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Design Function in Innovation Processes*

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ABSTRACT
Some words emerge at a given moment to catalyse ideas and give new meaning to old terminology. *Innovation* and *design* are two such words. Innovation has traditionally been linked with the Applied Sciences, especially technology, whereas advances in the Pure Sciences tend to be termed *discoveries, inventions,* or *creations*. However, for decades now, innovation has been a *leitmotiv* in all fields of scientific knowledge in both the Pure and the Applied Sciences. Design has also emerged from the niche it once occupied for decades (and even centuries) at least insofar as its impact on the History of Science and of Philosophy is concerned. In fact, design's introduction into the academic world has gone hand-in-hand with Art and its impact on our daily lives. This paper analyses innovation processes in both the Pure and the Applied Sciences to discover how far new design theories over the last few decades have influenced innovation in fields such as Epistemology and Technology. We focus on Design Epistemology and methodological innovation, specifically in connection with design simulations and methodological models. We also look at the underlying design technologies and the key role they play in innovation processes.

Keywords: design epistemology, innovation, computer simulation, methodological model.

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Certain words emerge at a given moment to catalyse ideas that previously had other meanings. Two examples of this are the words *Innovation* and Design. Innovation has traditionally been associated with The Applied Sciences, especially technology, while changes in The Pure Sciences used to be classified as simply discoveries, inventions or creations. However, over the last few decades 'innovation' has been applied to all areas of scientific knowledge in both the pure and the applied sciences (Estany and Herrera, 2016).

Design has also emerged from the niche it once occupied for decades (and even centuries) at least insofar as its impact on the History of Science and of Philosophy is concerned. In fact, Design's introduction into the academic world has gone hand-in-hand with Art and its impact on our daily lives. It is hard to chart this shift but maybe The Industrial Revolution (with its mass-production methods) played a key role in Design's penetration into all fields of knowledge. The goal of this paper is to analyse innovation processes in both the Pure and the Applied Sciences to reveal the extent to which Design in recent decades has shaped innovation in fields such as Epistemology and Technology. While innovation can be approached from many perspectives and disciplines, we shall focus on the relationship between Innovation and Design. To this end, we will concentrate on: (1) Design Epistemology — a new perspective that entails innovation in the epistemological field; (2) simulation and methodological design models. In tracing these two strands, we shall consider Pure, Applied, and Design Sciences. Technology underlies all these scientific fields, playing a key role in innovation processes. Here, one needs to see the role played by design in technological innovation, and how it is reflected in artefacts and system modelling.

First, an overview is given of the main features of the concepts of innovation and invention. Second, the penetration of Design in sundry fields of knowledge is examined together with the Epistemology of Design and kindred concepts. Third, we delve into the role played by simulations in scientific research as epistemological innovation, and its practical applications. Fourth, we present McCrory's design methodology scheme, based on the proposals made by Herbert Simon in his work *Las Ciencias de lo artificial* (1996), and by the philosopher Ilkka Niiniluoto on Design Sciences, found in his paper "The Aim and Structure of Applied Sciences" (1993). Fifth and last, we propose a design culture as a framework for a comprehensive approach to invention and innovation. Each of these issues might merit a paper on its own but limitations of space means that we shall confine ourselves to a strategic overview. Many authors have written on these subjects. Our citation list is necessarily selective, focusing on those we consider to be most relevant to this paper's scope.

INNOVATION AND INVENTION

One might say that the world revolves around innovation. There is no theoretical or practical field that does not involve innovation — business, labs, cuisine, sports, the Arts, and Science, to name but a few. There is also a plethora of technological changes that occur in the Motor, Health, Energy, and Communication industries. Innovation covers achievements in Applied Science and to solving practical problems just like invention, ranging from the wheel and writing to the printing press and the telephone.

As a starting point we link innovation to Applied Sciences and changes in Pure Sciences to discoveries and creations. That said, the meaning of these concepts has changed within the framework of the philosophy of scientific practices and there are references to innovation in the descriptive sciences and discoveries in design sciences. For example, Brown (2009) refers to conceptual innovation in Physics (Galileo) and Chemistry (Proust and Dalton) yet these scientists were usually considered discoverers. Brown argues that Design is a way of approaching scientific dynamics from a less disruptive and more gradualist perspective. Nancy Nersessian (2009) refers to conceptual innovation as the changes that take place in some of the most important episodes in the history of Physics. In general, the idea of discovery in the descriptive sciences is understood as the contribution of new, substantive knowledge that boosts Man's ability to explain the natural and social world. Brown and Nersessian draw on this concept to re-label what were formerly considered 'discoveries' as 'conceptual innovations'.

The idea of innovation is clearly polysemic, thus a conceptual analysis is needed to find a common denominator among its features. We shall see that the definitions below, which are taken from Estany and Herrera (2016)[1], cover the Applied and Design sciences, although this is not made explicit. Some of these definitions draw a distinction between invention and innovation.

- 'Invention' (creation of a new idea) and 'innovation' (first use of a new idea) are both closely related to the word 'technique' (Edgerton, 2013).
- Innovation is the generation, acceptance and implementation of new ideas, processes, products and services (Shavinina, 2003).
- Innovation is defined as the set of original actions aimed at providing solutions to previously unsolved problems, in a unique and creative way (Renzulli, 2003).
- Invention is a breakthrough advance and innovation is its updating (Florida, 1990).
- Invention is the creative origin of a new process, which facilitates innovation with an impact on social, economic and financial processes (Hindle, 1986).
- Innovation occurs when some individuals produce new solutions and relevant members of this domain adopt these solutions, considering them valuable variations from common practice (Bailey and Ford, 2003).
- The term 'innovation' has two somewhat different meanings. The first refers to the invention, creation or discovery that provides something really new and useful. The other meaning is the adoption of what an individual or an organisation finds novel (Coates, 2003).
- Innovations are interactive processes that generate something new, transformative and valuable in certain settings and systems (Echeverría, 2017).

The common feature of 'innovation' and 'invention' as integrative concepts is the ability to solve practical problems. Many authors expand on this point, including the following:

- Nickles (2003): Novelty has to be useful, since both 'innovation' and 'discovery' refer to achievements. Sintonen (2009): "Applied research is the search for knowledge where the goal — according to the authoritative characterisation of made by the OECD some 30 years ago — is to use the results of basic research or even to discover new knowledge that may have immediate practical application".
- Renzulli (2003) points out that "science's goals tell us that one of the main purposes is to add new knowledge to our understanding of the human condition but in a field of applied knowledge in which there are practical applications."
- Marinova and Phillimore (2003) stress technological innovation, which they distinguish from social, educational or organisational innovation.

From this characterisation of the concepts of 'innovation' and 'invention' we shall see what all aspects of design can contribute to understanding innovation processes, ranging from methodology and epistemology to what Nigel Cross calls 'Design Culture'. Here we shall analyse some of the design models that are especially relevant when it comes to innovation.

1 The references to these definitions are taken from Estany and Herrera's book (2016), especially Chapter 2 of the same. Here, the book by Shavinina, L.V. (ed.) (2003) — *The International Handbook on Innovation* published by Elsevier Science Ltd. has also been taken into account.

THE EMERGENCE OF DESIGN

There are many diverse reasons why Design has been so strongly linked to Art and applied to everyday settings while making very little impact on the academic world. Here, we can say that the emergence of Design is a multi-causal phenomenon that ties in with the idea of innovation and that has seeped into new fields.

Industrial innovation is a field where design is crucial and present in a host of industries (furniture, cars, Information Technology, and so on). Here, the most widely-used concept is that of Design Thinking, which has been approached from varying perspectives and applied to many areas. One of the first issues is how to define it. The sheer polysemy of Design Thinking makes it hard to define from an essentialist perspective. It should be seen more as a theoretical framework whose common denominator is human-scale design.

Lockwood (2009) defines Design Thinking as human-centred innovation that stresses observation, collaboration, and swift learning. It is about applying a designer's sensitivity and methods to solve problems in a wide variety of contexts (business, commerce, leadership, public and private services, etc.). One of the examples provided by Lockwood (2009) — ski clothing — exemplifies Design Thinking. One of the key requirements of such clothes is protect the skier from the cold making tough demands on the materials used to make them. Innovation in ski fabrics stemmed from the collaboration among sundry professionals, especially designers, engineers, and entrepreneurs. These roles do not necessarily have to be played by different people but all three perspectives must converge in the product's manufacture. In this specific case, Lockwood himself contributed to the design and the commercial side given that he had studied Business Management for his bachelor's degree. The engineer furnished vital knowledge of the materials and insulation specs. Regarding users, the new garments were tried out by keen skiers. It just so happened that one of the people given the job of evaluating the product's commercial scope was a keen skier himself. To sum up, innovation involves diverse aspects that must be borne firmly in mind. Any novelty features are the outcome of participation by the main stakeholders, in this case: engineers, designers, users. Profitability also needs to be weighed up by any company engaging in innovation.

Vogel (2009: 5) considers that Design Thinking can bridge the gaps between intensive production focusing on profit, costs, and human-scale production. He notes that The Industrial Revolution created scope for mass-producing a host of products ranging from cars to washing machines, and from furniture to buildings. This spawned two main approaches to Design. One focused on industry, represented by the likes of Carnegie, Rockefeller, J.P. Morgan and Ford. The other sought to follow in the craft traditions represented by the likes of Charles Rennie Mackintosh, Frank Lloyd Wright, and Gustav Stickley. Vogel (2009: 5) cites the architect Peter Behrens and The Bauhaus School as examples of design thinking that tried to meld the two approaches.

Victor Papanek, in his book *Design for The Real World* (2014), advocates a Design approach fostering socially responsible production. He accuses designers of only pandering to well-off consumers. It is thus important to assess user satisfaction for any kind of product, taking into account parameters such as usability, accessibility, understanding, and experience.

When it comes to the emergence of Design in the academic field, one can say that both socio-political and ethical-moral factors lie at the core of practical knowledge. If theoretical frameworks can be found to address these phenomena, there would be a rational explanation of the elements affecting Science and their impact on society. One of these theoretical frameworks is furnished by what has been termed Science, Technology and Society (STS). Although this field is not usually linked to Design, it covers many aspects of science and technology's impact on society and thus dovetails with the idea of Design Thinking. Regarding the links between Innovation and Design, practical knowledge, and problem-solving, the criteria for good design all provide the underpinnings for the convergence of innovation and Design Thinking processes.

DESIGN IN THE EPISTEMOLOGICAL FIELD

The notion of design has now reached Epistemology, a field that at first sight seems far removed from the analysis of practical situations. That is because Epistemology, as a branch of Philosophy, seeks to discover the rational foundations underlying our beliefs. Moreover, applying Design to the epistemological field yields a new vision to that offered by Classical Epistemology. This requires conceptual clarification of the expressions used to describe the relationship between Design and Epistemology.

Bengoa (2011) makes a number of points regarding the practical application of Science. He argues that the Epistemology underpinning the doctrine and foundations of scientific method fits ill with the diverse objects populating our field of knowledge, rendering a sole approach impossible. In reality, he refers to constructed objects or artefacts, and wonders whether an epistemology of constructed objects can be based upon parameters other than the traditional ones. To this end he draws a distinction between an Epistemology 'for design' and one 'of design'[2]. Regarding the former, Bengoa says this has to do with "a science of knowledge that helps the designer." The latter, he argues, has to do with "an epistemology used by the designer to grasp the nature of his own design." The first definition fits in with an Applied Science epistemology. Yet the second definition seems unclear unless we interpret it as "an epistemology that uses design itself to shed light on reality." The idea is that design theories are a model for epistemology, both in their grounding of The Pure Sciences and The Applied Sciences. It could be objected that this approach is a vicious circle. We argue that it is indeed a circle but not a vicious one involving feedback between knowledge, artefacts and design. Starting from these two notions of the relationship between Epistemology and Design, we shall analyse a series of proposals bearing on the two meanings proposed by Bengoa.

The two expressions capturing Bengoa's two meaning are: (1) *Epistemology of Design* [the 'for' Design sense], and (2) *Design Epistemology* [the Epistemology 'of' Design sense]. Yet as we shall see below, most authors use both terms interchangeably without formally distinguishing between them.

D. Mahdjoubi (2003) in his paper *Epistemology of Design* classifies Design as an activity, as planning, and as epistemology. Here, activity means thinking about what the product will be like; planning means organising the steps for manufacturing the product; epistemology means the relationship between the analytical methods needed in the Applied Sciences (as opposed to analytical scientific methods). Mahdjoubi notes that the analytical methodology has shortcomings in tackling Applied Science. This deficiency has spurred synthetic methodology, with Design Epistemology offering a way of remedying said shortcomings, especially in fields such as Engineering.

Under the title *Design Epistemology*, D. Karabeg (2012) proposes Design as the alternative to tradition. This questions traditional epistemology, which does not slot in with an approach based on innovation as the main plank of scientific research. The key idea is what he calls *postulating epistemology.* The term means accepting the notion that epistemology goes beyond just the quest for the basis of truth and meaning.

2 This may seem to be playing with words but in fact there is a deep distinction that needs to be made. A parallel that might help us here is the distinction that Bengoa draws between "The Ethics of Neuro-Science" and "Neuro-Ethics". That said this comparison is a metaphor since Neuro-Science is based upon foundations and empirical results — things still lacking in Design Theory. Continuing with the metaphor, "The Ethics of Neuro-Science" studies the ethical implications of the advances made by neuro-scientists, and the nature of professional practice in the field. By contrast, "Neuro-Ethics" takes Neuro-Science as the basis for grasping and explaining social, moral, and philosophical decisions in the broadest terms. Another analogous distinction is that between "The Philosophy of Cognitive Sciences" and "The cognitive focus in the Philosophy of Science". The former refers to philosophical analysis of The Cognitive Sciences, in the same way that we think of The Philosophy of Physics, Chemistry, Biology, The Social Sciences, and so forth. By contrast, the latter concerns Science models anchored in The Cognitive Sciences — an approach pioneered by R. Giere.

Here, Karabeg's concept is not so different from Mahdjoubi's, even though the former calls it *Design Epistemology* and the latter *Epistemology of Design*. Thus Karabeg strengthens a perspective within an academic research framework that is an alternative to traditional approaches. If we consider the alternative for Pure Science, it would constitute what we call 'epistemological innovation', which would imply new ways of representing knowledge as changes in epistemological values (or at least, their prioritisation). In this respect, while remaining faithful to Karabeg, this epistemological innovation would be squared with Design models. Unlike traditional epistemology, the proposed approach to Design is more dynamic, allowing the incorporation of new elements emerging from the research.

Regarding the main features of Design Epistemology, Karabeg (2012), highlights what he calls *wholeness*, which he defines as "the feature that characterises a healthy, fully-developed organism, or a complete, wholly functional mechanism. All these parts work in concert so that they meet their purpose, ensuring the whole works well and can even fulfil its goals in broader spheres" (Karabeg, 2012: 3). This would imply 'trans-disciplineship" materialising in federative knowledge such that any phenomenon could be approached from different angles in a kaleidoscopic fashion.

Given the features that Mahdjoubi and Karabeg attribute to the relationship between epistemology and design, the keys seems to lie in: (a) an alternative to tradition and analytical epistemology, and (b) a commitment to synthetic epistemology in the Design field, bringing science closer to the designer's mental framework.

Design Theory is another concept that bears on the Epistemology of Design, which L. E. Östman (2005) addresses in his paper *Design Theory is a Philosophical Discipline: Reframing the epistemological issues in Design Theory*. According to Östman, Design Theory is neither a Social nor a Natural Science but rather a philosophical discipline that uses a pragmatic framework. It is not a question of pinning knowledge down to simple truth but of tackling problems and fostering understanding through clarification, reasoning and criticism. These statements constitute the basis of his proposal, focusing on the knowledge needed for practical problem-solving.

Thus we can say that the core of the relationship between epistemology and design — let us call it *Design Epistemology* — is thinking with the mindset of the designer, taking Design Thinking as a framework. In fact, the critique of Analytic Epistemology is not new and began in the 1950s, although the paradigm shift came a little later with Thomas Kuhn's (1962) *The Structure of Scientific Revolutions*, which established the pillars of 'inherited conception'. The historicist period was followed by the Sociology of Science and the Sociology of Knowledge and now we are in the era of the cognitive approach to science and technology. That said, the latest twist does not mean that the earlier lines of thought have vanished for they both co-exist with the latest approach and to some extent complement it. One can see the Epistemology of Design as gathering some of the criticisms of Analytical Epistemology with an eye on Applied Science and problem-solving.

COMPUTATIONAL SIMULATION AS AN INNOVATION IN THE SCIENTIFIC METHOD

Simulation has been greatly neglected by philosophers of the so-called 'inherited conception' school in their musings on Science Methodology. From Hempel to Kuhn, we have analysed scientific theories, laws, and explanations in a quest to determine how these kinds of knowledge advance our understanding of the world. The question is whether a simulation really broadens our knowledge of the world. That is why it is important to approach computational simulation (both with regard to its theoretical constructs — highly influenced by Physics and Maths — and to its practical part, for instance in predicting avalanches). In this sense, the Epistemology of Design is a good framework for innovating in methodological models, for which computational simulation provides an excellent tool.

In the Natural Sciences, one needs to grapple with problems that are inaccessible at the human level. For instance, in Astronomy, one paradoxically needs to know tiny details of The Cosmos' workings notwithstanding The Universe's vast scale. Another is the thorny Three Body Problem — a theoretical construct of The Solar System (or any other planetary system) in which the gravitational interactions of the bodies are essentially the same, no matter how many planets one considers. This treatment vastly simplifies the calculations involved. This result (which is far from obvious) has been reached after centuries of scientific thought. If we think of the idea in more general terms, we can see that it is the germ of modelling and the computer simulations that followed in its wake.

There are often phenomena at non-human scales (much smaller or much greater than ours) that are hot candidates for simulation-based approaches. Yet simulations are also valuable in purely human problems where ethical or other considerations prevent practical experimentation.

Modelling is the main analytical approach used in the study of matter, in the sciences of mathematical structure and in The Life Sciences. The models draw on mathematical thinking that is adapted to Physics reasoning, describing observations in a stripped-down form, peeling away the superfluous data to reveal their essential or structural characteristics and reifying them.

In this sense, a good theory describes a broad domain of phenomena based on simple models and makes testable predictions yielding reliable results.

Computational simulation as a methodological innovation involves two processes: the creation of models and the simulations based on them. Computational simulation is associated with the use of computers in scientific work. The simulation and the earlier creation of models are useful for grappling with problems that lie beyond Man's abilities and/or outside his experiential frame.

Computational simulation allows one to tackle those problems that Classical Epistemology cannot. The latter's limitations stem from its basing on very rigid models (such as the Concept of Theory or Hypothetical-Deductive Explanation), which are central to Logical Empiricism. Basically, Classical Epistemology is the wrong tool for dealing with the sheer complexity of many phenomena. This does not mean that scientists have limited themselves to a simplification of the scientific method but rather that they have to consider unexpected alternatives in order to fully test their ideas. Physical-mathematical models and simulation in the Natural and Social Sciences are used to throw up such alternatives.

Computational simulation supported by physical-mathematical models

Structured computational simulation on the scaffolding of Physics-Maths models has commonly been used over the last few decades. In fact, this approach was greatly consolidated in Science (including Computer Science and The Life Sciences), technologies and Engineering in the second half of the 20th Century.

The model occupies an intermediary position between the observer and the observed object[3], providing information that spurs knowledge (yet without falling into the trap of directly identifying the model with the object so modelled). It is important to avoid this trap because the world is independent of what we can say or think about it. As stressed above, the model is an idealisation whether by excess or default, not reality itself. The model boils down to a rationalisation or a coherent logical system (albeit one formulated in mathematical language).

3 'Object' is used in a broad sense to designate phenomena, process and thus both the known physical world and imaginary worlds. Objects tend to be built from questions and other intermediary elements.

Computational simulation in the Social Sciences and Humanities

The Humanities take a non-mathematical, discursive approach to knowledge; their studies and analyses are usually conducted using natural language, citations and comments to steadily delve into the content and to develop it.

This working method cannot be used to verifying mathematical methods themselves. Thus there is no scope for formulating modelling in terms of equations, general mathematical logic, and 'proofs'. In this respect, the sheer variety of objects cannot be mathematically modelled as a whole and so there are no universally applicable rules and 'laws' for conducting computational simulations. This shortcoming might be tackled in some research situations by taking an intermediate step as a kind of 'bridge'.

Collaboration between historians and students of Brownian Motion in a fluid has yielded productive collaboration. In an effort to model social conflicts, accurate historical data is being compared with data provided by Brownian Motion experts, and certain patterns of behaviour in human movements are being found in diverse kinds of social conflicts, revealing certain similarities with the Brownian Motion exhibited by atoms. This motion can be expressed in terms of the same equations and can thus be computationally simulated. In fact, *ad hoc* papers are already appearing on the subject. Although such research is still in its infancy, the results to date are encouraging.

TECHNOLOGICAL INNOVATION IN SCIENTIFIC WORK

The powerful technology of our age is constantly nurtured by feedback from myriad sources, fostering new considerations and interactions between Man, machine, and the world they belong to. This process leads to more questions and a quest for answers. Why is it that we find technology so fascinating? What drives us to seek solutions to the puzzles posed? We take this environment (which is built up in a linear, cumulative fashion) for granted, scarcely pausing to think about the huge positive impact it has on our lives. Is it the sheer emotional attraction of novelty that enthrals us or do we vaguely sense that it puts the world at our fingertips?

Sceptics wonder whether over-exposure to and worship of technology are devaluing reflective knowledge, Science, and what was hitherto considered real progress. Yet might it be that we have found a new, authentic form of the same knowledge?

Perhaps that is why we seek to give robots some vestige of 'emotions' in an effort to make them seem more like us.

The example given below (avalanche simulation) fully falls into one of the design goals, namely coming up with a solution to a real-life problem.

An example of computer simulation: Avalanches

An avalanche is a mass of snow and ice that careers down the side of a mountain, creating an icy blast of wind that bulldozes and buries everything in its path — rocks, trees, pretty Alpine villages, and unwary skiers.

Avalanches are caused by the build-up of the layers of snow laid down with each snowfall. The snow is the sum of these layers, each one with different density and stability characteristics determined by weather, freeze-thaw cycles, compression from overlying layers, ambient temperature, aspect, gradient, wind, and so on. Strong winds and thawing commonly trigger avalanches.

Avalanches can cause a great deal of damage, hence the need to analyse the risk at any given moment and so protect lives and property.

The interest in assessing avalanche risk goes back a long way. Mountain folk at the beginning of the 20th century described different types of avalanches, which they classified to predict their path and how much damage they might cause. They also tried to identify those conditions most likely to lead to avalanches, and strengthened buildings to protect life and limb.

Before the simulation is computed, one first needs to precisely determine and formalise the physical phenomenon to be studied to come up with the numerical model. Snow's fluid-like interactions are highly complex and thus very hard to model. That is why it takes the powerful Navier-Stokes equations used in fluid mechanics to model avalanches. To get the first approximations, average behaviour is considered without going into fine details because these make little difference to the predictions and their reliability.

The complementary terms typical of avalanches are introduced into these Navier-Stokes equations, modifying the mathematical structure and thus shaping the solutions found. Some specific elements of the equations are crucial for describing how the avalanche unfolds.

Observation of real avalanches and computational simulations can be compared. This is a highly active field of research with intense interdisciplinary links among key actors: engineers, physicists, mathematicians, computer scientists, snow and avalanche experts. This challenge sparks interest in many fields — not only at the scientific one because of the pure mathematics and physics involved but also in sports, geological, and environmental spheres, among others.

The simulation of avalanches not only seeks to gain a better understanding of how nature works but it also has practical applications. In this respect, simulations make additional use of the mathematical models and methods traditionally used in Physics. In this case, the aim is to solve problems through a Design Thinking approach.

METHODOLOGICAL DESIGN MODELS

Methodological Design Modelling is a field that affects the approach used in the Applied Science in that it seeks an alternative to Analytical Epistemology. The classical scheme of the scientific method (Figure 1) consists of testing a hypothesis. If the prediction is borne out, the knowledge obtained is added to the body of general knowledge. In practice, methodological processes are more complex and consist of several stages, especially when a new problem arises or when procedures need to be changed because no valid result is obtained. However, the scheme in Figure 1 continues to reflect the general idea of hypothesis testing. Despite this, researchers in The Applied Sciences have questioned whether the classical scheme is the best one for their fields. This dissatisfaction with the classical approach helps explain why Design Studies methodologies have emerged.

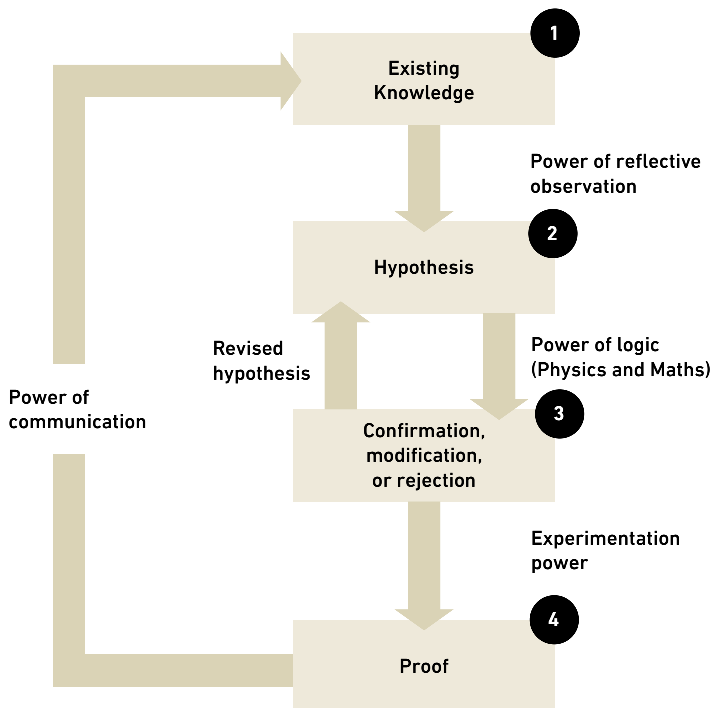
The Design Sciences are the result of a process of scientification and mechanisation of The Arts when it comes to practical skills and activities. Simon (1996) points out that the traditional model of Science offers a misleading image of fields such as Engineering, Medicine, Architecture, Economics, Education, etc., which are interested in 'design' insofar as this achieves a practical purpose. In other words, these disciplines are less interested in the nature of things and more in resolving practical problems.

Engineers are not the only professional designers. The intellectual activity involved in making material artefacts is not so very different from prescribing drugs, drawing up a new sales plan for a company, or a welfare policy. Conceived in these terms, Design is at the heart of The Applied Sciences and reflects the professionalisation and modernisation of the craft skills of old. Engineering, Law, Architecture, Education, and Medical schools orbit and are institutionalised by the Design process.

Various approaches to Engineering Methodology have been proposed, including ones by Gerald Nadler (1967), M. Asimov (1974), A.D. Hall (1974) and R.J. McCrory (1974), among others.

Despite the differences among them, all models exhibit a set of features and positions on Design Methodology that are in keeping with the practical purposes for

Figure 1 **Representation of The Scientific Method according to McCrory (1974: 160).**

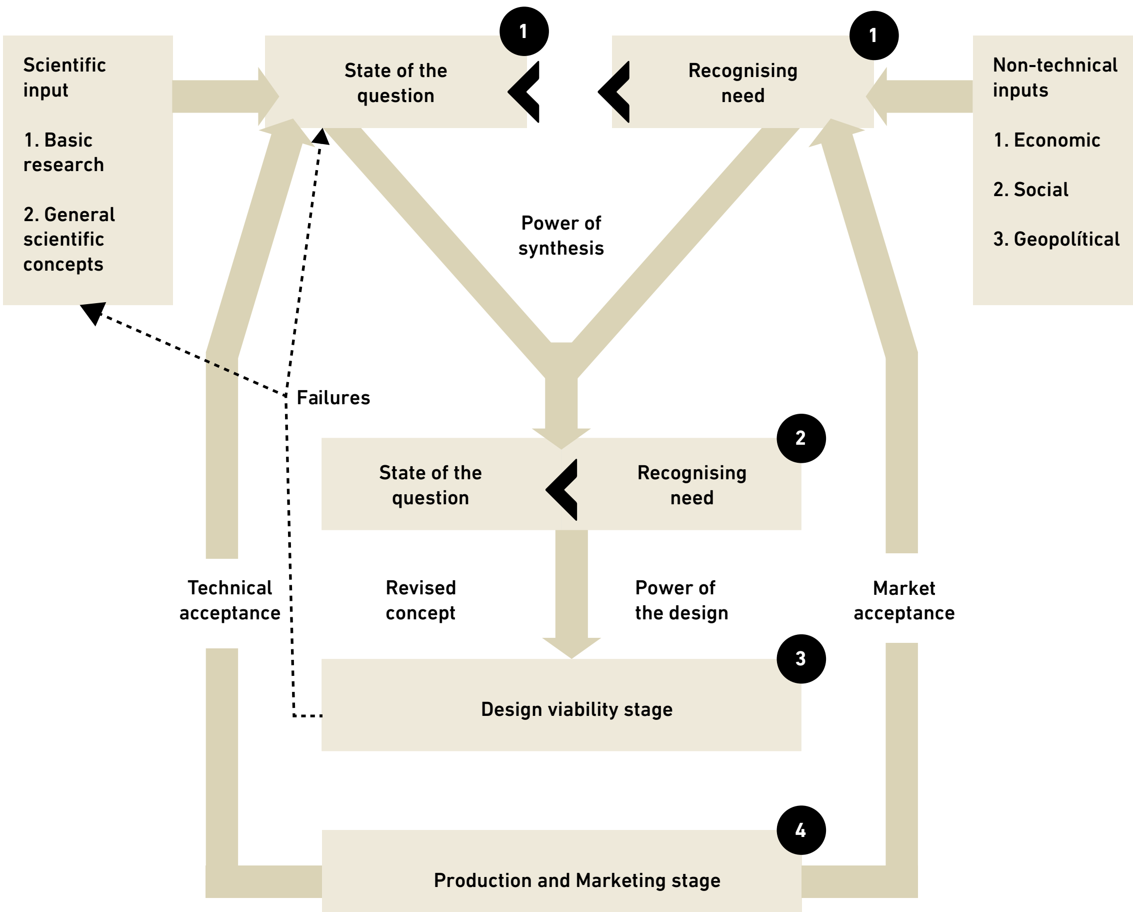


which they are intended. Thus, Nadler points out that designing consists of coming up with processes to yield useful results, and of drawing on knowledge, laws and theories based on research and/or the descriptive sciences to this end. Asimov considers that Engineering Design is an activity that seeks to satisfy human needs, particularly those that have to do with technological aspects of our culture. Hall distinguishes three dimensions in any Engineering system: (1) time; (2) the problem-solving procedure; (3) the body of facts, models, and procedures defining a discipline, profession, or technology. Although we can find the equivalent of these three dimensions in the other models, it is the third dimension that is especially valuable for defining the identity of a professionalising discipline. Defining a discipline gives substance to a host of professions, turning them into university degrees and institutionalising them.

Last but not least, McCrory sees Design as drawing upon scientific knowledge for practical ends, not as the source of said knowledge. Here, the designer's role might be considered similar to that of an artist insofar as it gives rise to new creations. The idea is that state-of-the-art scientific knowledge and the needs constituting non-technical input (shaped by social, economic, geo-political factors, etc.) converge in Design.

In this model, the design is not included in the non-technical input but it makes sense to add it and take it into account at the second design stage. In this

Figure 2 Design Method flowchart as set out by McCrory (1974: 162).



stage, we focus on the desired outcome, whether it be an artefact, a drug, an aeroplane or a study plan. In particular, it is important that the design bears future user needs in mind.

THE CULTURE OF DESIGN BETWEEN THE SCIENCES AND THE HUMANITIES

Based on what we have said about innovation and its impact on the epistemology and methodology of Science, *Design Culture* (as Cross calls it) seems the best framework for tackling innovation and invention processes in which theoretical and practical elements converge. The approach is one that provides a new, integrating perspective of Science and The Humanities.

Cross (2006) in his work *Designerly Ways of Knowing* sees the discipline as a form of knowledge linked to the Epistemology of Design and to Design Thinking. One of the key ideas in his proposal is that Design should constitute a third culture after The Sciences and The Humanities, and be part of the general education system rather than just the preserve of certain professions.

Thus, just as there are ways of approaching phenomena from The Humanities and from The Sciences, one can also tackle them from a Design perspective (as per Cross' *Designerly Ways of Knowing*). Cross points out some differences between these three cultures regarding the object of study, the method followed and the values enshrined. In Design's case, the object of study is the artificial world. Among the methods he cites is finding patterns. Design's main values are practicality, empathy, and fitness for purpose.

Other key features of 'designerly ways of knowing' are: the manipulation of non-verbal codes in material culture; the connection between doing and thinking; the relevance of iconic modes of cognition (2006: 11). Regarding design skills, Cross highlights the following: solving ill-defined problems; adopting solution-focused strategies; using abductive reasoning, and non-verbal/graphic means to represent knowledge (2006: 20). All these characteristics are at the core of innovation and invention processes.

Drawing on Science and Design concepts, he distinguishes three forms of connection between the two, corresponding to different senses:

(a) Scientific Design covers any field but tends to focus on Industrial Design, for which the designer uses scientific knowledge.

(b) Design Sciences are those whose goal is not to describe the world but to transform it. They cover Engineering, Medicine, Education and Information Sciences, among others fields.

(c) The Science of Design is the body of design theories applying a given practice to a product and drawing on scientific method to do so.

It should be noted that Cross made it clear that *The Science of Design* was not the same thing as *Design Science*. We can ask whether Cross' distinction is a fruitful one for clarifying the broad, complex design field. The first thing that should be said is that, in practice, both concepts are intertwined in any design activity, product, or process. Yet because this is a relatively new field, it is important to conduct an initial conceptual analysis from an academic standpoint.

We can say that Design Culture seeks to create a framework for developing many of the kinds of things discussed in this paper. Indeed, the very idea of the role played by Design in innovation would make little sense without such a framework. Furthermore, the three forms of connection between Science and Design highlighted by Cross (namely Scientific Design, Design Sciences, and The Science of Design) give meaning to the goals and their development.

CONCLUSIONS

We have seen that Design permeates all scientific and cultural spheres in the conceptualisation of the natural and social worlds. Even so, we sometimes forget that the social world is part of the natural one. Design offers a new perspective for approaching the complexity of the real world. When it comes to innovation, Design Thinking provides a scaffold to build on human interests and skills to ensure innovation is fit for purpose. These conclusions, although concise, are of great significance for current thinking and for philosophy in regarding the meta-conceptualisation of knowledge. Given the huge challenges Mankind now faces, Design's practical vision of knowledge and its commitment to solving problems will have a big impact on the way.

BIBLIOGRAPHIC REFERENCES

Asimov, M. (1962). A Philosophy of Engineering Design. In *Contributions to a Philosophy of Technology* (p. 150-157). Dordrecht: Springer.

Bengoa, G. (2011). *Distintos acercamientos epistemológicos: cinco enfoques sobre los objetos* [Seminar]. Facultad de Arquitectura, Diseño y Urbanismo, UBA Universidad de Buenos Aires.

Brown, H.I. (2009). Conceptual comparison and conceptual innovation. In J. Meheus and T. Nickles (ed.), *Models of Discovery and Creativity* (p. 29-41). Dordrecht: Springer.

Cross, N. (2006). *Designerly Ways of Knowing*. London: Springer.

Echeverría, J. (2017). *El arte de innovar. Naturalezas, lenguajes, sociedades*. Madrid: Plaza y Valdés.

Edgerton, D. (2013). *Quoi de neuf? Du rôle des techniques dans l'histoire globale*. Paris: Éditions du Seuil.

Estany, A. and Herrera, R. M. (2016). *Innovación en el saber teórico y práctico*. London: College Publications.

Hall, A. D. (1974). Three-dimensional Morphology of Systems Engineering (1969). *Contributions to a Philosophy of Technology*.

Karabeg, D. (2012). Design Epistemology. *Information,3,* 1-x.

Kuhn, T. (1962). *La estructura de las revoluciones científicas*. Mexico: Fondo de Cultura Económica.

Lockwood, T. (ed.) (2009). *Design Thinking. Integrating Innovation, Customer Experience, and Brand Value*. New York: Allworth Press.

Mahdjoubi, D. (2003, June). Epistemology of Design. In *Integrated Design and Process Technology* (p. 1-5). IDPT.

McCrory, R. J. (1974). The Design Method — A Scientific Approach to Valid Design. In F. Rapp (ed.), *Contributions to a Philosophy of Technology*, (p. 158-173). Dordrecht: Reidel.

Nadler, G. (1967). An Investigation of Design Methodology. *Management Science, 13*(10), B-642.

Nersessian, N. (2009). Conceptual change: creativity, cognition, and culture. In Meheus, J. and Nickles, T. (ed.), *Models of Discovery and Creativity* (p. 127-165). Dordrecht: Springer.

Niiniluoto, I. (1993). The aim and structure of applied research. *Erkenntnis, 38,* 1-21.

Östman, L.E. (2005). *A pragmatist theory of design. The impact of the pragmatist philosophy of John Dewey on architecture and design* [PhD thesis]. School of Architecture, Royal Institute of Technology. Stockholm.

Östman, L. E. (2005). Design theory is a philosophical discipline. Reframing the epistemological issues in design theory.*Design System Evolution*.

Papanek, V. (2014). *Diseño para el mundo real. Ecología humana y cambio social*, 2nd edition in Spanish. Barcelona: Pol·len Edicions.

Shavinina, L.V.(ed.) (2003) *The International Handbook on Innovation*. Elsevier Science Ltd.

Simon, H. (1996 [1969]). *The Science of the Artificial*.Cambridge (Massachusetts): MIT.

Vogel, C.M. (2009). Notes on the Evolution of Design Thinking: A work in progress. In Lockwood, T. (ed.) (2009), *Design Thinking. Integrating innovation, costumer experience, and brand value*. New York: Allworth Press.

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