analysing these interactions can discover new needs or reformulate the current needs. Design for innovation's aim is to support the needs identification and requirement specification, by presenting a representation of different type of stakeholders' needs and their reciprocal influences in these activities. In other terms, the method consists in the study from a multi-stakeholder perspective of the inter-actor influence in order to do the needs analysis. (M. Cantamessa, 2016)

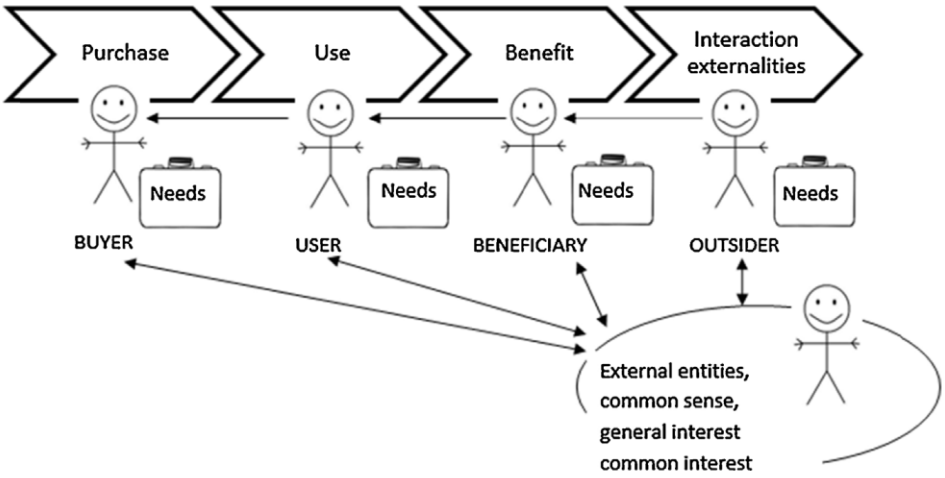

Figure 16. Multistakeholder framework. Cantamessa 2012

In the model (Cantamessa, 2012) proposed three situations beyond "use", i.e., purchase, benefit and interaction externalities and includes four stakeholders' roles: buyers, users, beneficiaries and outsiders. Each stakeholders act accordingly a set of specific needs; these needs can derive form the actors itself, i.e., native needs or can results by influences among actors, i.e., reported needs

2.2.2 Design Methods to support Idea Generation

The generation of idea is the essential and central part of designing and implies an act of creativity or logical process of problem solving, with the purpose of creating something new that does not yet exist. However, the creativity process that happen in a relative mysterious way, it can be seen as a re-ordering or recombination of existing elements (Cross, 2005). The selected method to support the idea generation are listed below in the (table 6).

Method to support Idea Generation	
1	Morphological chart
2	A-design
3	Brainstorming

4	Enlarge the search space
5	Synectics
6	Scamper
7	Design Thinking
8	Gamification
10	Theory of inventive problem solving
11	Biomimicry
12	System thinking
13	Role playing and Scenario
14	Design for X
15	Value Analysis & Engineering
16	Classification tree
17	Combination tables

Table 6. List of methods to support idea generation

Morphological chart

The morphological chart methods' aim is to enlarge the research space for new possible solution, generating a complete new set of alternative design solution for a product. The procedure starts with a list of functions or features with an appropriate level of generalization. Make a list of means by which features or function might be achieved, to do that we can include sub-solutions. Draw a chart containing all the possible sub-solutions and this represent the morphological chart, in which identify and pick-up the feasibility combinations of sub-solutions and reducing the list of selected by introduction of constraints or criteria. In other terms, it is a systematic study of shape or form of a product or machine that might take and making a chart of the analysis. From the chart making different combinations of sub-solution, that might be leading to new solution. (Cross, 2005)

A-Design

The A-Design theory (Campbell et al, 1998) is an iterative process that incorporates both populations of designs as well as populations of agents, the creators of the designs. This methodology is the basis for an automated design tool that generate design configuration alternatives for electro-mechanical system, relying on designers' knowledge and computational process. The iterative approach of A-Design is used to overcome multi-modal, non-linear, discontinuous design spaces that are typical of electro-mechanical and other design problems and to capture the evolutionary nature of design. The bulk of computation in this methodology is accomplished by software agents that are both autonomous and semi-autonomous agents with different strategies for solving design problems. The "A" in A-Design stands for various characteristic:

- The technique is Agent-based.
- The agents are Animate
- The approach is Adaptive
- Objects have an Artificial life

Thus, assumptions lead to an architecture through the interaction of a multitude of agents, that generates design alternatives. It leads to a representation of electro-mechanical components which implies functionality and detailed specifications

Brainstorming

Originally invented by (Alex F. Osborn, 1953), to overcome his employees' inability to develop creative ideas, individually, he started to host group thinking section, then called "brainstorm session", based on the concepts of the use of "the brain to storm a problem", and on the insight that ideas have to be judge afterward e not during the session. The main guidelines of the sessions are:

1. *Judicial judgement is ruled out.* Criticism of ideas happen after the session
2. *Freewheeling is welcomed.* The wilder the idea, the better it is.
3. *Quantity is wanted.* The greater the number of ideas, the more the likelihood of winners
4. *Combination and improvement are sought.* The participants have to contribute with their own ideas, and with suggestions how ideas of others can be turned in better ideas, or how can be joined together

During the sessions the leader shall check the participants, and avoid the criticism, according to the quote: "Think up or shut up", and he must drive the sessions in a way to keep high the engagement of the participant, self-encouragement and mutual encouragement is needed. The ideal size of the group should be between five and ten, while there is no specification on the type of participant, male, female, or neophyte or veteran, but it usually helps if in the group includes a few self-starters. There is the need of an organization lead, but the group must be non-hierarchical, the role of the session lead is just to ensure the progress of the session, following the methods.

Enlarging the search space

It can be considered as a set of technique that has the aim of remove the boundaries within a solution is sought, in other terms enlarging the "search space". (Cross, 2005) This can be done by:

- *Transformation* consists of in to transform the search from a solution from one area to another, and it is usually done by applying verbs, such as magnify, minify, modify, unify, subtract, add, divide, multiply, repeat, replace, relax, replace, dissolve, harden, substitute, eliminate, rotate, combine.

- *Random input* has the aim of stimulate the creativity by inputs from random sources.
- *Why? Why? Why?* consists in asking string of “why?” there may be a series of answer to any particular “why?” and these will be ordered as a network of question and answer and chains
- *Counter-planning* is a technique based on the concepts of dialectic, i.e., counterpose the idea, the thesis with its opposite, the antithesis to generate a new idea, the synthesis.

Synectics

Synectic can be seen as an evolution of brainstorming, with the aim of generating ideas by metaphor and analogies. Synectics is a problem-solving methodology, it is a way to approach creativity not ex-post but ex-ante the facts. The three main assumptions made by (Gordon, 1961):

- *The creative process can be described and thought*
- *Invention processes in arts and sciences are analogous and are driven by the same “physic” processes*
- *Individual and group creativity are analogous*

Taking in considerations these assumptions, the prerogative of Synectics is that people can be more creative if they know how the creative process happen. People who exerts this method have to emphasized emotion and irrational over intellect and rational, and throughout the understanding of them, the problem solving can be more successful. Prince (Prince, 1970) focused on reducing the inhibition, to unleash the creativity, and he developed a series of tools to apply a creative behaviour to design process.

One of the main tools is the “metaphorical process” to make the “familiar strange and the strange familiar” but also "Trust things that are alien and alienate things that are trusted." This can lead to surprising solution and unexpected analogies. With Synectics, a technique calls “spring-broad” is invented to get creative beginning ideas. To do that, the method encompasses brainstorming and metaphor and most of the success of the process relies on the trained facilitator.

Scamper

It is a complementary technique to brainstorming, that drive with additional considerations the idea generation process. Scamper technique was introduced by Bob Eberle to support problem solving or stimulate creativity in the brainstorming sessions, with the use of addressed questions. The method is based on the assumption that new is a modification of existing old things that surrounds us, and it stimulate new idea by modification or addition or modification of something that already exists. The stimulus come from a series of unexpected questions, that the reason behind the name of the methods:

S—Substitute: think about substituting part of the product or process for something else (e.g., components, materials, people)

C—Combine: think about combining two or more parts of the product or process to make something new or enhance synergy (e.g., mix, combine with other assemblies or services, integrate)

A—Adapt: think about which parts of the product or process could be adapted or how you might change the nature of the product or process (e.g., alter, change function, use part of another element)

M—Magnify/Modify: think about changing part or all of the product or process, or distorting it in an unusual way (e.g., increase or reduce in scale, change shape, modify attributes)

P— Put to other uses: think of how you might put the product or process to another use or how you might reuse something from somewhere else

E—Eliminate: think of what might happen if you eliminated parts of the product or process and consider what you might do in that situation (e.g., remove elements, simplify, reduce to core functionality)

R—Rearrange/Reverse: think of what you might do if parts of the product or process worked in reverse or were sequence differently (e.g., turn inside out or upside down)

The creative process follows a scheme: preparation, concentration, incubation, illumination, and verification (production testing). In organizations, its fruitful application depends on the existence of an enabling environment. There are, of course, personal blocks to creativity but these can often be removed. Supervisors who do foster creativity listen, are willing to absorb the risks borne by their subordinates, are comfortable with half-developed ideas, do not dwell on past mistakes, expect subordinates to succeed, capitalize on the strengths of subordinates, enjoy their jobs, and can make quick decisions. They must then help sell ideas to senior management. This involves assessing the "sellability" of ideas and developing persuasive arguments.

Design Thinking

Design thinking is a term used to represent a set of cognitive, strategic, and practical iterative process that teams use to understand users, challenge assumptions, redefine problems and create innovative solution to prototype and test. After 1990, with IDEO, Design thinking become an approach to create design-focused workplace, in which innovation can happen systematically. It becomes a design methodology that provide a solution-based approach to solving the problems, also wicked problem, its utility is in understanding the human needs, by reframing the problem with human-centric focus, generating new ideas by brainstorming sessions. Design teams use design thinking to tackle *ill-define unknown problems*, because they can reframe these in human centric ways and focus on what is most important for users.

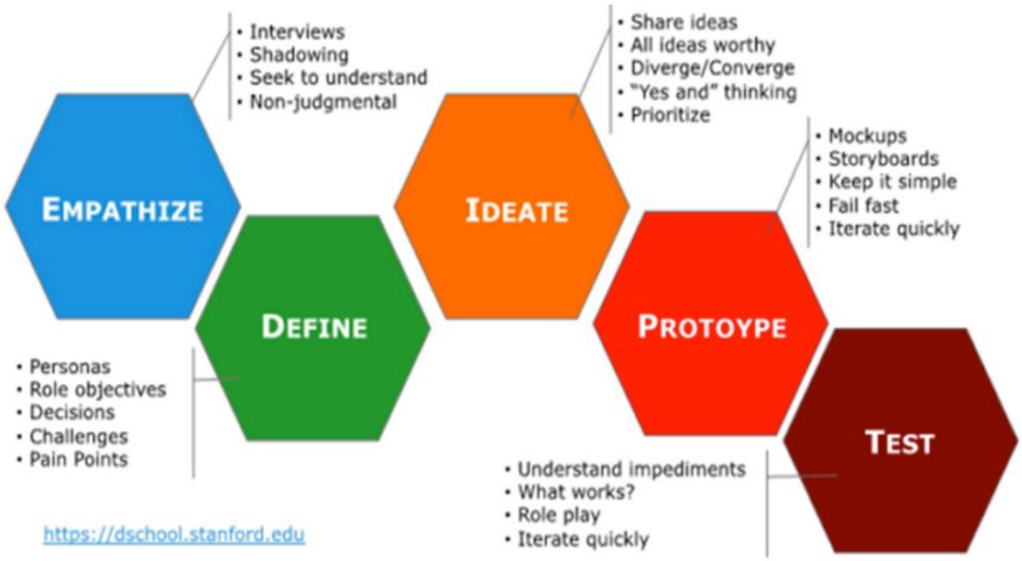

Figure 17. Design thinking process. Hasso-Plattner Institute of Design at Stanford University

Stanford University, started to teach Design Thinking as broader approach to technical and social problem, it consists of a five-stage process, as illustrated in the (figure 17)

1. Empathise: understand the human needs involved
2. Define: Re-framing and defining the problem human centric ways
3. Ideate: Creating many ideas in ideation sessions
4. Prototype: Adopting a hands-on approach in prototyping
5. Test: Developing a testable prototype/solution to the problem

Design thinking is a non-linear method, the five stages are not always sequential steps, they have not a specific order and the can happen in parallel and be repeated. The method is a solution-based approach, with the aim of "thinking outside the box", and these is related to the design thinker's personality profile

(Brown, 2008). Design Thinking includes also many other creative thinking methods like wicked problem and lateral thinking:

Wicked problem are problems with many interdependent factors making them seem impossible to solve. The term "wicked problem" was first coined by Horst Rittel (Rittel & Webber, 1973). Design theorist and academic Richard Buchanan (Buchanan, 1992) connected design thinking to wicked problems in his 1992 paper "Wicked Problems in Design Thinking." Design thinking's iterative process is extremely useful in tackling ill-defined or unknown problems—reframing the problem in human-centric ways, creating many ideas in brainstorming sessions, and adopting a hands-on approach in prototyping and testing.

Lateral thinking (De Bono, 1992) is a complementary approach to the traditional logical thinking, especially useful in problem solving and in the generation of new ideas, the first one is generative, the second one is selective. Lateral thinking makes a different use of information from logical (vertical) thinking, the last one makes immediate judgement to go from one step to the other, instead lateral thinking might delay the judgement in order to allow the information to interact and generate new ideas. Lateral thinking is strictly connected with insight and with creativity, but instead to usually observe these two aspects as outcome of the process, it is a conscious way of using information driven by these two aspects. Starting from the assumption that "the mind is a pattern making system", lateral thinking's aim is to do a provocative use of information and challenges the accepted concepts, in order to restructure the patterns.

Gamification

A first approach to Gamification comes from Nick Pelling in 2002 (Pelling 2011), who defined as the "application of game-like accelerated user interface design to make electronic transaction both enjoyable and fast." After that the concepts evolved, creating a more strictly link between the game experience and design, since the wider accepted definition from (Deterding, 2011) as "the use of game design elements in non-game contexts".

In the 2011, it become officially a buzzword, when Gartner added it to its "Hype Cycle" list. According to Yu-Kai Chou, author of "Actionable gamification", defines gamification as: "*the craft of deriving all the fun and addicting elements found in games and applying them to real-world or productive activities*". In other words, gamification's aim is to offering incentives to users and encouraging them to accumulate rewards throughout their journey can instantly boost their involvement with your service.

According to (Aldo Mora, 2008) to it has been proposed a preliminary list of nineteen game design items taken from the literature, clustered and then organized into five categories:

1. *Economic:*
   - Objectives: are the specific performance goals.
   - Viability: a previous study, evaluation and analysis of the potential of applying gamification or refuse it.
   - Risk: a probability or threat of damage, injury, liability, loss, or any other negative occurrence.
   - ROI (Return On Investment): the benefit to the investor resulting from running a gamified experience.
   - Stakeholders: a technique used to identify and keep in mind the people who have to interact with the design process.

2. *Logic:*
   - Loop: the game mechanics combined with reinforcement and feedback in order to engage the player in the key system actions.

- End game / Epic win: a pre-established end of game or glorious victory in the system, usually stretching players to the limits of their abilities.
- On-boarding: the way of starting the new participants.
- Rules: the body of regulations prescribed by the designer.

3. *Measurement*:
   - Metrics: the standards of measurement by which efficiency, performance, progress, process or quality.
   - Analytic: the algorithms and data used to measure key performance indicators.

4. *Psychology*:
   - Fun: the enjoyment or playfulness.
   - Motivation: the behaviour which causes a person to want to repeat an action and vice-versa.
   - Social: the interaction between players.
   - Desired behaviours: the expected response of the players after the interaction.
   - Ethics: a branch of philosophy that involves systematizing, defending and recommending concepts of right and wrong conducts.

5. *Interaction*:
   - Narrative: the story and context created by designers.
   - UI/UX: refers to everything designed into the gamified system which a player being may interact and the player's behaviours, attitudes, and emotions.
   - Technology: the use or need of a software component for development.

Theory of inventive problem solving

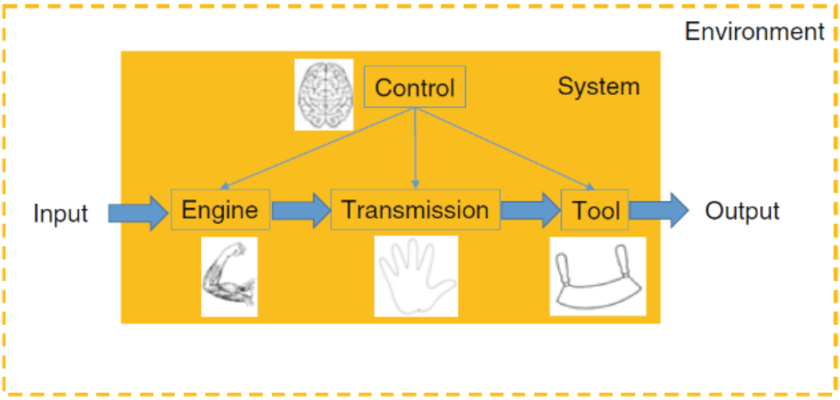

Figure 18. Technical System composition according to TRIZ. Cantamessa, 2016

The "Theory of inventive problem solving" (TRIZ), coming from the intuition of the Russian, Genrich Altshuller, with the intent of develop a general theory on inventions and their underlying principles. TRIZ is based on the analysis of a 40,000 of patents and inventions, in order to come out with a general rule that explain how the creativity of the designer brings to the innovative solutions. A basic assumption of TRIZ method is that any Technical System (TS) able to fulfil function is composed of four elements, as illustrated in (figure 18) :

- Tool, the working elements that allow to fulfil the function
- Engine, the elements that provide the energy required by the tool to fulfil the functions
- Transmission, the allow the transfer of energy from engine to tool
- Control, the elements that command one or more of the other elements

The technical systems are not static, and they evolve over the time, in the direction of reducing human interventions. This happens accordingly to the *first law of evolution,* i.e., the design system will evolve in a way that increase the technical performance and reduce the human involvement. This evolutionary process requires solution of technical problems, that has to do with *Contradiction.* Contradiction are conflicts between a system and its environments, or between the components of the system itself. Every time, designer meet a contradiction this can be express by three elements: one "control variable" and two "evolution parameters". Given the contradiction, the designer have to find a "solving approach":

- *Satisficing* the contradictory requirement consists in understanding the contradiction and looking for a compromise solution. Most of the time, this will simply lead to finding an acceptable tradeoff, without making any substantial change in the underlying technical solutions. This leads to the least inventive results and to incremental innovations that do not depart from the original paradigm. In other cases, the satisfaction of the contradiction will be achieved by a radical change in technology, which will therefore lead to radical innovations and—potentially—to a paradigm shift.
- *Bypassing* the contradiction. This is an explicit decision not to deal with the contradiction at all, and to focus design effort on other contradictions that characterize the design problem.
- *Overcoming* the contradiction by finding technical means that allow the separation of the contradictory requirements. This approach can lead to highly innovative solutions, typically consisting in change to product architecture.

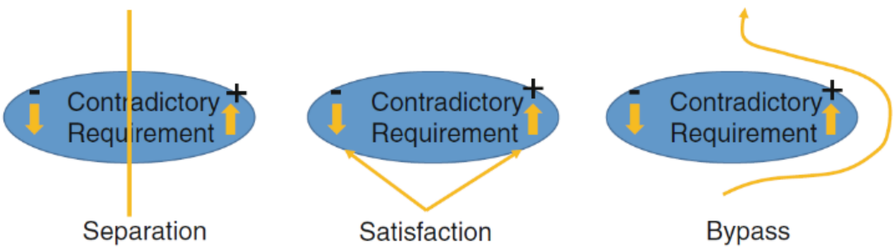

Figure 19. Solving approach according to TRIZ. Cantamessa 2016

The core of the TRIZ method is the concept of "separation", that can be made in four ways, i.e., in space, in time, between parts and the system, and between states; Altshuller identified 40 technical “separation principles”, that the designer can used to solve designers.

Biomimicry

Biomimicry is the practice of applying lessons from nature to the invention of healthier, more sustainable technologies for people. Biomimetic designers are concentrated in understanding, learning from, and emulating the strategies used by living things, with the aim of creating designs and technologies that are more sustainable. Janine Benyus Innovation Inspired by Nature, has defined biomimicry as the “conscious emulation of life’s genius.” That is:

- “Conscious”: being intentional
- “Emulation”: learning from living things, then applying those insights to the challenges humans want to solve.
- “Life’s genius”: recognizing that life has arrived at well-adapted solutions that have stood the test of time, within the constraints of a planet with finite resources.

(Hargroves, K. & Smith, M., 2006) The Biomimicry Design Spiral is a tool to apply the biomimetic design, in order to solve a specific problem or see a design opportunity by using a biological model as inspiration, as illustrated in (figure 20):

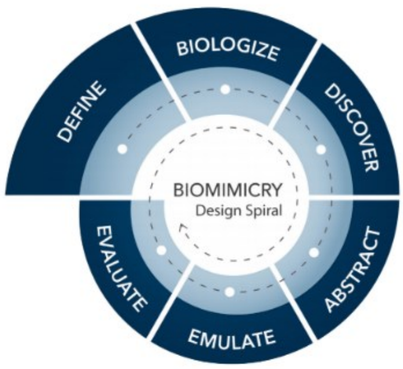

Figure 20. Biomimicry design spiral. Biomimicry Institute

1. *Define*, clearly articulate the impact you want your design to have in the world and the criteria and constraints that will determine success.
2. *Biologize,* analyse the essential functions and context your design solution must address. Reframe them in biological terms, so that you can "ask nature" for advice.
3. *Discover*, look for natural models (organisms and ecosystems) that need to address the same functions and context as your design solution. Identify the biological strategies that support their survival and success.
4. *Abstract*, carefully study the essential features or mechanisms that make the biological strategies successful. Use plain language to write down your understanding of how the features work, using sketches to ensure accurate comprehension.
5. *Emulate, look for patterns and relationships among the strategies you found and home in on the key lessons that should inform your solution. Develop design concepts based on these strategies.*
6. *Evaluate, assess the design concept(s) for how well they meet the criteria and constraints of the design challenge and fit into Earth's systems. Consider technical and business model feasibility. Refine and revisit previous steps as needed to produce a viable solution*

System thinking

System thinking is an approach to problem solving, that view "problem" as a part of wider, dynamic system. "System thinking", by (Forrester, 2010), consists in viewing the system as important, and believing that intuition will lead to effective decisions, i.e., it is the process of understanding how things influence one another as part of a whole. This methodology is based on system dynamics, that has to deal with how things change through time and involves interpreting real life systems into simulations, in which is possible to observe how the structure and the decisions making process determine the behaviour of a system. The computer simulation represents the acting of people in the real system and reveals the behaviour implications of the system, as the model considered. (Forrest, 1993).

The aim of System Thinking is to understand and systematically design the flow of value that comes from different aspects of organization to ensure synchrony, consistency, integration, and maximization between people, activities, process, policies, places and resources. In other term, it consists in a "top-down" approach from big-picture and detail visualization. (Tjendra, 2018)

Value Analysis & Value engineering

In 1961, Lawrence D. Miles (Lawrence, 1962) stated:

"Value analysis is a problem-solving system implemented by the use of a specific set of techniques, a body of knowledge, and a group of learned skills. It is an organized creative approach whose purpose is the efficient identification of unnecessary costs, i.e. cost that provides neither quality nor use nor tool life nor appearance nor customer features."

Value analysis is a systematic approach used to analyse and improve value in a product, system or service. It is a new concept of functional analysis, mainly based on "value" and "function". The aim of value engineering is to increase or at least maintain the value of the product to the buyer while reducing its costs to the producer. The first step consists to list the components of the product, and identity the function served by each components, and creating a component-function chart. Then determines the value of the selected function, and for value it is intended the one perceived by the customers. The next step is determining the costs of components, at the end of the production and assembly process. Here there is the central point of the value engineering method, i.e., reducing the cost without reducing value, or adding value without adding cost, in other terms this step has the purpose of increasing the value/cost ratio. Having seen the alternatives, select improvements.

This method has the aim of improving the product, with no purpose of creating radical new design concepts, but making modification of the existing one. So, a relatively new alternative approach to VA/VE is Design-to-Value (DTV), it is defined by McKinsey (Henrich, 2012) as:

"is a fact-based, multi-dimensional approach that typically enables companies to improve margins by 350 to 900 basis points through improvements in product preference together with reductions in packaging and raw material costs of 10 to 20 percent."

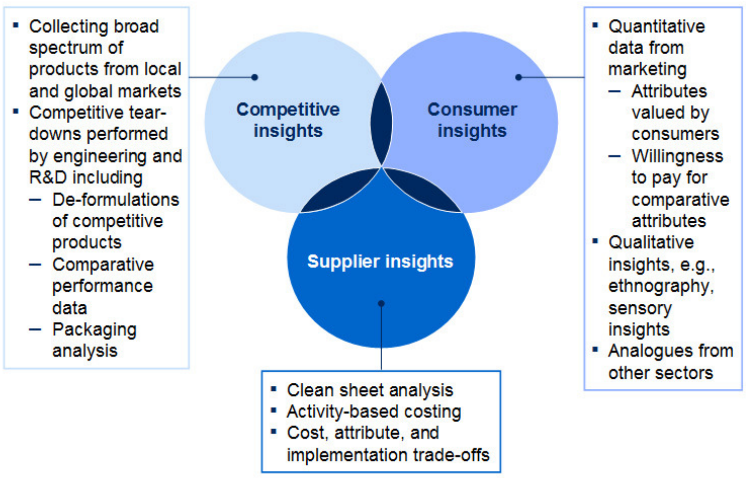

Figure 21. DTV combines consumer, supplier, and competitive insights. McKinsey&Co

DTV distinguishes from traditional VA/VE, because requires more knowledge about the consumer value in product, competitive insight and supplier insight and interdisciplinary activities and collaboration of different department at the beginning of the process, such the marking dep. Furthermore, DTV push the team to optimize the whole product, rather than just the component level, as suggested by VE.

DTV bridge the gap between the development engineers and consumer data, by leveraging on consumer insight that should guide the product design, by providing a richer view of consumer preferences based on research (done by different technique). With these premises the development team can redesign the product in order to match what the consumer value the most.

Leveraging competitive insights allow to create a new benchmark for design efficiency, by deconstructing competitor product and conducting efficacy and sensory test on them.

Leveraging supplier insights provide the missing information for optimize the product and can be a source of design ideas to reduce costs.

However, DTV is a method to collect together all the above insight and generating new design ideas to improve to product and reduce the costs at the same time.

Design for X

Design for X or Design for Excellence are interchangeable terms, X represent different variable, such as manufacturability (M), Assembly (A), Disassembly (D) , Quality (Q), etc… It is based on the concepts that a design easy to manufacture, result in a better product that cost less. The group of design for X techniques, as illustrate in the (table 7) has been create with the aim of capturing knowledge of expert and giving designers guidelines for engineering and re-engineering. In traditional corpore organization design engineers send to manufacturing engineers that make a lot of changes based on predetermined decision. The aim of design for X is to make conscious design engineer of this constraint to allow them to adapt the design before.

DFX results in a longer design period, and less manufacturing setup, it can be seen as an alternative to concurrent engineering; both they differ from the sequential engineer in which shorted design period and longer manufacturing setup.

DFX Acronym	Meaning
DFA	Design for assembly
DFD	Design for disassembly
DFEMC	Design for electromagnetic compatibility
DFESD	Design for electrostatic discharge
DFI	Design for installability
DFM	Design for maintainability
DFM	Design for manufacturing
DFML	Design for material
DFP	Design for portability
DFQ	Design for quality
DFR	Design for redesign
DFR	Design for reliability
DFR	Design for reuse
DFS	Design for safety
DFS	Design for simplicity
DFS	Design for sustainability
DFT	Design for test

Table 7. DFX type

Role Playing and Scenario

Role-playing is a process based on the ideas of imagining and performing, it is regarded as a method to support idea generation in design research, it consists in type of prototyping or simulation technique that help to eliciting the user experience from a product or service from the target audience. Some participants must follow a script, and some are asked to play themselves or specific roles. After the acting, information is recorded and analysed and/or replayed if some adjustments are needed. A variation of this method consists in split a scenario in smaller and more manageable scenario and with some or different participants acting these different scenarios and evaluate how the response of the participants change. An enhancement of this method consists in the collaborative scenario design development and the use of props as boundary objects to stimulate the imagination process. (Lily, Diaz 2009)

This method brings participants into a shared activities physical rather than just mental, making the process more experiential and creatively generative. the user can feel more involved in the design process, making this a user-centered approach, the participant act and react more naturally in the simulation with product or service. (Simsarian, 2003)

Classification tree

The classification tree is a method used to divide the domain of possible solution into several different classes, that allow a better comparison and pruning (Ulrich & Eppinger, 2015). The aim of this method is to explore the solution proposal in order to understand which branches need to be pruned, refined, developed. The classification tree method is mainly used in the software development, to test the design, it was originally conceived and improved by (Grimm and Grotchmann, 1993). This method is based on two step activities: identify separately the input aspects of the object to test and then recombine the different partition to create new test cases.

First, the tester must define the relevant aspects to the test, and each aspect should be clearly differentiated as possible input of the test object. Secondly, the partition of the input domain under each aspect, and each partition is a classification in mathematical sense. The recursive application of classifications to classes determines a tree of classification and classes, the method give a visual representation of gradual fine tuning of the partition. However, the method drives the tester and give us a structured and systematized approach to test case determination making it understandable and documentable.

Combination tables

Combination tables is a method to explore systematically the combinations of solution proposal, in other terms it is a simple way to force associations between different solution proposal to stimulate the creative thinking, however merely selecting a combination does not lead to an overall solution. Operatively this method consists in making a table, in which the columns correspond to the fragmented solution coming from the internal and external search (Eppinger &

Ulrich, 2015).

2.2.3 Design Method to support Idea Selection and Concept Formulation

The idea selection and concept formulation is the last, but not the least important activity to do in the development process. Usually it is a delicate phase, in which there is a comparison of the generated concept or solution proposal to a early defined problem, with the customer needs and other criteria. There are a lot of numerical method, but most of the time the decision is influenced by experience of the decision makers. For this reason it is useful to support the activities with methods that avoid subjectivity in favour of “best” proposal to fit the design process goal. The selected methods are listed in the (table 8).

Method to support Idea Selection and Concept Formulation	
1	Weighted Objectives
2	External Decision
3	Concept Champion
4	Multi-voting
5	Intuition
6	Prototype and Testing
7	Pros and Cons
8	Multi-criteria Decision Making
8.1	*Decision Matrix*
8.2	*Weighted Rating Method*
8.3	*Analytical Hierarchy Process*
8.4	*General Morphological Analysis*
8.5	*Concept screening and scoring*

Table 8. Method for supporting Idea selection and Concept generation

Weighted Objectives

The weighted objectives methods consist in the comparison of utility value of different design proposal, according to the performance against differentially weighted objectives. This method is particularly useful when designers have to manage a set of similar solutions or there is a not clear understanding on what is "correct" solution. The method consist in creates tables, following the steps:

1. List the alternatives
2. Determine & list comparison criteria
3. Layout the Weighted Objectives Table
4. Weight the Comparison Criteria
5. Gather Information
6. Score the Design Alternative
7. Calculate the Weighted Score

8. Find the Total Weighted Score

In running this method, the important aspects are not biases on the pre-weight of the comparison criteria, in order to be impartial in the judgement.

External Decision

The concepts are delivered to clients, customer or other external entity, who will select the preferred solution. (Eppinger & Ulrich, 2015)

Concept Champion

An authoritative member of the development teams chooses the concept accordingly to his personal preference. Of course, this method has a certain degree of subjectivity, but in exchange of the past experience of the member as driver of the decision. (Eppinger & Ulrich, 2015)

Multi-voting

Each member of the team votes the different concepts, and the concepts which received more votes is selected. This technique has many declinations, because of common uses in the industry, but it implies also statistic problem. (Eppinger & Ulrich, 2015)

Intuition

The selected concepts result by feeling of the development teams or some member of the development teams the "best" solution, without any criteria or trade-off in place. (Eppinger & Ulrich, 2015)

Prototype and Testing

A prototype of the concepts chosen is built and tests them, the decision will be taken accordingly to the results of these tests. (Eppinger & Ulrich, 2015). The prototype can be tested by the development team and/or by the users.

Pros and Cons

Each member of the team makes a list of the strengths and the weakness of each concept and after a group decision the concept is selected. (Eppinger & Ulrich, 2015)

Multi-Criteria Decision Making

Multiple criteria decisions making (MCDM) is a branch of operational research, that encompasses a set of methods that explicitly evaluate conflicting criteria in decision making, which are used to typically to facilitate the analysis and selection of decision making alternatives against the pre-define criteria (Belton & Stewart, 2002), used mainly with problem with conflicting objectives. When there is not an optimal solution for a problem, and it is necessary to use the decision makers preference to differentiate between solutions. Solving can be interpreted in different ways:

a) it could be choosing the "best" alternative from a set of available alternatives, where best can be interpreted as "the most preferred alternative" of decision maker.
b) Sets of best alternatives
c) Efficient or Nondominated

Multiple Criteria Decisions Analysis (MCDA) provides different ways of: disaggregating a complex problem, measuring the range by which the options achieve the objectives, weighted the objectives (Soota, 2014).

Here below, a list of methods belonging to the Multi-Criteria Decision Making:

a) <u>Decision Matrix</u>

Decision Matrix is a method invented by S. Pugh (Pugh, 1981), it can be also called Pugh's Selection methods it is a procedural tool for sorting out ideas to achieve the best design approach. This method assumes of "concept vulnerability", and the method is formulated to eliminate or minimized this aspect. Conceptual vulnerability is represented in two ways:

1. The final chosen concept is weak due to the lack of thoroughness in conceptual approach
2. The concept chosen is the best available, but the reasons for its strength are not know or fully understood.

Keeping in mind that it is impossible in absolute sense to evolve and evaluate all possible solution to a particular problem, Pugh introduced the principle of conceptual vulnerability to minimize the possibility of wrong choice of concept. It is a two phases process, phase I consists in sorting out ideas (Pugh, 1987). The basic rules to follow are:

- All ideas and solution proposal has to be generated on the same product specifications
- The criteria against which the concepts are evaluated need to be chosen without ambiguity and misunderstanding between all the participants
- Generate a set of solution to problem by hand, in form of sketches

- Build the comparison and evaluation matrix, generated concepts evaluated against the chosen criteria
- A datum is chosen against which each concept will be compared
- Consider each concept /criterion against the chosen datum, with the following symbol: + (plus) means better than, cost less, etc., or – (minus) means worse than, more expensive, etc., or S means same as datum.
- Look for some concepts particularly strong, if it is not, and the assessment of the individual concepts score are similar, the criteria are ambiguous and needs to be redefine or one or more concepts are a sub-set of the others
- Selecting the strongest concepts to end the first phase.

The phase II consists in the development of the strongest concepts emerging from the phase I. The matrix is refined with revised criteria and more detailed concepts and the first phase is repeated. The end of the phase II leads to the convergence to the "best" possible concept, but since it is not in absolute mathematical sense, the decision remains with the user.

b) <u>Analytical Hierarchy Process</u>

The analytical Hierarchy Process (AHP) is a general theory of measurement, and it can be used to obtain ratio scales from both discrete and continuous paired comparisons. The main concern of this method is on consistency of the measurements and on the dependence within and between the group of elements. This method is a non-linear framework for consider inductive and deductive thinking, by taking in consideration simultaneously many factors and making numerical trade-off to arrive to a synthesis or conclusion. The AHP method can be used to define a measures in both the physical and social domains.

The three main principles of AHP method are:

- Decomposition
- Comparative judgements
- Synthesis of priorities

c) Weighted Rating method

Ulrich and Eppinger (Eppinger & Ulrich, 2015) presented an improved version of the Pugh concept selection methods, called Weighted Rating method (WRM), where the weight of the criteria and the evaluation is done on a scale from 1 to 5.

Relative Performance	Rating
Much worse than reference	1
Worse than reference	2
Same as reference	3
Better than reference	4
Much better than reference	5

Figure 22. DTV combines consumer, supplier, and competitive insights. McKinsey&Co

This increases the resolution of the analysis, without increasing the difficulty of understanding. The team prepares a matrix and identifies a reference concept and criteria with a more detail level. If a hierarchical list of customers exists, the second and the tertiary needs are good to use as more detailed selection criteria.

d) General Morphological Analysis

General Morphological Analysis was invented by Fritz Zwicky, as a method for structuring and understanding the set of relationships contained in multi-dimensional, non-quantifiable, problem complexes.

This method was developed mainly for complex problem in which the complexity is non-reducible, or it cannot be fully described or delineated. The word morphology comes from antique Greek (morphe) and means shape or form, and it means the "study of from or pattern" of parts of object to create the whole.

F. Zwicky proposed as morphology analysis research:

" Attention has been called to the fact that the term morphology has long been used in many fields of science to designate research on structural interrelations – for instance in anatomy, geology, botany and biology. ... I have proposed to generalize and systematize the concept of morphological research and include not only the study of the shapes of geometrical, geological, biological, and generally material structures, but also to study the more abstract structural interrelations among phenomena, concepts, and ideas, whatever their character might be."

(Zwicky, 1966, p. 34)

This method starts with the identification and definition of parameters (or dimensions of the problem complex, and to each parameters a range of values are assigned. A morphological box, also called "Zwicky box" is created, by n-dimensional box containing one particular value or condition for each parameter (figure 23).

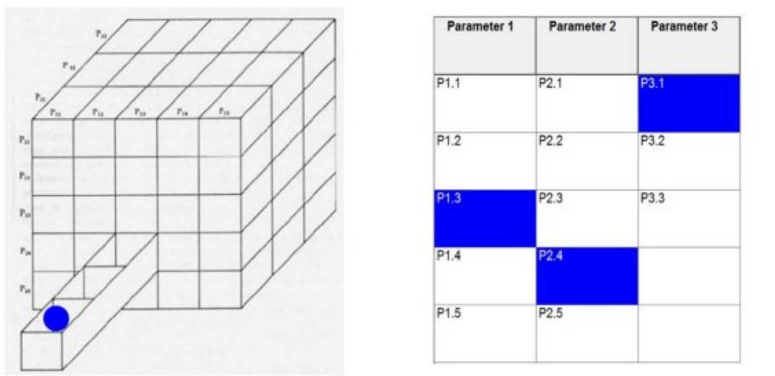

Figure 1a: 3-parameter "Zwicky Box" in typological format, containing 75 (5x5x3) cells (Zwicky, 1969).

Figure 1b: 3-parameter field in morphological format. (The blue configuration corresponds to the blue marked cell in Figure 1a.)

Figure 23. Morphological matrix, called "Zwicky box". Zwicky 1966

This tridimensionality box is a *typological field format*, containing all the possible relationships involved, and since the dimensions of space are three, three is the limits of variables that can be considered in the analysis (typologies of greater dimension, represent hyperspace, if there are more than three dimensions, usually are embedded one each other. To avoid the difficulties in reading 3-dimensional box , it is used *morphological field format,* i.e. the “matrixing” of parameters, in order to uncover the multiplicity of relationships.

The next step in the analysis synthesis is to reduce the total set of possible configurations in a smaller set of internally consistent configuration, the so called “solution space”. Here Zwicky introduced the principle of contradiction and reduction, and the process of “cross-consistency assessment”. The application of this principle allows to identify all those configurations containing this pair of conditions would also be internally inconsistent. There are three type of inconsistencies:

- *Logical contradiction*
- *Empirical contradiction*
- *Normative constraints*

The CCA reduction allow to focus on a manageable number of internally consists configurations.

2.3 Design Activities-Variables comparison

2.3.1 Introduction

After an extensive literature review about a collection of methods to support the main activities, the methods identified in the previous paragraph have been analysed in relation with the selected design variables. This was done for two main reasons:

1. Analysing the state of art of design methodology in supporting smart object design and to highlight possible gaps to understand where further analysis can be done.
2. Creating a framework that can support the analysis of any additional design method and approach, that can be taken into consideration. In this case Objectomy.

To do that, a comparison table has been created, in which in each cell contains the relation between the design variables (the columns) and the design methods classified for each activity they support (the rows).

2.3.2 The Table

In the following pages, the table has been splitted according to the design activities.

Design activities:		Design methods:		Design Variables:				
Phase	Sub-phase	Industrial Design methods	Engineering Design methods	Function (F)	Behaviour (B)	Structure (S)	Architecture	Affordance
Design Task clarification	Needs identification and Problem definition	**Interview**		Asking directly to the customer, to identify the needs and translate them into fucntions				The affodances of the competitor object can emerge with a set of specific question
		Focus group						
		Observation of product in use		From the observation it is possible to evaluate expected fucntions, but also discover unexpected functions	The behaviour of the new object or existing one can be evaluated directly with the potential final users			The affordances can be observed from the human-object interaction, evaluating if the interaction happen naturally or not
		Objective's tree		From the agreement between the client and designer, the purpose of the product has been defined, i.e. fucntions				
		Meta-design		Looking for meaning of technologies, market, user in order to determine value, i.e, functions expected	Looking at the beahaviour of the part of the system allow to discover unxpected fuctions.	The structre is simulated in the system, it is not the real one.		
		Mental/Conceptual maps		From the maps it is possible ordered the concepts with meaning, an idirectly defining the fucntions				
			Performance specification	Setting the performance of the object, imply defining a set of fucntions by which the performance are measurable	The required performance indirectly determines the behaviour of the object.			
			Computational thinking	Decomposing the problem in smaller parts, allow to understand small part to solve with fucntions				
			Quality Function Deployment	The interpretation of the "voice of customer" to be translated into tehcnical requirements implies fucntions definition and undestanding				
			Functional analysis	The functions are organized in the function tree, in order to define the concepts' architecture. The fucntions considered are the "expected" ones	The behaviour is a consequences of the selected functions	Thanks to the function tree, throughout the connections with components, it is possible to determine the structure	From the components connected to the fucntions it is possible to make assumption about the product architecture	
			Design for innovation	Going "beyond the use" Taking into considerations multiple stakeholders, different sets of needs can be analyzed, targeted to the specific stakeholder and obtaining the functions.				

Design activities:		Design methods:		Design Variables:				
Phase	Sub-phase	Industrial Design methods	Engineering Design methods	Function (F)	Behaviour (B)	Structure (S)	Architecture	Affordance
Idea Generation	Internal Search and External Search	**Design Thinking**		In the empathize and define phase, a deep analysis of the problem allow to define functions.	In the prototype phase it is possible to observe the behaviour.			The affordances can be evaluated thanks to the prototyping and testing
		Biomimicry		Find out functions, emulating nature solution for similar problem				
		Brainstorming		The purpose of the sections is to generate ideas that can solve the problem, that can be seens as functions				
		Synectics		From unepexted question new why of solvign problem can arise, that determine new fucntions				
		Scamper		Changing the product or process, the fucntionality can change, i.e. new set of fuction			Interchange, eliminate, adding, subsitute part of the product, i.e. playing woth the product architecture cna help to generate new ideas	
		Enlarge the search space		New fucntion can be discovered by the application of the different technique	New behaviour can be discovered by the application of the different techniques			
		Gamification		Defining the performance goals consists in defining the fuction of the service-system	Defining the UX/UI is an idirect way of defining the expected behaviour of the product or the system			(Digital) affordances can be evaluated, through the experience of the mockup
		Biominicry		Reframe the essential function in biological term	Look at the natural model that address the same function to understand the behaviour		Look at the ecosytem or organisms architecture to be inspired for the product architecture	
		Role playing and scenario			By observing the actions of the participant, it is possible to observe the behaviour of the object and of the users more in detail, discovering new aspect of the interaction user-object			Looking at the acting of the user, and at her/his behaviour, it is possible to evaluate the affordances of the product
			Morphological chart	Making a list of functions or features in order to identify the "means" of the product.		Making a list of "means", i.e., functions by which functions can be achieved, those will determine the shape or form of the object.		
			A-design	The functions are determined as consequences of the interactions between agents.	From the observations of the agent's interactions, the designer can observes the behaviour of the "object"	The structure is simulated with an abstraction of the concpets, at the first hint	The architecture is determined by the multitude of interactions between agents, that generate alternatives	
			System thinking	The fucntions are referred to the system, not a single product or service	Observe how the structure and the decision making process determine the behaviour of a system	Observing the model simulation in order to understand the structure of the system	Creating the model od the system you can determine the product architecture	
			Theory of inventing problem solving	The fucntion is the purpose of the technical system, and the tool is the elements that allow to accomplish it	The behaviour is how the system transform input into output	The engine, the transmission and the tool represnet the structure elements	how tool, engine transmission work together define the technical system architecture	

	Systematic Exploration and Concept combination		**Value Analysis/Engineering**	Create a function chart, and than determine the value or each fucntions		Making a list of all components that compones a product/system or service	It is possible to improve and optimize the architecture of the system	
			Design for X	The functions are already given, but the relationship can change	The behaviour is a consequence of the other variables	The structre has be determined accodring to the X variable selected	The architecture is optimized for manifacturing	
			Classification trees					
			Combinations tables	Thank to combination of solution is possible to derive other solution, i.e., function				

Design activities:		Design methods:		Design Variables:				
Phase	Sub-phase	Industrial Design methods	Engineering Design methods	Function (F)	Behaviour (B)	Structure (S)	Architecture	Affordance
Idea selection and Concept Formulation	Concept selection and Concept formulation	**Intuition**						
		Prototype and testing		The function of the prototype can be evaluated	The beahaviour of the prototype can be evaluated with the testing activitiy.			The affordances (digital) of the prototype can be evaluated in the testing activity.
		External Decisions		The clients evaluate if the function of the concepts satisfy his/her needs	The clients evaluate behaviours of the concepts			The affordances (also digital) of the concepts can be evaluated by clients
		Pros and Cons		Each participant make a list of the pros and cons of the fucntions related to a concept				
		Concept Champion		If the function of the concept meet the requirements is decided by an expert				
			Weighted Obejctives	The set of functions related to each concept proposal are evaluted indirectly by a utility value of the concepts				
			Analytical Hierarchy Process					
			Decision matrix	The functions of a concept are evaluated in the decision matrix, in relation with selected criteria				
			Comparison tables	The same of decision matrix, but with a pre-defined scale rating				
			General Morphological analysis	The set of functions can be evaluated accodringly to selected parameters (with n-parameters)				

2.3.3 Observations

As stands out from the critical observation of the table, traditional methods, that were invented to support the design of technical artifact or system, are mainly focused on the stan-alone artifact or system. The determination of the function is an ex-ante activity, and from them the structure and the behaviour are determined. Following the HCD principles, the analysis of the affordances allows to the designer to evaluate if the artefact is able to communicate the user the natural way by which has to be used.

Digitalization enabled artefacts with new digital capabilities, and the digital artifact are now interactive and adaptable. Traditional methods seem to have become slightly reductive in supporting the design process. More recent methods consider the multiple interactions between artefacts and systems, for this reason these methods are primarily focused on the broad system view. In many cases, a simplified model of the system has been created, in order to run a simulation and observe as the different elements of the system interact with each other. The entity, that can interact and eventually can take decisions is called "agent". Running the simulation will help designers to understand the behaviour of the model, the possible structure as well as the expected functions and might help to discover additional unexpected functions.

Some methods are mainly developed and used in the software industry, rather than physical artefact and they mainly relies on the observations of the behaviour of the system/service. Moreover, thanks to the re-programmability, part of the functions are usually at discretion of the users, (i.e., on-demand functions). However, except for some considerations of the A-design methods, it is clear that there is a lack of methods to support the design of a particular class of digital artefact: the smart object.

3. Objectomy Approach

3.1 Introduction

With the increasing penetration of the Internet, digitalization, and the advent of digital artifacts in consumer home, the two cultures of design and engineering have been focusing on a common interest in *on demand use* and *user experience*. The recent, more design friendly approach to the topic, lead to the introduction of the notions of *Interaction Design and Perception Design* (Moggridge, 2007). The intent in using this approach is that of going beyond the concepts of utility and efficiency, taking into account aesthetic of interactions, quality of use, and the concept of usability change meaning, as well. Interaction design strongly counts on the non-instrumental, emotional, aesthetic, and ethical qualities of the design outcome.

In the past, the tendency was to focus on instrumental and technical aspects in human-computer interaction (HCI), usability engineering and human factor (Carroll et al, 1991). With the digitalization, HCI moves off the desktop to the analysis of the dynamic co-evolution of the activities of people, experience, and artifacts, such as interactive object and environment, that help these activities to be accomplished. HCI becomes understanding and evaluating the interactive technologies people use and experience, and how those interactions evolve as people appropriate technologies, in other terms, understanding human practices and activities become important as requirements and design opportunities, in order to explore design species and creating new system and devices through the co-evolution of activity and artifacts, the task-artifact cycle (Saffer, 2006).

That said, while the design process of physical artifacts and non-physical digital artifacts is supported by a variety of methods and tools, the design of physical digital artifacts seems to miss a consistent approach. Objectomy approach has the premises to support the design process of interactive and evolutive objects/systems, like autonomous vehicles, smart objects, etc.

Obejctomy approach derives from a design philosophy developed and implemented in Chris Bangle Associates, managed by Chris Bangle. This chapter is an attempt to provide an analytic study and an exhaustive description of this approach, at its current state of art, by a theoretical comparison with the main current design methods, analyzed by the academic literature.

3.2 Design principles

"Objectomy means to project yourself to the mind of the object,
to begin to see the world as it sees it, through its own physicality,
to understand its hopes, its dreams, maybe even its own limitations"

(Bangle, 2020)

Objectomy consists in designing with an object and not against it, it gives us a perspective through the "character" of the object itself. The object can be represented as an agent that acts in the environment, having interactions with other agents or with the environment. For the scope of this paper, "object" represents an abstraction of a product, service or system, both tangible and intangible part of the artifact. Recalling and re-elaborating some assumptions of A-Design method:

- The objects are animate, i.e., "objects are alive"
- The objects are able to interact, so can be considered agent-based object

- The objects are able to adapt and evolve

This is applied for all the selected objects that are considered in the design process. This process leads to a system architecture, that works through a multitude of agents, that interacts with each other. In other terms objects are “living creatures”, they act following their purpose, with the intent of answering the question:

- “What this object wants to be?”
- “Which emotions the object can feel?”
- “Which are the dreams and the desires of the object?”
- …

These questions can seem odd, for technical people, but they represent a way to enter in the right mindset to apply Objectomy. Translating these questions in a concrete way, they represent a tool to have a holistic view of the object life, i.e., over the whole product/service lifecycle. The object and the human create a sociotechnical system, in which the interaction and the purpose of the object “shape” the artefact, in the same way as the human defines himself by the interacting in the society.

These considerations change the “groundlogick” of the game: the designer has to change the point of view and also the criteria on which the design process is evaluated, in order to avoid taking for granted (with the same priority) traditional criteria of usability, desirability, ergonomics, aesthetics, etc. Quoting Chris Bangle, during an advance design workshop: “Real innovation happens when an innovator sets his sights of the groundlogick, why? It’s the one area that nobody thought to leverage change to their advantage”.

The principles of Objectomy can be described by the framework in (figure 24), to obtain a concept of the object (product or service or system). The FBS model of J. Gero, is here recalled and it is readapted for the scope of this paper.

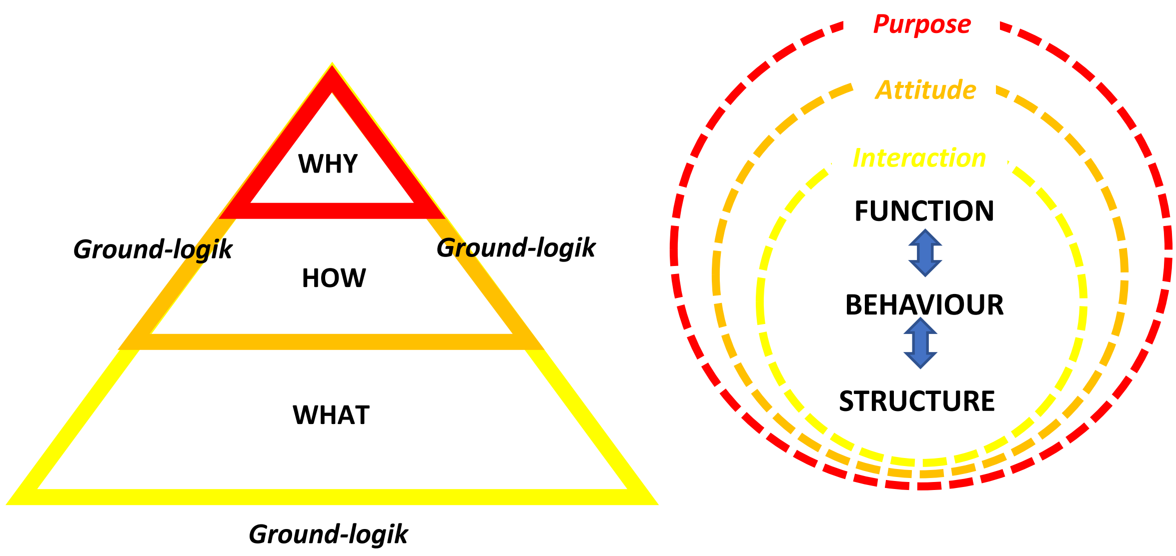

Figure 24. Objectomy framework

The FBS framework is encompassed by the "Purpose of inner life" of the object (Sapper, 2008), i.e., the meaning behind the object, that answers to the question: "why does it exist?". The object, during its lifecycle, acts through "interactions" that answers to the question "what does it has to do?" with the aim to fulfill its "purpose of life (life cycle)". This is done in accordance with its "attitudes", that answer to the question "how does it act?" (configurations). The attitude is a way of thinking of the object, temperament and viewpoint concerning external condition. Defining the attitude is important to know, how its temperament is influencing the way in which it acts. The interaction is something that generates an effect or an influence on something. The interaction can occur with another object or human, or in the object itself, for this reason the interactions are classified as follows:

- *Thing-to-Thing (T2T)*: it represents the whole bundle of actions that can occurs between an object and another object (also vice versa), or the object and itself.
- *Thing-to-Human (T2H)*: It represents the whole bundle of actions that can occurs between an object and human (also vice versa)

Both type of interaction can be tangible and intangible, for example, the interaction can be an exchange of data (intangible) or a physical actuation (tangible). Of course, the interaction can happen one or more time, and between one or more object and human, they can also be repeated.

The Function is “what the object does”, an object can do many functions, part of them is “expected” and part is “unexpected”. The Behavior is how the structure of the object enables the functions, i.e., the way by which the object accomplishes the functions. The Structure is all the working principles, tangible, or intangible (hardware and software) that allow the object to behave in the desired way.

3.3 Design practices

Objectomy approach is a three-stages process, that support the problem analysis and understanding and the conceptual phase of a design process. The different stages are sessions, led by a moderator in which all the participants are involved, and free to unleash new ideas. The three stages happen sequentially, even if the outcome of each one can be redefined each time, reiterating the process. The process is illustrated in (figure 25)

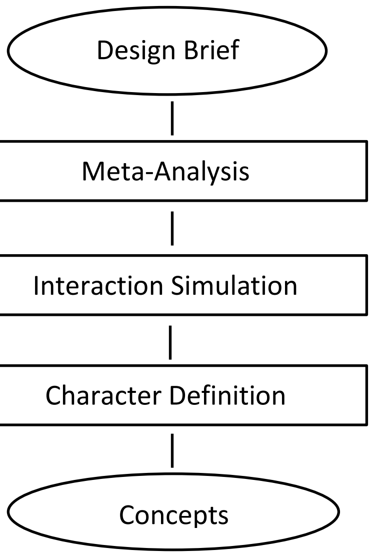

Figure 25. Objectomy, three-stages approach

3.3.1 Meta-analysis

Starting from the design brief, a meta-analysis of the problem is pursued to do a deep exploration of design problem, in which the outcome will be the boundaries of the problem, and a list of main agents involved (during the sessions they are called "actor"). This analysis is done with an abstraction process, and a series of questions and answers between the participants, it is mainly semantic based, and it required a multidisciplinary approach, with as much variety as possible among participants. This will help to view the problem from a different perspective and collect variegate ideas and feedbacks.

3.3.2 Interaction Simulation

Once the design domain and the actors involved are defined, the participant runs a model simulation, by role playing in a real environment (if it is possible), by impersonating the object selected, or by storyboarding, sketching or by computer simulation. The outcome of these stages is a collection of actions taken by the object and interactions between object and human or human and object.

3.3.3 Character Definition

From the analysis of inter-actions, a series of "attitudes" of the object and a list of possible "events" in which the object and human are involved can be determined. The attitude can be seen in analogy with the concept of configurations, that determine the way by which the objects act. Basically, the same function can be accomplished with different behaviours according to the chosen attitude. This stage allows a deep understanding and a definition or re-definition of the meaning of the "object", in agreement with Norman and Verganti, that state: *"design is meaning, without meaning you have no design"* (Norman et al, 2020). In other terms, it allows to define the purpose of the inner life of the object.

3.4 Objectomy applied to Smart Object

Following the evolution path of smart object and IoT and starting with the idea of "ubiquitous computing" introduced by Mark Weiser (Weiser, 1991) in the article "The Computer for the 21st Century" published in 1991, the smart objects, with their embedded computation capabilities, allow the distributed computing, and so, there is no more perception of the technology itself, but only of the interaction with it, all around us, to match our social behaviour and to support/guide our everyday activities. The prevision of Weiser was not completely correct: the technology is still perceptible today, even if it is mostly hidden to the user eye and it is manifested mostly through object-user interactions. In this environment, Smart Objects play a fundamental role as they represent the vehicle to these interactions.

Following the definition, obtained in the paragraph 2.1.2 of this paper, smart objects are characterized by the capabilities, such as communication, interactivity, awareness, identity, etc. All these terms are usually intended for, and belong to the realm of, sentient being, such as animals and humans, that are living creatures. For these reasons, Objectomy seems to be the design philosophy that better suits the smart object design, as it encompasses all these concepts. It projects the designer in the mind of the object and leads the designer to act and think as the object, in order to design the character and the story, in which the object can be involved.

The designer should think about the object, not as a stand-alone artefact, but as an agent that acts in the environment and, as such, has its sociality in the system of objects and humans. Thinking like that provides a support in the process of taking into consideration social dynamics into the design process. It also leads the designer to better evaluate the consequences of the interaction of the object with another object and human. The complete freedom from the technical boundaries allows the designer to go beyond the classical exploration of new ideas, pushing the frontier of the imagination and doing a clearer evaluation of the meaning and ethics of the objects, and of the use of the technologies, moving far from the rule of thumb: "If it works, it is ok". Starting from the character ideation, rather than from the object ideation, allows the designer to better evaluate the social and ethic aspects of the object and, only later, to evaluate the technologies that need to be embedded in the product.

3.5 Objectomy in the design methods-variables comparison

3.5.1 Introduction

Objectomy approach can be now compared with other methods in relation with design variable. To do so, the approach is inserted in the Design Activity – Variable table, as design methods. This is illustrated in the table at the following paragraph.

3.5.2 The Table

The table shows Objectomy's position in the framework created in chapter 2.

Design activities:		Design methods:		Design Variables:				
Phase	Sub-phase	Industrial Design methods	Engineering Design methods	Function (F)	Behaviour (B)	Structure (S)	Architecture	Affordance
Idea Generation	Internal Search and External Search	**Design Thinking**		In the empathize and define phase, a deep analysis of the problem allow to define functions.	In the prototype phase it is possible to observe the behaviour.			The affordances can be evaluated thanks to the prototyping and testing
		Biomimicry		Find out functions, emulating nature solution for similar problem				
		Brainstorming		The purpose of the sections is to generate ideas that can solve the problem, that can be seens as functions				
		Synectics		From unepexted question new why of solvign problem can arise, that determine new fucntions				
		Scamper		Changing the product or process, the fucntionality can change, i.e. new set of fuction			Interchange, eliminate, adding, subsitute part of the product, i.e. playing woth the product architecture cna help to generate new ideas	
		Enlarge the search space		New fucntion can be discovered by the application of the different technique	New behaviour can be discovered by the application of the different techniques			
		Gamification		Defining the performance goals consists in defining the fuction of the service-system	Defining the UX/UI is an idirect way of defining the expected behaviour of the product or the system			(Digital) affordances can be evaluated, through the experience of the mockup
		Biominicry		Reframe the essential function in biological term	Look at the natural model that address the same function to understand the behaviour		Look at the ecosytem or organisms architecture to be inspired for the product architecture	
		Role playing and scenario			By observing the actions of the participant, it is possible to observe the behaviour of the object and of the users more in detail, discovering new aspect of the interaction user-object			Looking at the acting of the user, and at her/his behaviour, it is possible to evaluate the affordances of the product
		Objectomy		The function is what the object do to accomplish its purpose, the fucntions are derived after the definition of attitude and actions	The behaviour is the way by whihc the function is accomplish, the behaviour refers to the desired behaviour	The structure is the working principle or group of working principles, tangible or intangible that enable the behviour	System architecture are proposed and simulated in the inter-action simulation	The affordances can be evaluated from the observation of the human to object interaction in the inter-action simulation
			Morphological chart	Making a list of functions or features in order to identify the "means" of the product.		Making a list of "means", i.e., functions by which functions can be achieved, those will determine the shape or form of the object.		
			A-design	The functions are determined as consequences of the interactions between agents.	From the observations of the agent's interactions, the designer can observes the behaviour of the "object"	The structure is simulated with an abstraction of the concpets, at the first hint	The architecture is determined by the multitude of interactions between agents, that generate alternatives	

	Systematic Exploration and Concept combination		**Value Analysis/Engineering**	Create a function chart, and than determine the value or each fucntions		Making a list of all components that compones a product/system or service	It is possible to improve and optimize the architecture of the system	
			Design for X	The functions are already given, but the relationship can change	The behaviour is a consequence of the other variables	The structre has be determined accodring to the X variable selected	The architecture is optimized for manifacturing	
			Classification trees					
			Combinations tables	Thank to combination of solution is possible to derive other solution, i.e., function				

3.5.3 Observation

The Objectomy approach is important for smart object design because it proves very difficult to design the smart object starting from the functions framing, since smart object is an interactive and changing object, i.e., a dynamic and adaptive system. Furthermore, according to Objectomy approach, this evolution of the object should be coherent with its purpose. Since the objects are considered as living creatures, not "static" objects, but instead interactive and "dynamic", the objects evolve during their life cycle, in different manner, upgrade, improvement, etc. This assumption seems to fit well the smart object design that simulate many common aspects of a living being. This has been confirmed from the relations created with each design variable, As it is possible to see from the table. Objectomy approach allow to explore all the design variables in the conceptual phase.

4. Analysis and Use-case

4.1 The Projects

In this part, two innovative projects, conducted in Chris Bangle Associates, are analysed. For company's policy, all the projects are under non-disclosure agreement, thus, for privacy reasons the company's name, participants' name and part of the results will not show in this paper. Some of the common aspects of these projects are:

1. Strong focus on the user experience and customer journey
2. No distinction between the product and related service
3. Absences of predetermined of creative boundaries in the conceptual phase
4. Objectomy approach as the design approach used for developing the projects
5. Ex-novo multidisciplinary projects

The first project analysed is called "The kitchen of the future", and it consisted in a series of multidisciplinary workshops with marketing, engineering, and design departments of a consumer-good multinational company. The mission of the project was creating a new experience in order to better understand the potential of new design processes for the participants, as well as generating unique ideas for future products.

The second project is about an "Megacity vehicle concept": it was conducted as brainstorming sessions between designers and engineers of a newco in the automotive industry, with the purpose of redefining the customer experience and the business model of the product and of observing the implication of those on the product characteristics and style.

4.2 Methodology

To highlight the peculiarities of Objectomy approach, here it is chosen to explain how the two projects were conducted and to show the obtained results. The parallel analysis of the two projects, that differ in the product-service of interest, but are similar in the design process applied, will allow the paper to underline the common principles in the two examples, that define and characterize the Objectomy design approach in all its applications.

Considering that, the application of Objectomy approach strongly relies on tacit knowledge, it is related to the training and engagement of the participants, the modality in which the approach is applied may show some differences, nonetheless, the design principles will be the same in both contexts.

4.3 Projects

4.3.1 The kitchen of the future

The first stage is the Meta-Analysis, it started with a session in which all the participants undergo round of questions-and-answers about the design problem and context, with the intent of defining the main actors (human and thing) and the design domain, in this case the kitchen environment. Below, the actors identified are listed in the (table 9)

Human	Thing
Mam	Fridge (and freezer)
Dad	Stove (and oven)
Child	Dishwasher
Friend	Washing machine
Guest	Hood

Table 9. List of human and object actor

It is implicit in the discussion about the design problem, questioning the purpose of the different identified objects. These are listed by each participant, but are not shown to the other.

The second stage is Interaction Simulation has been conducted as role-playing acting. Each participant was asked to impersonate one actor, based on the personal feelings about a specific object, and to interact with each other. In other terms, each participant was asked to take on the personality, and talk and act, as if the home appliances were living creatures. The acting was led by a moderator, and someone oversaw taking notes of all the acting, with sketching, texting, or storyboarding, or filming.

The outcome of this acting resulted in a collection of interactions of the object that can be classified in different types of interactions: Thing-to-Thing and Thing-to-Human. In part it has been decided to show the case of the fridge is the protagonist, in the (table 10):

Thing-to-Thing (T2T)	
1	The fridge talks with the stove to support the user in the cooking process
2	The dishwasher understands which object, mom is putting inside, and it suggests the best place for it
3	The stove communicates with the hood, that is turning on, the hood is ready to fan
4	The fridge clean itself
5	The fridge instal the upgrade of the embedded software
6	The fridge adjust the temperature accordingly to the food inside
n	....
Thing-to-Human (T2H)	
1	The dishwasher communicates to the user that needs to be opened after the washing cycle
2	The open fridge communicates to the user that is leave it open
3	The fridge communicates that inside the fridge is missing some frequent used food/drink
4	Mom looks in the display to set up the dishwasher cycle
5	Mom wants to open the fridge door without using hands
6	Dad is doing shopping and he want to know which item are missing in the fridge
n	...

Table 10. Interaction list

In the third stage, the Character Definition, from the list of interactions, it is possible to determine the role (in the design domain, in this case the kitchen environment) of the objects, and a series of situations in which the object is involved, that are called “events”. The possible events related to the actor and the context, are defined, and classified in term of frequencies (in this project) in which they happen in everyday, sometimes, rarely and special. In the case of fridge as protagonist:

1 Everyday:

a. The fridge refrigerate stuff (food, drink, etc…) at a certain level of temperature

b. The persona needs support on cooking activities

c. ....

2 Sometimes:

d. The fridge is dirty outside

e. The fridge is dirty inside

f. The persona (mom, dad, etc…) has to fill the fridge after shopping

g. …

3 Rarely:

h. The freezer compartment is full

i. The persona needs ice quickly

j. …..

4 Special:

k. It is the birthday of the user

l. Release of the fridge's system upgrade

m. ….

Another outcome of the interaction simulation is a series of questions about meaning of shape, characteristic, meaning of the object, etc. From that list, all the participants are asked to answer a meta-level question "which is the purpose of the inner life of the "x" object?" (Where "x" is one the object considered before). In other terms, it is required to the participants to do an abstraction to find a higher-level interrelationship, which is more generic and comprehensive. Following the previous example, here below some of those answers:

1. As a fridge, I can be a nutritionist

2. As a fridge, I can be a personal food shopper

3. As a fridge, I can be the kitchen's hub

4. As a fridge, I can be a sous-chef

From here on, these sentences have been seen as the “purpose of the object”. Some purpose resulted higher than other, and it can imply other purposes, for this reason it was decided to use the “fridge as the kitchen’s hub”.

After that, the personality of the object has been created, with the intent of defining the “attitude”. The participants were asked to list the desired personality traits of the object, in this case of the fridge, after a little bit of sematic elaboration:

1. Personal assistant
2. Helping friends
3. Silent servant
4. ….

After the definition of the attitude and events list, the events-attitude matrix is created, and each cell represents the relationship between the two, the way by which the object act in row-event and with a column-attitude is a function, and these is not related to a specific technology or existing object, but just a meta-object.

To determine the function, it asked to all participants to sketch a storyboard with a text explanation or making video simulations or quick and dirty prototype (such as paper prototype), below for the fridge example in table 11.

Event-Attitude matrix			Attitude			
			Silent servant	Personal Assistant	Helping friends	...
Events	Every day	The fridge refrigerate stuff	Fridge refigerate with less noise possible or has a silent mode			
		The user open the fridge	The fridge help the user in the opening and closing phase, incrase or decrease the force needed Self opening /closing door Soft closing door	Door opening/closing on voice command When the user open the door in the morning the interior light adjust the intensity		
		The user needs support on cooking		The fridge remind to the user the food near to deadline	The fridge suggests recipes that can be made with the food store inside	
		...				
	Sometimes	The user want to buy food and drinks	The fridge make a shopping list			
		The fridge is dirty outside	The outside surface of the fridge is made of self cleaning material	The fridge remind to the to clean the exterior surface	The fridge suggests best to clean the outside surface of the fridge	
		The user leave the door of the fridge open	The fridge close the door itself	The fridge notify the door is open	The fridge notify the door is open	
		....				
	Rarerly	The user needs ice quickly	The freezer has a device for rapid ice making	The fridge keep constant the level of ice or super freezing function		
		The freezer box is empty	The freezer compartment turn off			
	Special	User's birthday				
		Release of fridge's system upgrade			The fridge communicate the release of a new upgrade with "celebration mode"	
		...				

Table 11. Event-Attitude matrix

Here below, a list of consideration raised from the application of Objectomy approach in the project:

- the home appliances considered in the analysis have to be considered as “stand-alone” devices but also as part of the “kitchen system”. The objects can have different roles, as in this case the fridge plays the role of protagonist most of the time. This means that the humans give it more priority in the interaction with respect to the other objects.
- This new perspective has important influences in the way in which the hardware (shape, technical, etc.) and the software (programming logic, network protocol, etc.) are designed, enlarging the research space to new design alternatives.

- Defining the object's Attitude implies the definition of possible configurations that the object can assume during its lifecycle. According to the attitude chosen, the same object can accomplish the same or similar functions in different ways. An example is the necessary function of refrigerate stuff, that can be done in "silent mode" if it is night-time, or if the user is in a work meeting, or in "normal mode" if there is no needs of low noise.
- Asking the participants to be in the mind of the object, and being helpful to the user, allows the designer to define the "self-closing door function", in the case of the fridge. Most of the current models on the market, when the door is left open, communicate the problem to the user (via sound, text, message, etc), but an intuitive solution can be the "self-closing door" function. From the same intuition the door can close like a luxury car door, with the "soft-close" function. Additionally, for instance, the fridge can be designed to be a self-cleaning fridge with an internal washing system. The door can have an electro-controlled glass, that changes colour from black to transparent when the user touches the glass, and until the user chooses the item, indicating it, the fridge door does not open for energy saving.

4.3.2 Megacity vehicle concept

In the design brief arise, that in the big urban conglomerate cars are use for 10% of the time and 90% they are parked or stopped on road or garage. Furthermore, in the 10% of the time most of the cars are stuck in the traffic of the main roads. This problem is a kind or ill-defined problem, in which it is very difficult to find out a "best" design solution. Considering that these kinds of problem are not knew in the automotive industry, and in the recent story there are full of attempts to solve these problems, plus and minus successfully, the design team takes the decision of not following a traditional design approach. This was not an attempt of put in discussion the automotive paradigm but changing the starting point results in a change of priority in the criteria used in the design process.

In the meta-analysis, the starting point was not the same of a traditional automotive project, instead it was to create a space, with pre-defined geometric boundaries (i.e., the dimensions of a mini car), and fulfil this space with all the experience possible including the mobility experience. Furthermore, instead of selling an object in which is value is define by the 10% of the using time, trying to enhance also 90% of the time of the same object. The results were an inversion of the traditional design concept development of a traditional car, from the exterior to the interior, Instead it was from the interior to exterior, the process was called "inside-out design". The challenging part was that the process started from the definition of the inside, and the exterior volume was defined ex-post the interior.

There were identified a series of human actor the object actor, the vehicle, as in the table 12, and the design domain was the interior of the car.

Human	Thing
Mam	Vehicle
Dad	Road Infrastructure
Kids	Other Vehicle
Businessman	…
Techno-geek	

Table 12. List of human and object actors

The second stage is the Inter-action simulation, it has been used a wood mock-up, with the purpose of understanding the different type of interactions. The simulation was led by a moderator, and someone collect images, videos, but also sketches and storyboards. The outcome of this stage was a collection of interactions object to human, human to object and object to object, as indicated in the table 13.

Thing-to-Thing (T2T)	
1	The vehicle communicates with other vehicle the availability of a parking lot nearby
2	The vehicle communicates with other vehicle to do a consumption challenge
3	The vehicle park itself autonomously
4	The vehicle activates and regulate the intensity of the wiper system
5	The vehicle going into the charging station autonomously
6	The vehicle adjusts the temperature before and during the use of the interior space
n	....
Thing-to-Human (T2H)	
1	Businessmen use the infotainment of the vehicle to do a presentation inside the car
2	Techno-geek use the vehicle to playing game
3	Humans choose the driving mode
4	The vehicle adjusts the seat according to the human are going inside
5	The vehicle adjusts the seat layout according to the desired onboard experience
6	The vehicle communicates advertising to the human
n	...

Table 13. Interaction list

After the Interaction Simulation, the next stage is the Character Definition. From the list of interactions, it is possible to determine a series of situations, in which the actors are involved, that are called "events". The possible events related to the actor and context, are classified according to the protagonist actor involved. For example, in the table 14:

Vehicle	
1	The vehicle has low battery, and goes to charge itself
2	The vehicle goes from the parking place to the pickup point of the user
3	The interior temperature of the vehicle is too hot for human passenger

4	…
Businessman	
1	Organizing a private meeting inside the vehicle
2	Working on the vehicle, while is stop in the parking lot
3	Changing clothes after work to have a run
n	…..
Mom&Dad	
1	Changing baby dirty clothes on the vehicle
2	Store in trunk a lot of stuff for kids
3	Going to shopping for kids or other
n	…
Techno-geek	
1	Playing games with friend on the vehicle
2	Using the pc on the vehicle
3	….

Table 14. List of events

From the question-and-answer sessions, all the participants must answer a meta-level question "which is the inner purpose of the vehicle"?

1. As a vehicle, I can be a private mobile space
2. As a vehicle, I can be a shared mobile space
3. As a vehicle, I can be an on-demand mobile space
4. …

From the purpose analysis, it arises an important discussion about the private or sharing model, because this should have a lot of implications in the development phase. The final decision was about the private mobile space.

Defined that the "attitude" of the object has been defined. For example, some of them:

1. Personal mobile assistant
2. Sharing mobile space
3. Dynamic mobile space
4. Comfy mobile space
5. ....

Having defined the attitude and the events list, the event-attitude matrix can be created, each cell represents the relationship between, the row and column, the desired behaviour, how the outcome of the object is expected. Also, in this case the function is not strictly link a particular product or concept, but a meta-object.

Event-Attitude matrix			Attitude			
			Personal mobile assistant	**Sharing mobile space**	**Sport mobile space**	**...**
Events	**Mom&Dad journey**	Going to shopping with kids	The rear window change the trasparency accordingly to the sun intesity to avoid UV exposure to kids	The ceiling of the vehicle display light game to entertain kids during the trip		
		Changing baby dirty clothes on the vehicle				
		Store in the trunk stuff for kids	Rear seat slide forward to increase the trunk space			
		...				
	Businessman journey	Organizing a private meeting inside the vehicle	The vehicle reconfigure the seat layout to host a meeeting, with windscreen become a wall projector	The vehicle is not available for the booking time, to ensure a private meeting		
		Working on the vehicle, while is stop in the parking lot	The vehicle layout for office mode, automatic setting of temperature and humidity and air purifier			
		Changing clothes after wotk to have a run	The vehicle configure the the seat leayout in order to leave space for clothes changing and goes in privacy mode (obscure the window)	The vehicle configure the the seat leayout in order to leave space for clothes changing and goes in privacy mode (obscure the window)		
		Going from home to the working place	The vehicle configure for driving mode, activing the AC system, and set cockpit and the seat for the driver	The nearest vehicle available arrive to the home, in driving mode	The vehicle change is setup, with sporty mode, and suggests a road, in which the user enjoy to drive.	
		...				
	Techno-Geek journey	Playing games with friends on the vehicle				
		Using the pc on the vehicle, while is stop in the parking lot				
		...				

Table 15. Event-Attitude matrix

Here below, a list of consideration raised from the application of Objectomy approach in the project:

- Thanks to the application of this alternative design approach, a new concept of vehicle raised, not only in terms of "shape" (hardware or software), but in terms of business model as well. For example, when the user is in the car and he/she is not driving, many different activities can be done, and the vehicle can become a provider of services.
- In relation to the attitude, the vehicle can accomplish the same function in different ways. For example, considering an essential function of the vehicle, i.e., moving from A to B humans or things, the way in which can be done implies a completely different experience: If the vehicle goes from A to B with a "Comfy" attitude, this implies a quiet travel, adaptable suspension to absorb roughness of the road, a specific driving mode, etc.
- Looking in terms of system and interaction between different actors, it is useful for the designer to have a broader view, and not only fix his mind on the stand-alone object but on the system dynamics, but also to take into consideration the whole lifecycle of the object.
- Of course, new functionalities and a new degree of autonomously in the activity conducted by the vehicle has been explored.

Conclusion

Since the word design was introduced in its meaning as project activities, its specific meaning has been constantly changing, and it is still changing today. This can be the reason why the designer's job is a peculiar mix of activities, knowledge, experience, intuition, creativity, and so on. The designer's job is a complex process, that sometimes happens in a quite predictable manner and sometimes seems to occur spontaneously. The research of methods, approaches, tools, and techniques, that support design, represents an attempt to understand with a scientific view how the design process occurs and how it is possible to obtain a "better" result (better can be seen from many different perspectives, and it is intended in the broadest possible sense).

This work has been pursued, with the aim of supporting the stream of literature about design methodology (design science, according to Simon's definition, Simon 1966). In this paper, a framework is structured in order to provide a comparative analysis the relations between different design methods and the design variables and the way how this each relation provides a different support to the design process activities as a whole. The design process of a particular category of artifact, namely smart objects, has been chose for the analysis. This category of artifacts is complex to design due to their interactive and changing nature, consequence of the fact that they are part of a broader system: the so called Internet of Things. For this purpose, a new definition of smart object it has been proposed as well as a schematization of the design process in three macro-activities: Task Clarification, Idea Generation, and Idea Selection. Furthermore, a selection of design methods and variables are inserted in the comparative framework, as rows and columns respectively, and, where possible, each cell has been fulfilled with the relation between the two.

The framework displays how most of the methods are focused on the variable “function”, that focuses on defining what the object is supposed to do. This may be achieved in many ways, some of them appear more abstract and some more concrete, however during such process most of the time the “structure” and also the “behavior” variables are defined. Some methods build the structure of the product around the relations of the functional elements, to define the relations of the functional methods also means and involves at the same time to define the “architecture” of the product.

The methods that support the Idea Generation activity are focused not only on what the object is supposed to do, but also how this can happen, and they help the designer in generating a span of possibilities. For this reason, some methods help to define the desired behavior of the object, that is generally different from the behavior generated by the structure. The use of methods to supports the design activities is fundamental to deal with the complexity of design processes of a smart object.

In the same paper, the framework has been used to study a new design approach called Objectomy. This approach has been derived from Chris Bangle’s design philosophy, that bases its origins in the car design culture and tradition. The aim of the approach is that of projecting the designer in the mind of the object, in order to understand the essence and the meaning of the object itself. Adopting this new point of view allows the designer to temporary detach his mind from the technical functionalism of the object, to enlarge his/her searching space to find new idea/concepts and to better discover the object’s perspective in its interaction with the humans, with the aim of better understanding how the object can assist, support, and help the human. Objectomy can be considered as an alternative and a complement of the current design approaches, by offering a new perspective on the conceptual design, with the aim to explore a broader spectrum of aspects. For this reason, as it happens with lateral thinking, Objectomy allows us to explore unexpected features, non-obvious aspects, of the design research of a design project. In other terms, Objectomy can be considered a new support to creative thinking in the design of Smart Objects, as well as in other fields of design.

Limitation and further research suggestions

To develop the framework for the analysis of the design process, were taken into consideration some of the design variables that are usually used. Nonetheless, other possible variables intervening in the design process may be taken into consideration, in particular in the Idea Selection activity. The schematization of the design process in three macro-activities, does not allow to take into account the complexity of the design process entirely. The correlated topics of Artificial Intelligence, Machine Learning, Deep Learning, Neural Networks, Industry 4.0 are not discussed in this paper. However, for practitioners, the framework can be considered a starting point for further analysis of new design methods with more design variables.

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