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A NOTE ON THE DEBATE ON SCIENTIFIC PROCESS VS. DESIGN PROCESS

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ABSTRACT
It has been often claimed that the scientific process is quite opposite to the design process, mainly based on the former's analysis of existing phenomena in order to develop a theory, while the design process is an act of synthesis that creates something new in the world. In the light of the developments that led to this conception, and with reference to the current views of the scientific process, we maintain that the scientific process has more similarities with the design process than differences from it. As parallels can be drawn between the two processes, some implications for further research into the fundamentals of the design activity are discussed.

Keywords: design science, design process, design theory

1 INTRODUCTION

This work takes up and discusses a minor theme in the arena of research in engineering design, that of the recurring opposition that is proposed between the scientific process and the design process. It is often mentioned, for example, that the scientific process mainly consists in the analysis of existing phenomena in order to develop a theory allowing us to explain and understand them, while the design process is a synthesis act that creates something new in the world; or that scientists' reasoning to address their problems is quite different from designers' reasoning (see e.g. [1], [2], [3]). It seems, however, that this argumentation contains certain shortcomings, and that the scientific activity and design activity present many similarities.

The opposition between design and science is just but one — and probably a minor one — of the elements that affect the way the design process is perceived. We nevertheless feel that the similarities have some interesting consequences for the further development of the grounds on which the design process lies, and for its place in design science.

In order to understand what lies behind the presumed dichotomy between the design process and the scientific process, it is necessary to present the interplay between science and design that occurred as they developed, for that explains what we believe is a misconception of the scientific process. This is presented in Section 2. The arguments commonly put forward in favor of a differentiation between science and design are reviewed in Section 3, and the arguments against this differentiation are presented in Section 4. The consequences for research on engineering design are discussed in Section 5.

2 EARLY DEVELOPMENT

2.1 Science and art

The definitions of science have varied with the centuries and the thinkers. By the time the domain of engineering design is being defined, during the nineteenth century, *science* is mainly defined as it was during the Enlightenment (an oversimplification, but see [4]), that is, as clear and certain knowledge of things, based on self-evident principles, or on demonstration [5, pp. 32-33], [6,p. 787-788]. In other words, (a) science is the result of reasoning. The other domains of knowledge that were not based primarily on reasoning and were thus not labeled as "sciences" were those based either on "memory", that is elements transmitted without being well-founded, or on "imagination" (following the classification of the *Encyclopédie* based on the original classification of Bacon [7]). The crafts, trades and manufactures were based on "memory", while poetry, music, sculpture, etc. were based on "imagination". *Art* is the term now used to determine the latter, but it had a broader meaning then. It was used to denote a kind of ability or skill in performing an activity [8], [9], and knowledge of the processes and means to be employed [4, p. 5]. Therefore, one could speak of the art of geometry, as well as the military arts, the art in different kinds of craftsmanship, and of course the *fine arts*. The *art of reasoning*, or logic, the art that the scientist must possess, is also a part of the sciences as it is, recursively, well founded. Knowledge in architecture was divided in two: "Architecture" was a production of ideas from imagination, and "applied architecture" was craftsman's knowledge [8, p. iii], [9].

In the eighteenth century, machines, or artifacts is general, are considered the result of the *mechanical arts*, also the result of craftsmanship, as men of science have not developed the majority of them. The complexity of many of these artifacts and the ingeniousness of their creators is recognized though: "there are certain machines that are so complicated, and whose parts are all so dependent on one another, that their invention must almost of necessity be due to a single man. Is not that man of genius […] well worthy of being placed beside the small number of creative minds who have opened new routes for us in the sciences?" [8, p. xiii], [9]. The study of the properties of those objects is the object of science, as they are implicitly guided by natural phenomena, such as catoptrics and dioptrics, the sciences of mirrors and lenses, respectively.

Since Bacon's *Great Instauration* [7], [10], the different sciences (and the other knowledge domains) had been thoroughly classified. This enabled a coherent synthesis of current knowledge, defined clearly the different areas of interest and gave direction for future inquiries. In the *Encyclopédie*, catoptrics and dioptrics are branches of optics, a part of 'mixed mathematics'. The diffusion of this knowledge, the development of specific machines and machine elements (pump, piston) made it possible, and necessary, to develop parts of artifacts based on scientific results and not only on a craftsman's skill. It also became necessary to compile not only empirically-based, hands-on, guidelines for designing those machines, but also the principles of the different systems, so that their teaching would be simplified. Naturally those principles, based on physics (mechanics, hydraulics) and mathematics, were considered the result of scientific achievements and integrated within their mother branches. By 1834, Ampère had introduced the branch of *cinematic*, the science of movement, in mechanics, which included the study of machines [4, pp. 50-53].

2.2 The first theories of machines

Reuleaux, in the introduction to his *Kinematics of Machinery* (*Theoretische Kinematik – Grundzüge einer Theorie des Maschinenwesens*) [11], [12], gives an account of the development of a science of machines, and of their place in the system of sciences, such as the program outlined by Hâchette and Monge [13] and developed by Lantz and Betancourt [14], [15], Willis' *Principles of Mechanism* [16], and Ampère's classification of science [4]. Developed by men of sciences, based on scientific foundations (mathematics, mechanics), aiming at enabling the examination and understanding of the properties of machines, they can rightfully be considered a science. In Reuleaux' first chapter, its delimitation is discussed. The body of knowledge is sufficiently large to separate it from the general study of mechanics; the differences between machines (artificial systems) and 'natural' mechanical systems (e.g. planet movements) make that an important criterion of demarcation. Within the science of machines, or practical mechanics, four branches can be distinguished: the general study of machinery (Maschinenlehre), the theoretical or special study of machinery (theoretische Maschinenlehre, spezielle Maschinenlehre), machine-design (Machinebaukunde – development of specific machines following guidelines such as Redtenbacher's) and Reuleaux's own machine-kinematics (theoretische Kinematik or Maschinengetriebelehre) – the English terms coming from Alexander's translation. Reuleaux saw many advantages in trying to describe machines scientifically; not only facilitate learning and understanding them, it also could be used for practical purposes [12, pp. 1-2]. On that last point, Reuleaux made clear that the descriptions of the machines and their arrangements would not explain their synthesis, that is be coupled to the design process: "How did the mechanism, or the elements of which it is composed, originate? […] Have we simply to accept as data what invention gives us, the analysis of what is thus obtained being the only scientific problem left? It may be said that the last method has been hitherto followed exclusively" [12, p. 3]. For Reuleaux, there was also no difference between scientific invention and the invention of machines [17, p. 38]. Reuleaux showed, however, that the development of current machines has been made possible by the accumulation of inventions, that "the inventor's stream of ideas is developed out of another" [12, p. 3]. The synthetic presentation of a science of machines would no doubt ease their further development.

2.3 Increased importance of science

Meanwhile, with the increasing importance of science in the diverse layers of society and the even more important role it was thought to take in the future, the rapid progresses that were made, the emergence of a community, a profession, the scientists[1], deeper reflections were engaged on epistemological issues: characterize scientific knowledge in order to enable its development in other fields (its truth value, its certainty, its form), determine how to obtain this knowledge, how to test it, and continue the work of systematization of knowledge (cf. the work on German historiography). Some works also concerned the generation of ideas, of insights that led to changes in the state of knowledge, such as Poincaré's [19], [20] or Mach's [21], and were summarized in Wallas' [22] creativity model: Preparation, Incubation, Illumination and Verification. These works were however in a minority and were overshadowed by the extent of works on epistemology (the "science of knowledge"). Grounding knowledge was seen as the line of demarcation between sciences and non-sciences and was prioritized before creation of knowledge. From this angle, a scientific methodology was that of a controlled procedure to confirm, reject, validate or falsify hypotheses, in order to determine their knowledge status.

3 THE DIFFERENTIATION OF SCIENTIFIC AND DESIGN PROCESSES

With such a high status, the scientific process becomes naturally the standard upon which to compare and improve the design activity. To some, the scientific standard could be used directly. For example, Buckminster Fuller is credited with saying, at the meeting of the International Union of Architects in Paris, in 1965, that the World Design Science Decade (1965 to 1975) he inaugurated was devoted to "applying the principles of science to solving the problems of humanity". To others it is a starting point to reflect upon how a design method could look. For Hansen, the goal of research was oriented towards the knowledge of the substance of a phenomenon, while development was oriented from the substance of the task to the realization of a desired phenomenon. The design process was seen as using the same thinking processes as scientific thinking, but in reverse order [1, Chapter 3]. An analysis and abstraction of the problem was necessary in order to formulate the design task; the different solution elements could then be deduced and a global solution principle could be sketched. In research, the different elements linked to a phenomenon had to be gathered, and then an abstracted pattern of the original phenomenon would appear.

Hansen had showed that a rational design process was possible. At the same period, progress in other fields — hydraulics, electronics, cybernetics, system theories… — renewed the idea of generic descriptions of machines, this time on a much larger scale. It was possible in hydraulics and pneumatics to describe/develop a system at an abstract, functional, level. It felt possible to extend it to all machines [23]. Reuleaux' work and ideas that had not been further developed experienced a revival from the 50s to the 70s: it should be possible to develop a science for technical system synthesis, that is, a science of engineering design. Rodenacker [23], Roth [24], Koller [25] and others dealt with the taxonomy and representations of machines through functions, embodiment, working principles…. Hubka published a *Theory of Machine Systems* in 1973 [26], followed by a more general *Theory of Technical Systems* [27], [28]. With the development of such a theory combined with Hansen's basic process model it seemed possible to develop a firmly grounded theory of the design process. A technical system could be developed starting from an abstract description at the functional level that enclosed the whole design space that corresponded to the specifications; through a series of evaluations at different concretization levels, one could ensure an optimal design corresponding to the specifications. Such a body of knowledge being developed amounted to the crystallization of a design science consisting of the theory of design process and a theory of technical systems [29], [30], [31]. This dual system, popularized by the synthesis made by Pahl & Beitz in 1977 [32], [33], [34] is now the basis of many textbooks, e.g. [2], [35], [36].

In a vein similar to Hansen's, Simon [37], on the Anglo-Saxon side, also elaborated upon the specificities of design in comparison to scientific activity. With a current (at the time) engineering education based on sciences, the engineer was not armed to approach real-world problems. Like Hansen, Simon's conception of scientific activity at the time he presented his science of design, in 1968, was that it was dedicated to the development of explanations of the world, while design was to act upon it. A designer was anyone who "devises courses of action aimed at changing existing

[1] The term is coined in 1834 [18, p. 59]; any denomination is symptomatic of the emergence of an identity.

situations into preferred ones" [38, p. 111]. For Simon, design was "the principal mark that distinguishes the professions from the sciences" [38, p. 111]. There were several elements required to deal with that activity: an evaluation system, methods and techniques to generate solutions, and a good representation of the design solution (note the parallel with the German model in which the representation was the theory of the technical systems). All these elements were sufficiently specialized to represent a body of knowledge separated from the arsenal of scientific reasoning: a science of design.

It followed that in many texts of design research literature, design activity and scientific activity have been recurrently opposed. The view of the scientific process is largely shared. For Hubka and Eder, science aims at "finding relationships, structuring and systematizing" and the process is "(a) ask an appropriate question, (b) propose a model and a hypothesis, (c) collect data, (d) analyze the data, (e) formulate an answer, (f) accept the new knowledge and revert to (a)" [31, p. 36]. For Tomiyama et al., the scientific or rational process is a "process to extract facts from observations and to try to give best explanations (theorems) of these facts from a set of axioms or hypotheses generated from the facts. […] In this sense, the thought process […] is largely analysis oriented." [3, p. 73]. Synthesis is then considered opposed to analysis, and in the context of design, synthesis prevails as it consists in deriving attributive descriptions about the design object from functional requirements for the design object. Therefore another process is necessary. Gero [39, p. 27] has a similar view: "Designers are change agents in society. […] Design appears to be carried out differently from the way we are taught to understand the world, which is largely derived from the Greek view of the world. Science has been developed as a means of attempting to explain and understand the world around us. It begins with a description of the world (which in itself is not a trivial act to produce) and some behaviors and attempts to produce causal dependencies between them. Science can then be used to attempt to produce a purpose for the world. Design exists because the world around us does not suit us, and the goal of designers is to change the world through the creation of artifacts." Eekels and Roozenburg have made an in-depth comparison of the scientific process and the design process [40], [2, Section 5.5], [41]. They admit similarities between the processes, but for them, the engineering design process cycle consists in the steps of analysis of the problem, synthesis of solutions, analysis of the solutions, evaluation and decision, while the scientific process cycle consists in observation, induction, deduction, testing and evaluation of new knowledge. This is relatively similar to Hansen's view. They conclude that both processes are more different than similar.

Some accounts of design do not follow this general assertion, but they are scarce: Matousek considers the two forms of inventions, design and scientific discovery, as fundamentally identical "in the field of machine problems (by which are meant mechanisms) the same intellectual operations can be introduced as are used also by science in conducting research in other areas […] inventing is thinking, so that if we can organize the latter for our purpose we have also paved the way towards inventing " ([42], [17, p. 38], quoting Reuleaux). Especially, the C-K theory explicitly includes the scientist and the designer in one domain, both on the pragmatic fact that the research and design department activities should not be viewed separately as they both contribute to the final design of the product, especially in the case of new product development, and also on the more theoretical ground "that the creation of new knowledge is a logical necessity in any design process" [43].

4 SHORTCOMINGS OF THIS DIFFERENTIATION

This dissociation is problematic at several levels.

4.1 The scientific process revisited

Basically, the differentiation is based on two views of the scientific process. One is the inductive inquiry procedure, that is science aims at discovering patterns, making sense of observed phenomena by analysis and abstraction and building theories, while design consists mainly in a *synthesis* of existing knowledge [38]. The other view put forward is the hypothetico-deductive system: formulate a hypothesis and test it in order to confirm or reject the hypothesis (see e.g. [31, pp. 36-39]), the result being either false or true [1][2].

[2] As noticed by Roozenburg [41], this notion of analysis and synthesis is confusing because one could equally say that the scientist is doing a synthesis of a collection of observed elements.

First, the scientific activity takes more forms than is usually presumed, i.e. development and testing of hypotheses to a "given" scientific problem or creation of models or law to explain. We saw that another important activity was the discovery of a problem — such as a particular phenomenon, a contradiction in a previous theory or model, or theoretical development of a theory. The scientific activity also includes forming representations of the domain (ways of describing some phenomena), "Discovery (or design) of instruments and experimental strategies for attacking empirical or theoretical problems (e.g. the thermometer, recombinant DNA, the calculus)." [44, p. 450].

Second, it has long been recognized in the philosophy of science that the inductive and hypothetico-deductive procedures do not guarantee the *production* of knowledge. Hempel himself, though a logical positivist, summarizes the logical reasons in [45, pp. 11ff]: "How to collect data in order to determine laws without having some prior hypothesis? It is not possible to collect data without some pre-conception of what one wants to inquire. This conception of a hypothesis is a *fundamental necessity* of the scientific activity. "Scientific hypotheses and theories are not *derived* from observed facts, but *invented* in order to account for them" [45, pp. 15, emphasis in original].

Several authors from our field have noticed this aspect. Hubka and Eder write that "Either for starting the search for knowledge, or for using the results, we need a particular *category of thought*, namely "because *a*, therefore *b*". This is a form of *Anschauung* (view, opinion, perception, idea, conception, intuition, point of view), a human consideration and valuation that is not found in the happening" ([31, p. 36], , emphasis in original). Gero asserts that the scientific process begins with a description of the world "which in itself is not a trivial act to produce" but still differentiates both processes ([39, p. 27], see above).

Moreover, at the same time research in design was focusing on rationalizing the design process, the philosophy of science was already in crisis. The idea of a unified scientific, method was long gone, for several reasons. For example, in order to prove that one theory is better than another requires that both theories be expressed in the same language, so that the two can be compared. This translation requirement was a large piece of work from the positivists (mainly the Vienna Circle) that proved unfruitful, as many theories are "incommensurable": they do not manipulate the same concepts, do not have the same axioms, do not entail the same problems (some problems disappear and appear with the new theory). Other methods are available for choosing theories, based on their objectives or finality for example, but this is remote from the logical, deductive, way of reasoning. Even this is hardly a current practice among scientists: how many report on the choice of a theory based on utility theory or any other evaluation model?[3] Other elements are equally problematic, and most philosophers of science agree "that the aims and methods of science are, in the final analysis, matters of taste and individual preferences." [46, p. 16]. Researchers are guided by tradition, by the paradigms they are working in. The idea of a generic scientific process has been by and large abandoned.

4.2 Sciences of the artificial

Another objection is the misconception that scientists' process is driven by the natural phenomena "out there". As shown above, one cannot really start with a given phenomenon; one needs an idea of what one observes in order to distinguish it from others, to even start any scientific inquiry. Put it another way: one always reasons with models [47], [48]. That implies that one makes a conscious or unconscious choice about what to study and that the conception of what is studied changes along with the discoveries that are made. This is similar to the idea of co-evolution of the problem with the solution [49].

In his *Sciences of the Artificial* [38], Simon describes how artificial systems can be studied, the difficulty being that artificial systems behave in a *contingent* way, while natural systems are driven by *necessity* [38, pp. xi-xii]. For Simon, in the study of natural things, natural science is interested in their ontology (the inner structure of the phenomena), while the focus of sciences of the artificial should be on their teleology, their functional explanation, because the main characteristic of artificial phenomena is contingency to the environment. As there is always a relation between a thing’s goals, inner structure (called inner environment) and the outer environment, by analyzing mainly the outer environment one can deduce the goals of the artifact being studied, and there is also a lesser need to

[3] Note that if the selection of theories by explicit comparison and criteria is almost never done, but that science nevertheless is progressing, then the centrality of concept comparison in engineering design methodologies should be seriously questioned..

try to understand the inner, often very complex, structure of an artificial thing: this is the way the study of artificial worlds should be done according to Simon. One example given is that the explanation for the white color of furs in the Arctic is for escaping easily from predators (and for predators to approach easily without being seen). This is a teleological explanation, not a natural one (that would involve natural selection for example). In the same vein, the diagnosis of a physician is related to the context in which the unsatisfactory state emerged, and the behavior of the observed human body (for example coughing) and the functions of the different elements of the human body. There is often no need to know exactly which natural laws govern the inner environment to make a correct diagnosis. The same could be said about the behavior of artifacts. This strategy also resolves the problem of trying to understand something that appears to be very complex.

By arguing for the assertion that the sciences of the artificial are unlike natural sciences, Simon actually brings them closer. The numerous examples throughout his book illustrating the legitimacy of understanding the behavior of artificial things by their purpose are mostly taken from natural phenomena: the white fur animals in Arctic, the human body…. The natural sciences are not only interested in what systems are, but also in the teleological explanation of their existence; biology especially makes extensive use of this strategy. For natural systems driven by necessity, knowing *why* a system behaves in a certain way gives hints about *how* it works, as nature may apply the same strategies (for example economy of resources) when the same goals are targeted. Observing the environment, deducing goals and making hypotheses about the inner structure, is a strategy that both the natural and the 'artificial' scientist can use.

The problem of prescribing by describing, also evoked in Simon, is not the exclusivity of the artificial sciences. As was mentioned above, each time a natural phenomenon is described, it is through the eye of the scientist, through the whole scientific experience she has, and the set of theories, axioms, and methods her scientific domain approves (often called a paradigm). One has only to refer to the history of science to find examples of erroneous explanations of natural phenomena. This relates also to what was presented above on the nature of theories. So, in brief, the study of artificial and natural things has much in common, and the scientific activity in that area can be described in relatively similar terms.

4.3 Large similarities

Thus a large part of scientific activity is the development of hypotheses, the development of special tools to solve their problems, the design of their scientific process, the choice of "satisficing" models by lack of time for exhaustive evaluation…. What the scientist frequently desires is to change an existing situation where the current theories or models do not fit an observed phenomenon, and to develop hypotheses or courses of action to a preferred situation where the new hypothesis fits better. A scientist may also have discovered a new phenomenon and desire to explain it. From this angle, scientific activity fits the definition of design activity. The specific hypothetico-deductive activity concerning the validation of knowledge is not conceptually different from the development of prototypes or analyses in engineering design: validation of a concept. It also serves retroactively to prove formally one's model, but is not at the origin of it.

The most convincing argument is perhaps that Simon (and colleagues), thirty years after postulating a science of a design activity opposed to scientific thinking, came, in a comparative study of "Scientific discovery and inventive engineering design" [44, p. 463], to a nearly opposite conclusion: "Four conclusions emerge about the processes of discovery and design: The first is that both science and design are often intermingled with each other, and both require analysis and synthesis. So, invention often involves science and scientific discovery often involves design. […] The second is that both consist of a broad array of activities that range from routine to the creative and revolutionary. […] The third and major conclusion we reach is that at a deep level, the cognitive and computational processes that accomplish both activities are virtually identical […] The fourth conclusion is that the processes of design and discovery are structurally similar but differ in their goals and their knowledge bases."

5 DISCUSSION AND CONCLUSION

It has been showed that the scientific process presents more commonalties with the design process than are usually recognized: understanding of the problem, generation of alternatives, co-development of the problem and the solutions, evaluation…. The design process theories and models should be defined with regard to, and not in opposition to, the scientific process. What mainly differentiates the engineering design activity and the scientific is the *object of study*, not the nature of the process. Of course, at a more detailed level, differences appear between the processes, but these differences are as large between sciences and engineering design as they are between domains of engineering design, for example mechanical engineering design, chemical engineering design or software design.

5.1 Learning from the epistemological crisis

The parallel between scientific and design activity is also enlightening for further development of a design process model or a design methodology. It has been mentioned above that the idea of a "grand theory" of the scientific method or process has been somehow abandoned[4]. The conclusions of some relativists had been ever more pessimistic. Showing that the scientists are working within paradigms for abruptly changing during the so-called "scientific revolution" [51] was to admit that they did not behave rationally: if there were objective criteria or methods to decide the new grounds for research[5], then no revolution would be needed: everybody would agree to change paradigm according to new evidence. The idea that there is in any paradigm a core that is never questioned while other areas are more open, a so-called research program [52] makes the scientific communities no different than any others, with its taboos and traditions. This has led Feyerabend to assert provocatively that "anything goes" [53], for indeed there is no formal proof that theories can be objectively compared, or decisively refuted, or that there are systematically robust rules for the selection that guides scientific choice[6].

It is however not necessary to reject everything. There is still a mark of progress in science: for example the number of problems that new theories solve seems to increase [54]. Consequently, *a universal method is not necessary to achieve progress*. Scientists are practitioners who use experience, tacit knowledge and other practical skills as much as other professions. A PhD thesis takes at least three years of work, of scientific practice. This time frame has been judged necessary for the PhD student to prove through her "chef-d'oeuvre" that she is worthy of belonging to the community of scientists. During this time, the PhD student has a supervisor who guides her with the help of her accumulated knowledge and experience in the field. This is very similar to apprenticeship in the craft industries. Coming back to Section 2, one could speak of an *art*, that of reasoning and performing a scientific activity, instead of a scientifically grounded process. This suggests that intrinsic characteristics of the scientist — experience, practice, motivation, intelligence… — which allow for a relevant choice of methods and elements of solutions, are key elements in any successful scientific activity.

Research concerning the design process seems to be undergoing a similar evolution. From the development of rigorous, firmly grounded procedures in the 50s to the 70s, there has been a counter-reaction in the 80s (see e.g. [55], [56], [57], [58]) that has led to focus more on the designer as a "part of the solution". Most textbooks are, however, still oriented towards a procedural approach. There is no need to fall from one extreme to the other, as has been done in the philosophy of science, (e.g. [53]), but the development of the latter may lead us to question how much of a prescriptive process model the engineering designers need.

5.2 Implications for design science

A large part of design science concerns the design process (cf. [29], [30], [31], [38]). Many theories have been developed to make the design process a firmly grounded element of knowledge (see [59, p. 3]).

In the development of a design process theory, it should obviously take into account the similarities with the scientific process and not be defined in opposition to it. The C-K theory, by defining design as the creation of knowledge, does that. Simon's design theory was thought to be different from the scientific process; this latter, redefined as above, also seems compatible with this theory. A design theory should include the designer.

The very existence of a design process theory is questioned: If the search for a foundation and a demarcation of science has failed, the search for a universal design theory seems vain.

Importantly, many textbooks are based on fundamentals or theories that prescribe a procedural approach (e.g. [33], [2], [35], [36]). The similarities with a non-procedural scientific process do not

[4] There is still some research in that area [50], but this is no longer the main concern of the philosophy of science.
[5] Some reasons for their lack thereof have been exposed earlier.
[6] The critic is actually directed against science in general, see [46, Chapter 11].

speak in favor of this approach, rejoining here similar criticisms on prescriptive design process models, coming from the point of view of cognitive psychology; see especially [60].

The content of the specific body of knowledge that a design science would regroup is also at stake. If there is an art of designing as there is an art of reasoning scientifically, then not all design knowledge would need to be included in a design *science*. Some knowledge the designer may acquire by tradition, speculation, practice — without the obligation of formal foundations. Some recurring problems the designer faces may be solved through research, some by other means, such as consulting, team collaborations. *Ars sine scientia nihil est*, art without science is nothing [61]: both are necessary, and a reflection on the respective proportions of art and science that are needed for an effective and efficient design activity is needed. This reflection should allow for the development of a design science with adequate content along with the investigations of the following questions: what specific knowledge is needed for design activities and what merely needs to be borrowed from other disciplines, and what is the demarcation line between design sciences and other sciences, if there is any?

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