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► To cite this version:

Louis Vitalis, Natasha Chayaamor-Heil. Forcing biological sciences into architectural design: On conceptual confusions in the field of biomimetic architecture. *Frontiers of architectural research*, 2021, <10.1016/j.foar.2021.10.001>. <hal-03513125>

HAL Id: hal-03513125

<https://hal.science/hal-03513125v1>

Submitted on 22 Jul 2024

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Forcing biological sciences into architectural design: On conceptual confusions in the field of biomimetic architecture

Louis Vitalis*, Natasha Heil

UMR MAP-MAACC CNRS, National Architecture School of Paris La Villette, Paris, France

*Corresponding author.

E-mail addresses: louis.vitalis@paris-lavillette.archi.fr (L. Vitalis); natasha.heil@paris-lavillette.archi.fr (N. Heil)

Abstract

Certain confusion may be observed in the field of biomimetic architecture, as it emerges at the crossroad of two disciplinary domains: architectural design and biological sciences. If biomimetics is defined as a science, once it is applied to architecture, biomimetic architecture should logically be defined as a science too. This assertion collides with the nature of architectural design, which may rather be defined as a technology: its aim is to transform the world, not to explain it. On the one hand, there is no obvious relationship between architecture and life sciences. On the other hand, the biomimetic approach tends to redefine the concept of science itself by seeking to avoid the excesses of scientism. Moreover, existing applications of biomimetic design show that it is difficult to observe a genuine biomimetic architecture; most cases are closer to engineering component or urban planning and sometimes they involve little or no life sciences. The aim of this paper is to describe this conceptual confusion through two movements called “forcings”, occurring between design and science. These forcings are conceptualised as shifts between constructed scientific objects and given empirical objects. Models, used in biology as in architecture, allow these shifts by virtue of their double function. They are both tools for knowledge and for design, thus they may be conceptually forced into what they are not supposed to be, particularly in the field of biomimetic architecture where design process and scientific knowledge are said to meet.

Keywords

biomimetic architecture; architectural design; epistemology; design with biology; modeling theory

1. Introduction

Biomimicry or biomimetics is defined as a “new science” according to Janine Benyus, author of the internationally known book *Biomimicry: Innovation Inspired by Nature*. By stating that, she apparently did not have in mind what significance it should have for architectural design. Admittedly, Benyus’ book is written in a rather anecdotal way, and it is not the aim of this paper to analyse it. But it had such a wide audience that its effects have impacted various fields including architecture and the philosophy of science. These consequences in specific fields need to be studied. Indeed, when the idea of biomimicry or biomimetics enters the field of architecture, some odd consequences arise. Let’s first bring back how she defines biomimicry as:

“a new science that studies nature’s models and then imitates or takes inspiration from these designs and processes to solve human problems” (Benyus, 1997/2002, p. 7)

Here we see the concept of “science” put together with that of “design”. Architecture is certainly a design activity aiming to solve human problems, but it is not known as a science, at least not in any classical meaning of science. For this reason, the concept of “biomimetic architecture” may cause confusion.

In fact, certain confusion can be observed in the field of biomimetic architecture when looking for some conceptual clarity. As it emerges at the crossroad of two disciplinary domains — architectural design and biological sciences — it may carry ingredients of both. But where science stops, where art begins, where does technology help... are questions that biomimetic architecture cannot answer clearly. Architects are generally not trained as scientists and biologists generally not as designers, and therefore they tend to give contradictory answers to these questions. As we observed in studies and with students, architects are often misled by an overestimation of the role of science in biomimetic design. As a matter of fact, there is no shared explicit method to lead a biomimetic architectural design process. Implementations and case studies are mainly empirical and, expect few recipes and rules of thumb, there is no clear falsifiable theory. This conceptual mud would be trivial if the stakes were not that high. We see at least three reasons to be concerned about this conceptual confusion: 1) architects and students willing to start designing biomimetic projects will fail if they do not know whether they should engage in scientific activity and how it should transform their regular design practice, 2) the notion of science serves as a justification playing a role in various power issues (moral, institutional, media...), 3) if the sustainable aim pursued by biomimetic architecture is really an important issue for our world, then *biomimeticians* should be interested in not talking nonsense in the name of sustainability.

This paper analyses this conceptual perplexity. For this purpose, we will first recall how biology and science are dragged into biomimetic architecture. Secondly, we will show how these claims are problematic compared to real practices of biomimetic architectural design as empirically observed. Thirdly, we will propose and define the concept of two *forcings* movements to elucidate this confusion.

2. Science, Biology and Architectural Design: a Conceptual Debate

2.1. Prelude: Classical Meanings of Science, Technology and Architecture

For the purpose of this article, we need to clarify some conceptual distinctions. Before entering the confusion and mix between concepts, their unadulterated meaning should be recalled. We refer to these meanings as

“classical” only to distinguish them from the contemporary changes that will be observed afterwards in the field of biomimetics. It is a matter of common linguistic convention. Thus, using the adjective “classical” does not claim anything historical neither moral. The first step is to set down the main opposition between biomimetics and science; biomimetics cannot be described correctly through the idea of an explanation through causes (Meyerson, 1908), a verification of proposition and the rejection of meaningless sentences (Schlick, 1932), a falsification process (Popper, 1935), neither through a research program (Lakatos & Musgrave, 1970). There are two other ways of conceptualizing science that may seem less clearly distinct from biomimetics. First, science may be considered under the criterion of reproducibility, as a process of replicating experiments. Second, science may be considered as an operation of construction (Bachelard, 1934). It is beyond the scope of this article to enter in a precise discussion, but the main contradiction with biomimetics lays in the fact that, in science, the value of the reproduction of an experiment does not lay in the reproduced facts but in their meaning; the construction is a rational one. Indeed, conversely to all these ways of conceptualizing science, biomimetics is not interested in the truth of a knowledge about an existing state of the world, but in the transformation of the existing world for sustainable purposes. However, these classical understandings of science are under debate. The debate is further complicated by the rise of technology in our contemporary societies which has introduced the idea of “technoscience”.

The second step is thus to be able to distinguish these concepts. The philosopher of science, Anne-Françoise Schmid, who has precisely studied this transformation of science, provides a useful help to distinguish science from technology:

« If we want to avoid the transcendental illusion [between reality and its scientific description], we will define science as what describes reality without transforming it. This definition would suffice to distinguish it from technology – whose aim is precisely the modification of empirical reality – and from philosophy, which, somewhere, always seeks to transform the world and the essence of the human. » (Schmid, 1998, p. 69)¹

And more precisely:

«Science is a stance of description of reality without ever mixing the description with what is described. Thus, in the relationship between its representations and the real: there is no mix between them. [...] As for technique, it is the impulse to articulate heterogeneous elements according to a logic that does not belong to any of these elements. Such a characterization makes it possible to understand a technical use of science (articulation of models from different fragments of knowledge according to a logic that does not depend on any of its domains) and a scientific use of technique (where the results of these articulations of models will bring new representations among the scientific representations of reality). [...] Technology is the actual expression of these mixes, and in this, it describes effectivity. » (Schmid, 2002, p. 254-255)²

¹ Our translation, original text: « Si l'on veut éviter l'illusion transcendantale précédente [entre le réel et sa description scientifique], on définira la science comme ce qui décrit le réel sans le transformer. Cela suffirait à la distinguer de la technologie – dont l'objectif est justement la modification du réel empirique – et de la philosophie, qui toujours quelque part, cherche à transformer le monde et l'essence de l'homme. »

² Our translation, original text: « La science est une posture de description du réel sans jamais mélanger la description de ce qui est décrit. Ainsi, dans les rapports entre ses représentation et le réel : il n'y a pas de mélange entre eux. [...] Quant à la technique, elle est pulsion d'articulation d'éléments hétérogènes selon une

This view is consistent with Mario Bunge's conception of technology as an application of pure science for pragmatic purposes (1966). It follows that the idea of technoscience is an inconsistent concept when thought as an undistinguishable mix (see Dominique Raynaud, 2016). Mario Bunge further distinguishes between substantive theories and operative theories in technology, both may have a bearing on action; the first ones are applications of pure scientific theories to real situations, the latter are theories of action, which are rooted in applied research and borrow their methods from science rather than theory (Bunge, 1966, 331-332).

According to this conceptual framework, architecture and biomimetics (whether architectural or not) seem to share with technology the purpose of transforming the world rather than describing it. Biomimetics may be an application of substantive theories by applying theories of biology (as pharmacology does for example), but it may also be an operative theory by dealing directly with the action of humans in the world (as a resource management model for example). But from this viewpoint, we must acknowledge that biomimetics as a pure science would be a strange idea since it would entail a pure cognitive purpose of describing the world state of affairs without changing it.

A final issue to raise is whether the concepts of technology and architecture can be equated. There is no absolute answer. It is rather a matter of conceptual context. As Ferdinand de Saussure demonstrated, language works as a system: a word is not defined individually, but in virtue of its oppositional relationship in a system of words. Thus:

— Technology includes architecture when technology is to be distinguished from science. Design is here a shared characteristic inducing the equation between architecture and technology. Yet, in this view, we have no clue about which science is applied in architectural technology.

— Technology excludes architecture when architecture is related to the field of art and humanities which subsequently loads architecture with symbolic and poetic values which differ from technology. Nevertheless, this is due to an implicit supposition that the “sciences” in the “applied sciences” forming technology are natural sciences such as physics, chemistry, biology, etc. Couldn't we consider architecture as an applied science of social and human sciences, such as psycho-sociology, semiotics, poetics, art history, etc.? We shall come back to this question later in this paper.

2.2. Biomimetic Theorists Questioning the Concept of Science

Considering that the concept of science doesn't seem to fit with biomimetics, we need to look closer to what is called “science” when biomimetics is defined as a one. This question is actually under debate among biomimetics pioneers.

Janine Benyus' call for a paradigm shift is the first step towards a biomimetic understanding of science;

logique qui ne relève d'aucun de ces éléments. Une telle caractérisation posturale permet de comprendre un usage technique de la science (articulation de modèles relevant de fragment de savoir différents selon une logique ne dépendant d'aucun de ses domaines) et un usage scientifique de la technique (où les résultats de ces articulations de modèles apporteront de nouvelles représentations parmi les représentations scientifiques du réel). [...] La “technologie” est le visage actuel de ces mélanges, et, en cela, elle décrit l'effectivité. »

according to her, science should no longer be considered as an almighty problem solver as fantasized by science fiction. Instead, the place of humans should be rethought in a humble collaboration with its ecosystem (Benyus, 1997/2002, p. 33). Benyus is here rejecting *scientism*, namely an excessive belief or faith in the power of science. However, her allusion to “science fiction” transforms the classical meaning of science. Suddenly science shifts from a *descriptive* role to a *prescriptive* aim: transforming the world rather than describing it. Thus, this critique of scientism tends to conflate science with technology³.

The second step is the development of Benyus’ ideas by biomimicry theorists who challenge her view and have in particular criticized the unsolved dualism that separates human technology from nature (see Bensaude-Vincent, 2011; Dicks, 2016; Mathews, 2011; Pitrou et al., 2015). As Lauren Kamili summarized (2019), despite its rejection of scientism, the initial project of Janine Benyus was criticized, among other things, for its scientism; critiques point to ethical problems raised by a biomimicry framework based on a classical, occidental understanding of science and its power. Such biomimetics risks widening the gap between nature and culture, and producing technical artifacts that are not ecologically sustainable (see also Speck & al., 2017).

Some of these critiques are specifically pointing to the very status of scientific knowledge. For example, Bernadette Bensaude-Vincent (2011) argues that nature in itself does not teach anything, but rather that humans take inspiration from their understanding of nature, already shaped by a contemporary technological culture. Hence, knowledge in biomimetics relates to engineering rather than empirical sciences. Henry Dicks likewise proposes a shift in the way science is defined by biomimicry, but in an opposed perspective to that of Bensaude-Vincent. According to Dicks, knowledge in biomimetic science arises by learning *from* nature (rather than knowing *about* nature), it is a knowing-how (rather than a knowing that). Natural entities “possess knowledge” and are “capable of transmitting that knowledge to human subjects” (Dicks, 2018). These authors represent two ways of escaping the dualism separating human technology from nature: whether humanizing nature (looking at it with an engineer’s gaze), or naturalizing humans (learning from nature which possesses knowledge). It could be that —once this dualism overcome— no difference would remain between the two, but an examination of this possibility exceeds our scope.

A third kind of critique addresses the contemporary character of biomimetics and its claim to be a new and innovative approach. Instead of such a gap between old and contemporary practices, the anthropologist Perig Pitrou argues, after a study based on existing cases of biomimetics, that mimicking practices never mimic life as such, but rather as it is understood by humans. Within this frame, mimicking practices in traditional cultures are similar to contemporary biomimetics (Pitrou et al., 2015); older imitations of nature and new scientific biomimicry rest on the same epistemic ground.

This brief overview shows that science and biomimetics do not have a simple relationship, all the more so as

³ Science and technology find themselves together in some areas of applied biology itself: synthetic biology, genetic engineering and biotechnology... are doing more than describing the world and thus belong to technology. For a glance in biotech industry and its tense relation with academic biology see (Lee & Agapakis, 2018). But here the aforementioned definition of Mario Bunge may still apply since these applied sciences clearly rely on the results of pure sciences.

biomimetic theorists call into question the meaning of “science” and provide conflicting approaches. Bunge’s concept of pure science is thus criticized. Yet, his concept of operative theory seems to apply, but is called scientific by the aforementioned biomimetic theorists. As a new science, biomimetics tries to overcome the dualism between subject and object of knowledge on which pure natural sciences are classically grounded. Consequently, as the concept of science itself is not of shared understanding, its adjustments to the subdomain of biomimetic architecture merit a closer investigation.

2.3. Biomimetic Architecture as Biological Sciences Meeting Architecture

In this section we will see how the biomimetic way of thinking tries to involve a specific science (biology) into a design practice (architecture). Indeed, many researchers advocate for the use of biological sciences in design whether in general (Bar-Cohen, 2005; Lenau, 2009; Vincent et al., 2006) or in the specific case of biomimetic architecture (Baldissara, 2018; Gruber, 2011; Mazzoleni, 2013; Pedersen Zari, 2007; Ripley & Bhushan, 2016; Speck & al., 2017).

From now onwards, the focus is set on the subdomain of biomimetic architecture. Admittedly, nature has been a source of inspiration long before the idea of biomimetics (see the review of Portoghesi, 1999), but an account of this history is beyond the scope of this article. Contemporary biomimetics distinguishes itself as an innovative approach based on biology. And biology should be distinguished from nature by being a science; this epistemic level is our other focus point. Mimicking nature evidently requires preliminary knowledge of natural phenomena; this is why biology is introduced. As scientific knowledge about nature and its living beings, biological sciences provide an understanding upon which most theorists of biomimetics rely. They distinguish two kinds of approaches: *biology influencing design* searches for natural phenomena that may inform an innovative and sustainable design and be transferred into a designed object that is not defined prior to biological exploration; *design looking to biology*, follows the reverse procedure by starting from design problems and attempts to find natural phenomena that could be transferred to solve this specific problem (Helms et al., 2009). Both rely on biology, albeit more so the former, since biologists take part in the design process from the beginning. In both approaches, architecture and biology shall meet despite the chasm between them.

The biomimetic concept did not arrive in the field of architecture until around 2010. The architect Petra Gruber (2011) is one of the pioneers to have introduced biomimetic architecture. In her work, she tries to find overlaps between life sciences and architecture and focuses on conceptual frameworks that might be comparable such as: interaction of an individual with its milieu, environmental parameters and evolution. Similarly, in his more pragmatic guide for biomimetic architecture, the architect Michael Pawlyn (2011) consistently refers to biology. He even suggests that architects ought to acquire basic knowledge in biology. However, a deeper look reveals that Pawlyn doesn’t clearly distinguish nature and biology.

In *Bionik als Wissenschaft* (2010), Werner Nachtigall considers biomimetics as a science. But in his later collaboration with the architect Göran Pohl the identification with science disappears, although they describe their work as an application of biomimetics to the specific field of architecture (Pohl & Nachtigall, 2015). According to Pohl and Nachtigall, biological sciences are nevertheless a necessary foundation for this type of

architectural design. However, by calling for abstraction, they indicate the need to let go of some of the biological specificities and to deal with them in an emancipated way. Their work ultimately tends to define a method for biomimetic architectural design with the following stages: *knowledge, abstraction, implementation*. Another method was elaborated by Maibritt Pedersen Zari (2007) who established an alternate approach that hierarchises biology in levels which are more or less valuable for a transfer to architecture. From the lowest to the highest, the levels are: form, process and ecosystem. Similarly, in the classification of various approaches within and around biomimetics elaborated by Speck & al. (2017), the use of science defines a higher degree of biomimetics.

The recent ISO norm reiterates this hierarchy of values: it states that biomimicry is based on models of nature abstracted through an observation of a biological system. The presence of science is explicitly required judging by the definition of *biomimetics*: “interdisciplinary cooperation of biology and technology”. Nevertheless, *bio-inspiration* is considered as a creative approach that tends to have a loose relation to the biological system (ISO 18458, 2015).

Overall, a scientific knowledge of nature is commonly recognized as a requisite for biomimetic architecture. While only biologists (Benyus, Nachtigall) seem to think biomimetics *as* a science, the subdomain of biomimetic architecture is more about the *use* of a science, namely biology. Thus, the idea of applied science seems to be suited for this field. More specifically, the situation matches with Bunge’s concept of substantive theory, as an application of biological sciences for technological purposes. But this seems to be at odds with the whole possibility of the new scientific approach outside the nature/culture dualism. Additionally, some standpoints indicate the need for other non-scientific ingredients such as abstract interpretations, or more open creative processes. At this point, it should be said that in this overview we tackle the problem through concepts and definitions. We may notice that as a self-proclaimed innovative or emerging approach, biomimetic architecture relies more on a speculative discourse about new ways of designing rather than on observed design practices.

3. From Concepts to Real Design Practice: a mismatch

Rather than speculating about what biomimetics could or should be, empirical observations can lead in the architectural field. They show that the idea of a biomimetic architecture, that would be both scientific and genuinely architectural, is problematic. First, because the practice of architectural design seems neither scientific, nor genuinely grounded on biological sciences. Second, because when biological sciences seem to be successfully involved, the result doesn’t seem genuinely architectural.

3.1. A Fleeting Science Inside the Design Space

Reflecting on historical cases of mimicking nature in architecture history, Gilles Rion (2017) describes the benyusian paradigm as a naïve scientism that leads to normative aesthetics. According to him, it enables to judge good biomimetics, and rejects bad imitations, specifically imitations based on formal resemblance. On the contrary, he proposes to consider and to highlight that from the standpoint of architectural design “‘everything is nature’ or ‘everything is biology’” (2017, p. 110). By doing so, he abandons the specificity of science, conflating

biology with nature itself: “biomimetic” is just a new trendy name given to an old unchanged practice. He notably rejects the idea of the superiority of function-mimicking over form-mimicking. By doing so, his position contrasts with that of most biomimetic theorists like Pedersen Zari.

Biomimetic researchers often complain that biomimetic designs are not rigorous or lack theoretical consistency (Vincent, 2006; Lenau, 2009). They thus propose normative frameworks, so called “methods” that designers should follow. Another way to consider the situation is to observe how design processes work and if they are not rigorous, to explain why. This is a contribution that design science may provide to biomimetic architecture. The design science discipline has shown that architectural design is a domain of non-optimal solutions and heuristic processes. This is to say that designers do not have resources nor time to find an optimum, and that it is not possible to list all solutions since the problem is not known from the beginning but constructed through the exploration of the design space (Simon, 1996/2004). According to a general overview by Boudon and Dehayes (1997), studying design means to take interest in 1) virtual objects (rather than built architecture), 2) process (rather than the states to which the process lead), 3) the relation between material and cognitive aspects (rather than a clear cut between natural and human sciences) and 4) in action (rather than an untouched world, the design space is teleological, explored by human purposes). With exception of process, each of these characteristics seem in contrast with biology.

When studying cases of biomimetic architectural design, it has been observed that the role of biological sciences seems to be fleeting. In some cases, biology acts as a mediation that leads to other sciences like mathematics, physics, and geometry. Moreover, the biological knowledge used during design tends to be approximate or obsolete. Finally, the biological models need to be completed with much more other non-biological information in order to become architectural (Heil & Vitalis, 2021). Similar lacuna is observed in the urban design field, where the model of the forest has been more artistic than scientific (Dicks & al., 2021).

In other case studies, as in the one of the Beijing Stadium designed by Herzog & de Meuron (Vitalis, 2020), the inspiration from a bird’s nest, simply has nothing to do with biology. It was an artist in the design team, Ai Weiwei, who brought up the natural source model. The analysis of the design process shows the freedom of the designers who set the bird’s nest at the same level as porcelain glaze’s cracks. If both have nothing to do from a biological standpoint, they are equal from a geometrical standpoint adopted by the architects at a specific design stage. But there is something more to porcelain from a cultural standpoint. This design case can be downgraded to bio-inspiration because of its lack of biological science (according to ISO, 2015 or Speck & al., 2017), but by doing so we miss its specific value. From another side, the results are not that different when studying the design process of a biomimetic project involving biology and biologists from the beginning: in the case of the design of the series of timber pavilions of the ICD/ITKE at the University of Stuttgart, the presence of botanists was shown not to have influenced designers who took urchins as models (Vitalis, 2021). The botanical knowledge was neglected in the name of fitting the skeletal model. In addition, biological knowledge was more useful when animals were considered as mechanical structures rather than living beings. However, the lack of primary literature and firsthand analysis of design data in the field of biomimetic architecture, should prevent us from generalising upon these results.

3.2. A Fleeting Architecture Between Complex Engineering, Simple Pavilions and Urban Schemes

On the one hand, a lot of architecture classified as biomimetic tends to be architectural components rather than whole architectural spaces. There are many examples such as the living façade by Chartier Dalix studio, the BILAME shading façade system by Art&Build architects, or bioluminescence material by Tangram architects (see Heil & Vitalis, 2021). The famous *Flectofin* louver system than can be implemented on any building. These components, no matter how complex they are, can be applied to diverse architectures. They miss the issue of location; being located implies a site-specific design and results in architectural objects that are generally not replicable unlike industrial production (Raynaud, 2001). Industrial components certainly play a role in architectural design, but the issue of design process precisely exceeds them to articulate parts into a whole that has to be coherent according to the architect's aesthetics. Thus, these components are addressed as engineering devices. The same observations are made by Ripley and Bhushan (2016) who infer that mimicking is not a suitable process for architectural design and thus came up with the idea of "bioarchitecture"; another futuristic speculation about what architecture could be.

On the other hand, there are only a few cases of genuine biomimetic architectural *spaces* built, but they tend to have limited functional complexity and are small in size. The work led by Achim Menges at the University of Stuttgart with an interdisciplinary team of architects, engineers and biologists is to be mentioned here. They achieve the transfer from biology to architecture in an interesting manner; they avoid the component problem and are thus getting closer to genuine "biomimetic architectures" by building whole specific spaces. Nevertheless, they build only small pavilions. The work of Neri Oxman, Alisa Andrasek or Marc Fornes can be considered of the same kind; high-level interdisciplinary work achieving a transfer to architectural scale, but yet small in size and programmatically simple built implementations, often restricted to academic or exhibition installations (see Migayrou F. & Brayer M.-A., 2013).

The implicit claim behind these pavilions is that they show a possibility of biomimetic architecture and therefore that more complex architectures could be biomimetically achieved through a linear process of small improvements. This inductive way of reasoning (big forecast induced by small possibilities) implies a concept of complexity defined as a gradual progression: starting from simplicity, complexity may be achieved through linear steps. By reasoning this way, we wager on the final result, forgetting about it, to only focus on the next small improvement. However, if we can find empirical proof for the possibility of small simple biomimetic architecture, there is no proof of the final result through linear small improvements. But what if there is a logical impossibility to this linear progress? Designers are free to try, but in the meanwhile this question remains unanswered. And, as existing whole complex biomimetic architectures remain rare today, the question needs to be addressed. We should nevertheless mention three types of counter-examples to consider how they relate to the problem.

First, the Eastgate Center in Harare (Zimbabwe) by Mick Pearce, inspired by a termite mound, is so over-mentioned in the literature that it raises doubts. A single achievement is never a general proof. Hence the question should be: why did this one succeed? An insight is certainly to find in the fact that the natural model is

an animal construction. What is mimicked, in a way, is already architecture. Artifacts built by living beings seem to be more relevant for biomimetic architecture than living beings themselves. A second case is the Beijing National Stadium designed by Herzog & de Meuron inspired by a bird's nest. This one could be a good example of a complex architecture produced in the construction industry. But, as we mentioned, this inspiration involves an artist rather than biologists. The third case are biomimetic urban schemes. Among them, let's mention the Skolkovo district 11, a master plan of 90 accommodations inspired by Emperor Penguins huddles, designed by Bechu+Associés office. If these cases reach a significant size, they fall into the opposite of the engineering component problem: the master plan might be biomimetic, but it determines little of the specific architectural form, and may be filled with a multiplicity of architectural spaces. These observations open the question of a genuine complex biomimetic architecture that may be conceptually defined by its distinction from both biomimetic engineering and urban design.

Let's summarize the situation. Biomimetics defines itself as a science but changes the meaning of "science". Biomimetic architecture is supposed to use "biological sciences" without being clear on its exact role. However, in the view of empirical biomimetic architectural design cases, the concept of "science" seems inappropriate to apply. When it does, then it is the concept of "architecture" that seems inappropriate.

These concepts are supposed to describe reality, but the way they are used in the field of biomimetic architecture seems instead to force this reality.

Facing this critical situation, we propose to elaborate on a hypothesis of two "conceptual forcings" to explain the confusion.

4. Two Conceptual Forcings

To understand the confusing relationship between biology and architecture in the case of biomimetic architecture, our proposal is based on the distinction of two kinds of objects. What should be distinguished in both biology and architecture is not only a content, but also a formal difference between scientific objects and empirical objects⁴. Architecture is particularly prone to be considered as various constructed objects: urban sociology, design studies or perceptual psychology do build different constructed object that may be applied to the same given architectural object. Taking a construct as a given is often a source of misunderstanding⁵. Adding objects from the field of biology is even more confusing. Suppose we were speaking about purely empirical objects (given) — a duck and a specific act of drawing a house (both seen as a given) — or purely scientific objects (constructed) — the homeostasis process and the architectural design operation of scaling (both constructed in a specific theoretical frame). In this case, things could have been simpler. We argue here that the aforementioned conceptual transformations can be explained through a mix-up of these objects:

— If you consider the duck as a scientific object, an already constructed biological object you might

⁴ On the difference between given (empirical) objects and constructed (scientific) objects, and architecture as an empirical object that can be taken from the standpoint of various scientific objects, see Boudon (2001) based on Canguilhem (1968/2002a, p. 16).

⁵ Objects denote here terms that are apprehended either with a conceptual apparatus (constructed) or as a data (a given) to which the conceptual apparatus may be applied. Of course, an object is never *simply* given, last two hundred years of philosophical thought has grappled with the idea of how it is given to us, but architects do not always have these thoughts in mind since they are not trained in philosophy. This appears clearly in the architectural research literature where conceptual apparatus are sometimes not explicit.

disregard the multiplicity of understandings one can draw out of it, according to various standpoints (for example its cultural significance in a specific society). The empirical object is being forced into what it's not. However this can be helpful for transferring it into the process of drawing house, since implicit choices reduce the complexity of the empirical.

— If you consider the homeostasis as an empirical object, you might disregard the conceptual system within which it has a meaning (a teleological idea of life, the relation of an individual to its environment, some measurable variations...). The constructed object is being forced into what it's not. However it can be insightful for mimicking this homeostasis to draw a house, since it may bring intuitive ideas of a façade as a regulating membrane.

This can be diagrammatically formalized (see Figure 1).

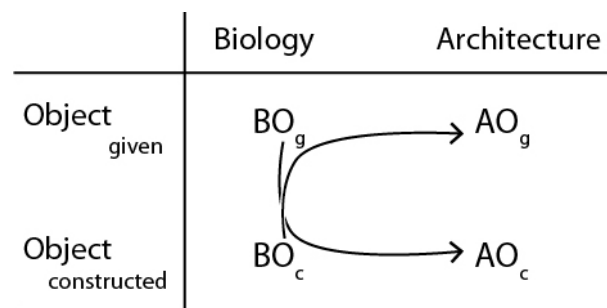


Fig. 1 Shifts between constructed and given objects in biomimetics (diagram by authors)

Each arrow represents a semantic shift, where an object is mistaken while crossing domains from architecture to biology. We propose to consider “models” as playing a main role in these shifts. The concept of model plays a significant role in architecture and in biology. Although being constructed objects, models have a wide range of functions among which some are not intended to be scientific in either a descriptive or an explanatory way (Varenne, 2014). In architecture, models with retrospective and descriptive roles may always be used for prospective design aims (Coste, 1997). Let's now refine our schematic examples by adding that the house drawing is done through a digital 3d model and that the act of drawing happens at a stage of design where it is not already built. Hence, this model does not pursue a scientific aim but a technological one. It does not point toward a yet existing state of reality but participates in its transformation. Moreover, although being a model, it remains a given phenomenon from the standpoint of design science and its scope of modeling design with design scale operations (a meta-model of the 3d model). Here are some ensuing problems:

— you can apply the 3d modeling to the duck, but by doing so, you might not produce biological knowledge. You can apply the homeostasis theory to the house but by doing so you might not produce architectural transformations. If you disregard the constructed model as having a purpose, either scientific or technological, you may force biology or architecture into a purpose they do not have.

Consequently, a construct can always play the role of a given for another construct. These shifts of given/constructed objects that are able to exchange the scientific/technological functions of models is the ground of conceptual confusions. They follow two problematic movements that we propose to call *forcing*, and to

describe as moving the relationships with reality. An initiating key dynamic in science is to start from an emancipated relation to reality (hypotheses, concepts) and then go back to it (test, measurements...), while design goes the other way, departing from an existing reality (site, needs, measurements...) and emancipating from it (inventing something new)⁶. Instead, the forcings⁷ strain the focus towards the other direction (see Figure 2): either disregarding design practices in order to look at things as already scientifically constructed objects (F1), or an attempt to use biology as a non-constructed but given material suited for architecture (F2). These movements are conceptual because they affect how things are understood (the concept meanings), not how they are (their ontological status). The confusion due to these forcings occurring between architectural design and biological sciences, is thus specific to the fields crossroad. Unlike any confusion, its peculiar modality is shaped by the semantic shifts that models facilitate. As it is a matter of standpoint, it is not easy to think both movements together; one is avoiding the other. Thereafter, this abstract scheme will be illustrated with misunderstandings stemming from it.

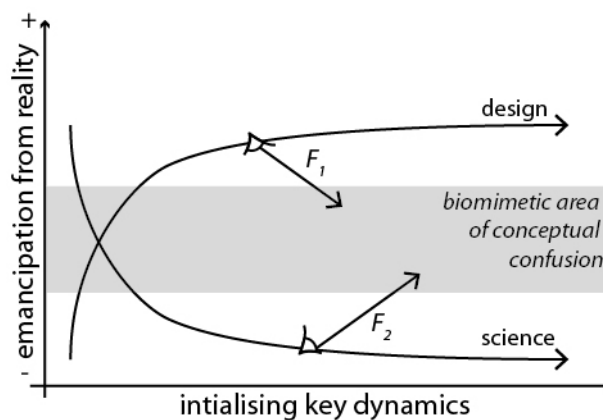


Fig. 2 The two forcings (F1 and F2) as shifting the focus outside regular processes (diagram by authors)

4.1. Making Scientific; F1 Forcing Architecture into Something Else

In order to trace this F1 movement, the very nature of architecture and its relation to knowledge will be left aside. The vanishing point of this movement is a scientifically constructed object. This movement has two side effects: one concerns architecture, by asking too much rigor from the design process, the other biology by not considering its complexity. Both effects disregard the empirical nature of practices.

The first effect occurs in the design science field. As history of the discipline has shown, with the failure of the design methods movement, rigorous (supposed) scientific methods do not fit into the serendipitous practice of design. Attempts to make the architectural design process scientific end up normalizing design. Biomimetics tends to impose new methods. Nachtigall's analogical transfer is one of them. The fact that methods need to be imposed and that designers remain skeptical or simply do not adopt them, shows the gap. By doing so, the

⁶ Admittedly, design goes back to reality (and becomes production) and science invents new hypotheses, but we are catching here one initial key dynamic, not a realistic historical complexity.

⁷ Although it should be recalled that forcing is a mathematical technique formalized by Paul Cohen, we are only refer here to it in a loose sense. What is important to our eyes is the idea of some expanding movement that changes the set of what is usually called science or design. The coherence of the result of the forcing operation is not essential in this article. However a mathematical formalization of the forcing between architectural design and biological sciences that we try to grasp here is beyond the point and the space of this article.

scientific target creates an ambiguity around science. The fact that design processes could be studied ‘*as they are*’ is being somehow forgotten. An obvious parallel is to imagine an astronomer willing to change the orbit of a planet instead of trying to understand its trajectory. Similar problems would arise by not distinguishing nature and biology, society and sociology, language and linguistics...

This normative manner can also be found when other domains approach architecture from their specific standpoint. For example, the epistemologist specialized in computer science, Franck Varenne (2020), shows the benefit that architecture could draw from various digital models. His point of view, as he recognizes it, is “normative as for methods”. Conversely studying design practice as a given, enables to understand that digital technology certainly plays a role for architects, but not as an all-in-one block. Empirically observed design processes (de Boissieu, 2013) show that computation is used in a complex interplay of tools and cognitive processes, where paper and pen might not disappear but assist digital modeling. Focusing on methods, as a constructed object, raises an ambiguity between scientific method and design method.

The second is subtler to see for architects and designers, because biology seems, from their point of view, far enough to be indubitably scientific. By making science the critical point to distinguish biomimetics from bare non-scientific bioinspiration, biomimetics is often idealistic: biology, as a discipline, is a heterogeneous field of practices among which all do not all play a pure scientific explanatory role. Making architecture scientific at all cost, using biology, creates the risk of mistaking what biology is. There are at least three cases where theories and models in biology and design are not that different:

— Some researchers regret the lack of biomimetic theory: “Biomimetics as a scientific discipline needs to formulate theories that will explain the relations between nature and technology” (Lenau, 2009). Without any deep insight in the field of philosophy of biology, it should be said that the question is also a debate in biology. Lenau’s statement would match with the position of George Canguilhem according to whom there is no authentic theory in biology⁸. Conversely, we can mention the work of J. H. Woodger who was explicitly working on rigorous theoretical biologies. The absence of theory in biology could be seen as a relief, for it is simplifying the use of biology for biomimetic architecture; everything would be a matter of model. But not only epistemological views on biology vary, they also vary on models: the boundary between theory and model is not fixed (Schmid, 1998, p. 129), especially not in architecture research as shown in the recent study of their interplay (Vitalis & Guéna, 2019).

— Beyond the shared *use* of the word “model” in design and biology, some common *meaning* is conceivable. But the model a biologist elaborates to explain the way a natural phenomenon works differs from the one an architect elaborates in order to control the aspect of a future building; the natural phenomenon shall exist rather than being invented. The fact remains that the model, as an abstraction, allows its transposition to non-existing phenomena. It follows that, depending on the way nature is modeled, the model might be more or less easy to use for designing new artifacts. Let’s recall here the anthropocentric vocabulary used in biomimetics to speak about nature: “she” is a designer-engineer facing and solving problems, finding economical solutions through a

⁸ According to Franck Varenne (2014, p. 32) comments on Canguilhem (1968/2002b, p. 313).

specific rationality... A functional role can be seen in these ways of speaking. Language is a first basic level of modeling, and speaking of nature as an engineer facilitates transposition into technology. This goes back to the aforementioned Bensaude-Vincent's statement that humans look at nature with a technological culture. A consequence to investigate would be that biologists, by modeling nature, are participating in a very first step of a process that can be studied as a design process. For example, we can argue that when the biologist Telford (1985) wrote about living organisms in terms of construction, domes and arches, he laid the basis for a design process later continued at the ICD/ITKE (Vitalis, 2021).

— Historical analogy with mechanics and technology did participate to biology's development. Let's mention here the canal lock model of vein valves by Harvey, the digesting duck of Vaucanson encouraged by surgeons as Quesnay and Le Cat, the electrical wire model of a nerve by the physiologist Ralph Lillie (Canguilhem, 1968/2002b). This use of artifacts for the understanding of life could be coined as "reverted biomimetics" (Bensaude-Vincent called it technomimetism), but it doesn't go without raising issues. In a nutshell, shouldn't we then consider the call on biological models to be a false innovative insight, and as a step backwards for biomimetics? The forcing at play here, avoids the possibility that, instead of innovating, designers find in biology only what technology has already put into it.

This last point could be seen as a reason why biomimetics seems always closer to engineering than to architecture. But such an inference would be exaggerated ... as exaggerated as the promise of *Nature as a genius engineer*⁹. These exaggerations are erroneous because biology is certainly more than technological induced models and this is where it gets interesting for scientific knowledge. Canguilhem suggested that biological discoveries may be more helped by experimental analysis methods than by model methods. This point requires a wide discussion, but if we were to elaborate on this, we wouldn't be discussing architecture anymore. Conversely, we propose to elaborate on non-scientist biomimetics, considering the possibility of biology to be sometimes of no use. For example, Vincent Beaubois (2015), a design researcher, proposed to abstract *schema* from natural forms to innovate in technology. He gave the same example of the vein valve that could help to imagine innovative technical valves. If innovation is possible here, it is because the *schema* (or the model) is based on the intuition of the organ, not on the organ itself. Thus, from one empirical object can be derived multiple constructed models (whether scientific or not).

4.2. Making Architectural; F2 Forcing Biology into Something Else

In order to trace this F2 movement the very nature of biology will be left aside. The vanishing point of this movement is the empirical object of architecture. This movement has a main side effect on biological sciences, because it disregards its nature of constructed object, to use it as if it was a given.

It should be asked whether biomimetic architecture can escape the fate of the alternative between engineering components (that can be used for various architecture and are, in this sense, not architecturally specific) and

⁹ See Janine Benyus's idea of 3.8 billion years of research and development. On the contrary, some biologists involved in architecture declare « Beware, however, of the spontaneous tendency of the human mind to regard any biological element as the result of ad hoc positive selection. » (Vernoux et al., 2018 our translation). This opposition is not without link with the polemics around intelligent design.

urban schemes (that can be built with various architectures and again disregard architectural specificity). In other words, should “form” be regarded as a swear word? The role claimed for analogy in the design process is here a sensitive idea to discuss. Analogy should be the mean to take a model from biology and to make it architectural. It nevertheless appears not to be neutral, since all analogies don’t have the same values for biomimetics. Maibritt Pedersen Zari, among other theorists, stated that the form of an organism is the lower level of inspiration while the ecosystem function is authentically relevant for biomimetics¹⁰. Thereafter, it will be discussed how the way architectural design constructs and models its objects tends to be irrelevant for the scientific purposes of biology.

Values of analogies and models for science are not based on form. There is a conventional value hierarchy at play in biology and generally in science which prizes abstraction and despises form. Underneath, we find a concept of superficiality necessarily associating the meaning of surface with a lack of rigor and absence of deep understanding. We can find this in the views of the biologist Ludwig von Bertalanffy (1968, p. 84) who distinguishes analogy (based on non-relevant similarities) from homology (based on functional similarities; analog in the mathematical sense). Moreover, for classificatory concerns, functional analogy is disregarded because it does not provide any biological understanding; flies’ wings should differ from birds’ wings. Yet, visible similarities are not relevant either. After analogy and homology, the concept of homogeny is introduced to define a kind of homology in the development. Only homogeny is useful for a biological understanding; the analogy between a bird’s beak and a turtle’s one is only a form convergence but they have no common evolutionary lineage (Lecointre & Huneman, 2020). But if we agree on the fact that the development of architecture differs from the development of living beings, then architects will be bound to use analogy of no biological value.

Yet, models have been described as the place of lower rigor and more creative processes in science: models play an imaginative role of metaphor (Black, 1962) or analogy (Hesse, 1966). Hence, this use of scientific models, although imaginative, does not aim to produce artifacts as do biomimetic processes, but to produce explanations. Conversely in architectural design mimicking nature, we are not dealing with the relation between a model and an *explicandum*. The natural system is a model of yet another architectural model. And architectural models are made by the aggregation of multiple models that address multiple issues among which some are specifically human (for example, an aesthetic integration in an historical urban fabric). The architectural model has no *explicandum*; it is an intermediary tool, useful to test some properties before the building exists.

Thus, all analogies do not bear the same value. The valuable ones for biology are not necessarily valuable for design. Science Philosopher Mary B. Hesse distinguished positive analogy, negative analogy, and neutral analogy. She argued that models including negative analogy (models that include properties that the original doesn’t) were misleading scientific discovery. But which model helps the design process? From an architect’s point of view, the presence of more properties than the ones required for explanation is a source of inspiration. In any case, architects work in the end on models that contain a lot more than biological phenomena do. And this does not prevent the design process, quite the contrary.

¹⁰ “in terms of environmental impact” specifies Zari. But as we discuss below, this doesn’t take into account a symbolic environment for example.

Franck Varenne (2006) showed that analogies are used in science from a specific epistemological standpoint that could be coined as the “analogy of analogy”. It characterizes models in a problematic manner because of an unsolved linguistic hypothesis: imperfect linguistic signs are opposed to an infinite nature, which leads to a devaluation of icons as formally resembling signs. If we are not bound to this hypothesis, analogical icons may be considered as valuable items.

It is worth noting that some scientists did not subscribe to such a depreciation of form. René Thom claimed that form does not have a less profound ontological status than other concepts, and that its study would provide richer account for reality (Thom et al., 1980/1983, p. 112-113). But when we take a look at the model of the dog’s aggressiveness behavior dynamics proposed by Erik Christopher Zeeman following Thom’s theory (Thom et al., 1980/1983, p. 77-79), we are compelled to note that it remains a really abstract “form” from an architect’s standpoint, and therefore it will seem irrelevant to imitate within a building.

In the case study of the use of a bird’s nest in architecture, it has been showed that biology needed to be simultaneously *forgotten* and the model *enriched* for the need of the design process. Biology is “forgotten” because, from a certain point of view in the design process, or, to speak in a strictly architecturological sense¹¹, at a certain scale, the bird’s nest is equivalent to a Mikado game or a spaghetti plate (Vitalis, 2020) ; here the geometrical scale operator filters what is relevant for design. The ability to hold back only a few biological properties is essential to architectural design. Biology is “enriched” because architecture is the result of a complex multi-scale process¹².

Because of this constitutive complexity within architecture, the use of natural inspiration should lead to not give up on forms, images and symbols which are part of the architectural know-how. A famous theoretical treatise (Venturi et al., 1977) did actually elaborate precisely on the symbolic value that a duck form may have for architecture opposed to the shed decorated with the word “duck”. Therefore, biology is also, from an architectural standpoint, a question of symbols and appearances. It can be more than that, but symbols are not to be undervalued either. Symbols and images are also objects of sciences. And if they are systematically neglected in favor of supposedly more serious (because experimental) sciences, then we might understand the affinity of engineering with biomimetics.

Starting from the fact that architects take forms seriously, we could also assume the value of the “barely” visible, and then open the door to elaborate on non-functionalist biomimetics. Were we to elaborate on this, we wouldn’t

¹¹ Architecturology is an architectural design theory. It models the design space through scaling operators. They operate on an architectural model which is defined through the interplay of a multiplicity of scales and their complex interactions during the design process. The theory was constructed through a collective conceptual work by a group of researchers based in the architecture schools of Paris La Villette and Nancy, initiated by Philippe Boudon and Philippe Dehayes.

¹² Franck Varenne (2013) has already called for a multi-scale approach. As important as his insight is, he seems not to consider, in this text, that the architectural design process deals with models that are not only computationally formalized. Rather, this design process may still be multi-scaled through many other techniques altogether. Philippe Boudon has shown for fifty years the general significance of the multiplicity of scales in architectural design. Most recently, he tackled this fact in its difference with geometry (2019).

be discussing biology anymore. Thus, one constructed object can be (relevantly or not) applied to multiple given objects.

5. Conclusion

We have seen how the meaning of “science”, “architecture”, and “biology” shifts in the field of biomimetic architecture. The shift can be explained with two forcing movements acting in opposite directions and altering the relation that a model bears to its real object: explanatory or transformational purposes are being exchanged. Whether the contemporary transformations induced by biomimetics are desirable or not was not the purpose of this text. Confusion is not always negative; it may lead to new ideas. By trying to grasp the characteristics of the transformations in the expression of two *forcings*, our purpose is rather an attempt to clarify the confusion. The forcing clarifies the conceptual confusion by showing how the meanings of “science” and “architecture” are expanded to other correlates and by showing how this expansion is made possible by the mistake between given and constructed objects that models — ambiguous objects after all — facilitate.

It is now possible to look back to the current debate going on about the nature of science in biomimetic architecture. Going back to Rion’s statement: “‘everything is nature’ or ‘everything is biology’” (Rion, 2017, p. 110). We may now disagree with the “or”. This is to say that nature as an empirical field of investigation is not equivalent to the language (*logos*) we use to speak about it. Biomimetics, as long as it won’t clearly distinguish those levels of understandings and the various interrelations they might weave, will lead to epistemological misunderstandings.

Discussing these misunderstandings, we tackled the problem of an authentic biomimetic architecture, that would not be reduce to a patch-up of engineering device neither to any filling of a urban scheme. To overcome this problem we were led to propose non-scientist biomimetics (where sometimes biology is of no use for design) and non-functionalism biomimetics (where form is not of less value than ecosystems or functions) in the same way non-euclidian geometries can be built by changing axioms.

Acknowledgements:

We would like to thank Ariane Lebot for the careful English checking support of this paper.

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