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Back to Darwinian metaphors: The evolution of artefacts

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Abstract: Evolutionary concepts may have great appeal when studying material culture and its designed objects. As a matter of fact, there is robust tradition in using biological analogies to understand designs, as it occurs in the field of bionics, where the simulation of vital processes advocates not only an approach of a purely cognitive nature but, rather, an operative programme allowing the translation of isomorphisms between living organisms and technology into effective design solutions. More generally, natural sciences offer an uncommonly rich *apparatus* for analogies to be applied to the domains of the sciences of the artificial. But how widely applicable are Darwinian metaphors? To which extent do the Darwinian concepts of variation and selection provide meaningful theoretical tools across product innovation? What can they add to the analysis of product designs? To this end, this study takes the form of a literature review about evolutionary approaches to the analysis of technological change, along with a number of interpretations about the analogies between natural evolution and the dynamics of product variety generation.

Keywords: Biological analogies - Evolutionary theories - Darwinian metaphors - Technological darwinism - Product genealogies - Product variety - Artefact evolution

[Abstracts in spanish and portuguese at pages 50-51]

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Introduction

The generalizable ideas on the analogy between biology and technology are recurrent in many disciplinary fields. A bio-technological approach was opened in the Fifties, with the studies of the German zoologist Franz, who introduced the expression “bio-technical progress” (Franz, 1951) to define those structural and functional improvements of organisms which could be measured through their efficiency. The meaning of progress in living systems and technical systems was later extended in the Sixties (Robinette, 1961) and further investigated in the contributions to the morphological progress in living systems and technological systems (Hertel, 1963; Urbanek, 1988).

The developments and consolidation of bionics –on it side– are largely disseminated: the simulation of vital processes and structures have merged into the research domains and applied studies translating natural structures and processes into models for artificials designs (Robinette, 1961; Yeang, 1974; Pearce, 1978; Di Bartolo, 1981; Coineau & Kresling, 1987; Nachtigall & Kresling, 1992, 1992a; Kresling, 1995, 2012).

The evolutionary theories of technological change also largely sustained approaches that invested as much the laws of technological change as the ways through which technological development leans on economic implications (Penrose, 1952; Winter, 1964; Nelson & Winter, 1974, 1977, 1982; Hirshleifer, 1977; Di Bernardo & Rullani, 1984; Saviotti & Metcalfe, 1991; Faber & Proops, 1990, 1992; Mokyr, 1991, 1992, 1998; Dosi & Nelson, 1994; Ziman, 2000).

A further trajectory of studies –often lacking formal elegance and disciplinary autonomy– is denominated *technological Darwinism*. Unconfortably placed between bionics and the formalisation of economic evolutionary theories, this domain gathers recurrent visions and interpretations about the way artefacts and technologies evolve.

The methodology embodied by technological Darwinism implies that a natural organism, structure, or process may produce a model to be extended to an artificial system (or artefact, or structure, or process). Here we will use “artificial” in as neutral sense as possible, “meaning man-made as opposed to natural” (Simon, 1969, p. 6).

The analogy is not necessarily meant to provide a resolutive design pattern or theory. Rather, it may suggest or inspire correspondences to provide insight for conceptual analysis or possible design solutions.

Natural, cultural, and technological evolution

Why may we learn more (or differently) on man made products by referring to natural evolution? Is the analogy a non-sense?

Many elements that grounds the analogy between biological and technological evolution should discourage –rather than encourage– any comparison. As noted by Gould (1980), biological evolution is a wrong model for technological or cultural progress, due to basic motivations:

> (i)-the rhythm of any cultural evolution is incomparably faster than any biological change;
> (ii)-any technical progress is Lamarckian, as changes may be acquired and transmitted directly to offspring. Conversely, natural evolution is Darwinian, the favourable changes being transmitted to offspring only if originated from genetic changes;
> (iii)-biological evolution is a process of constant divergence: once a change has appeared, either by mutation or variation, evolution is irreversibly at work. Conversely, technological or cultural progress may either diverge or converge, any change being reversible.

Whyte (2007, p. 47) confirms that "theories of evolution do not provide a basis for extrapolation of design prescriptions. The progressive view of the mechanism behind evolution is simply not supported by empirical data, and should be little more than a footnote in contemporary discussion".

Why, therefore, in spite of these unfavourable premises, the analogy still makes a sense?

Here we will simply assume that both cultural and technological evolution, which incorporate material culture, are patterns of change and processes of deployment whose order is open to systemic investigation. Comparing evolutionary principles –derived from either the classical darwinian theory (Darwin, 1872) or the Modern Synthesis (Huxley, 1963)– to technological evolution is not intended to directly produce design theories (Pizzocaro, 1994, 2020). What is demanded, at the most, is whether it is possible to obtain augmented understanding about shared regularities that may govern the laws of change in both natural and artificial domains.

There is no strict similarity, therefore, to be theorized between living organisms and man made artefacts, between natural and artificial systems (Pizzocaro, 2020). Rather, what is claimed invests the conjecture that the basis of structurally similar systems that proceed by different self-evident rules, there may be unifying principles, as theorized by the epistemological studies on the general nature of change in biological and cultural systems (Laszlo, 1985, 1986, 1988).

Lesson from biology

Biology and natural sciences offer an uncommonly rich *apparatus* for analogies to be applied to the artificial domains. Businaro (1983, p. 464) argues that, when considering biological evolution, one may refer to three points of view: the palaeontologist's, the biologist's, the molecular biologist's. The first aims at understanding the phyletic evolution of the biological world (Grassé, 1973); the second mainly focuses on the evolution of single species through the study of populations (Dobzhanski, 1970); the third investigates the basic principles of evolution at the level of biochemistry (Monod, 1970). Also the progress of artefacts may be approached from a hierarchy of perspectives, including the paleontological perspective on artefact evolution and the population perspective on families of products.

Moreover, if main evolutionary units in nature are the organism (basic unit of independent life that contributes to reproduction), the species (set of all organisms whose genotypes are so similar to allow interbreeding), the biological system (consisting of a set of interacting species), also within the artificial systems a hierarchy of evolutionary units can be traced, including the single artefact (i.e. the typological perspective), the product aggregates (i.e. the population perspective), the artificial system as an ecosystem (i.e the socio-technical system perspective). The micro-scale of the evolution of the single artefact and the macro-scale of the evolution of large technical systems constitute the two poles of these perspectives.

While evolutionary theories offer a wide range of analogies for understanding designs, however, a strong objection precisely invests the variable units of evolution to be examined, as it may be rather unclear what evolves, or on what grounds selection occurs, or at what level (Whyte, 2007, p. 52).

The genealogies of artefacts

The genealogical perspective on artefacts is recurrent in literature. It dates back to pre-industrial times (Butler, 1863) and it appers in modern or current perspectives (Simondon, 1969; Campbell & Whelan, 1985; Deforge, 1985; Basalla, 1991; Pantzar 1991, 1992, 2010). According to this perspective, any specific artefact may represent an evolutionary unit, whose variations (or mutations) may suggest recognisable trajectories of morphological and functional progress.

The Darwinian analogy mainly relies on the essential Darwinian principles of the struggle for existence, the survival of the fittest, the concept of variation (Darwin, 1872). As Simon (1969, p. 52) observes:

> One way to create an artefact is to let it spring from the brain of a creator. Another is to let it evolve in response to some kind of selective force. The simplest scheme of evolution is one that depends on two processes; a generator and a test. The task of the generator is to produce variety, new forms that have not

> existed previously, whereas the task of the test is to cull out the newly generated forms so that only those that are well fitted to the environment will survive. In modern biological Darwinism genetic mutation is the generator, natural selection the test.

From the angle of man made artefacts, this analogy tends to converge in a vein describing the evolution of the products of human activity as the paleontologic reconstruction of the artefact offspring (Lane Fox Pitt-Rivers, 1906; Blackwood, 1970; Steadman, 1979; Basalla, 1988; Petrovski, 1994). The progression from simple to complex, from homogeneous to heterogeneous, embodies the principles on which the scale of material progress may be grounded. Natural history may thus be a resource to derive analogies and patterns to be extended to artefacts classifications, so to obtain artificial *genera*, *species* and varieties describing diachronic and synchronic sequences of artefacts, with their missing links, that is the difficulty in establishing the adequate insertion of an artefact in a evolutionary genealogy or the explicit absence of intermediate morphological or functional steps.

The key concepts derived from Darwin's theory are often confined in a paleontological interpretation of material culture. A concept of an *orthogenesis of tools* was first introduced by Leroi-Gourhan (1964), reinforcing the hypothesis of the analogy with paleontological evolution as a generalizable fact for technology. The principle of variation, on its turn, has frequently resulted into the speculation on the notions of artificial genotype and phenotype, inherited variations and environment-induced modifications in artefacts, along with selective processes affecting artefact survival and adaptation (Businaro, 1982, 1983; Campbell & Whelan, 1985; Grassman, 1985; Basalla, 1988; Pantzar, 1992). The progress of technological evolution may be then intended as a progressive sequence of artefacts demonstrating the evolution of the fittest, the gradual modification of the survivors, the extinction of the less fit ones. According to Businaro (1982, p. 27), the genotype of a product could be intended as the product specific traits and its technological *regime*. A specific product design (the model) could represent its phenotype and a product series could be intended in terms of product population. Ranges of products might then be the equivalent of races or subspecies.

Businaro's model (1983) is employed to highlight major characteristics of changes in technological innovation and in the time phasing of industrial inventions and innovations. The analysis is applied at the level of the industrial sector and it is used as a heuristic example of the metaphor, with a focus on innovations in the car industry.

The evolution of artefacts –if merely intended as an artificial palaeontology– may have rather limited implications, resulting into classifications or taxonomies of extinct artefacts. A significant function has any way to be recognized, as products taxonomies and genealogies deepen the knowledge about the *status* of existence of artefacts, whose offspring that can be retroactively analyzed, toward the genesis, ancestors, and archetypes.

Overcoming the strictly metaphorical approach or the paleontological description, Deforge (1985) formulates the evolutionary model in terms of genetic offspring for industrial products, with their own laws of evolution and the systemic dimensions where systems of products may co-evolve with their environment. The concept of evolution is theorized as an effective design principle: both the idea of genetic offspring and the formulation of evolutionary laws converge in the process of industrial products diversification within the process of adaptation to the product *milieu.* Deforge's perspective stems from two levels of analogy: the phenotype and the genotype. In one case, morphological and technical variations affecting artefacts and products are explained in terms of survival of the fittest, the progression from simple to more complex structures, the increase (or decrease) of product variety, the dominance or decline of morphological and functional solutions. In the latter, the reflection mainly invests the idea of the product typology as genotype, that is the equivalent of the pool of genes. Mechanisms of Lamarckian or Darwinian selection are also proposed to interpret product proliferation or extinction, providing interpretations about the generation of product variety.

The hypothesis of the associated environment of a product, on its turn, opens the innovative horizon of a more systemic interpretation, with genealogies of artefacts intended as families of products evolving within a system of production, machines and tools within a system of use, goods within a system of consumption. Such a model suggests a more articulated notion of in-context evolutionary unit, integrating the industrial object into its *milieu associé,* as in Simondon (1969, p. 57).

Populations of products

The population perspective applied to artefacts may also integrate the principles of competition and selection. The population (or ecological) perspective opens a systemic dimension that is absent in paleontological visions. According to this approach, human populations and populations of artefacts may coevolve through a selective use of technological systems to produce socio-cultural systems (Gallino, 1987, p. 186).

Moles (1969) first introduced the concept of the demography of artificial products –with species and subspecies, rates of birth and ageing of products– within the perimeter of an ecological perspective where *artificial species* may be analyzed through their dynamics of competition. The definition of species in the natural world still raises disputes among biologists. In case of sexually reproducing individuals, a species can be defined as a reproductively isolated group of populations. Species may also be intended as a taxonomic group, with individuals classified because of their similarities. In the case of man made objects, only such a taxonomic sense may provide a correspondence (Businaro, 1982, p. 15).

The definition of *technical species* was introduced by Simondon (1969), who frequently refers to the notions of genesis, ontogenesis, philogenesis, morphogenesis, mutation, claiming a strict analogy between the terminology of living beings and the rationale of techniques (Maldonado, 1998, p. 210). According to Hottois (1984, p. 29) intuitive, self-evident common factors legitimate the population perspective applied to the artificial world:

> (i)-morphological continuity (that incorporates novelties and perpetuates old forms in nature; the evolution of species would correspond to the appearance of new artefacts in the artificial world);

(ii)-the progressive occupation of the ecological niches (on one side the survival of living species in the appropriate micro-habitat; on the other, technical species that may coexist only within infrastructures that assure its reproductive processes, conservation, and nourishment);
(iii)-a general principle of the struggle for survival (the fittest survives in the biological world as well as in the technological world);
(iv)-the tendency to morphophilia (on one side the extraordinary exuberance of living organism morphologies and interspecies variations, not necessarily motivated by related needs in term of function and adaptation; on the other, the exuberant patterns of proliferation of products);
(v)-the abundance of variations, which do not always find an application (the unfavourable or recessive variations in nature; inventions and patents in technology);
(vi)-the nature of innovations as an integrative process (which as much in biology as in technology can reorganize everything that already exists);
(vii)-the sequence of stability and sudden discontinuities (mutation in nature, inventions in technology).

The ecological perspective: the process of co-adaptation as a model

The developments of the notion of adaptation (Lewontin, 1977) may provide further useful insights for possible interpretations of the evolutionary dynamics of man made systems and the related design strategies. Lewontin (1977, p. 198) observes that adaptation is a concept related not only to life evolution but to culture in general, where it is referred as functionalism. The description of adaptation in terms of solutions to problems implies that a problem comes first, and then living organisms adapt to that condition with a dynamic process: this process is called adaptation and the result is being adapted (Lewontin, 1977, p. 199). The fundamental question raised about this traditional vision of biological adaptation concerns the pre-existence of problems. The principle that organisms adapt to the environment implies that ecological *niches* exist apart from organisms. But this is in contradiction with the definition of the ecological *niche*, which is constituted by the multidimensional relations of an organism with the surrounding environment (Lewontin, 1977, p. 200). To avoid this contradiction it was theorized that living organisms themselves generate their *nich*e: but in this case all species should be already adapted and they needn’t be adapted any more. So how could a species be adapted and in adaptation at the same time? (Lewontin, 1977, p. 201). This paradox in biology has been solved by admitting that the environment is in constant decay and that its organisms are forced to evolve to maintain their condition of adaptation. The Red Queen model, named from the character by Lewis Carroll and developed by Leight van Valen (1973), theorized that the environment is unceasingly decaying and that selection operates so that the living organisms’ adaptation is maintained, not improved. Evolutionary adaptation is an infinitesimal process: organisms are unceasingly adapting, adjusting their traits to the conditions of an environment that is constantly changing (Lewontin, 1977, p. 201).

In the classical context of the survival of the fittest the environment stands as a resource and an obstacle, the organism is active and the environment is passive and static. Conversely, more recent views (Lewontin & Levins, 1978) postulate that organisms and their environment can not be isolated: the environment is the product of the organisms' activity. A considerable part of modern evolutionary biology thus assumes that the evolution of living beings is an active agent of transformation of the environment, which in turn influences organisms (Lewontin, 1977, 1983). A constant process of co-adaptation postulates that organisms select their environments, positively reacting to favourable signals; they modify their environments by consuming resources, disposing wastes derived from their activity, building habitats; environmental factors interfere with the physical structure of organisms; organisms react to environmental changes.

Should the above statements be converted into analogies for the artificial world, it could be assumed that artefacts, products, large technicla system select their environments, positively reacting to favourable conditions; they also modify their environments by consuming resources, disposing wastes, producing habitats; artefacts, products, and systems are integrated in their environment, so that no components of a man made system can be isolated from its context where a dynamic process is constatly at work; evolutionary unit (artefacts, families of products, product populations) are co-evolving in reciprocal relation and contsatly adapting to chaging environments.

As there are limits to the constant process of co-adaptation between man-made systems and their environment, it could also be theorized that sudden environmental change of large entity may allow neither chance nor time to adaptation to new conditions. At the micro-scale of industrial products this could occur whenever a specific need ceases, causing the extinction of products related to that need. At the macroscale of the industrial systems, the hypothesis that a technological system and its environment constitute an integrated unit goes with the concrete possibility (Luhman, 1986) that a man made system may affects its environment on such a large extent, that it can not exist in that environment any longer: a process biology describes as the excessive exploitation of an ecological *niche*.

Beyond the heuristic function of the metaphoric procedure, wide perspectives are opened towards co-evolutionary visions where biology, technology, social and cultural processes are at work. Human organisms, technological systems and socio-cultural systems may interact in a co-evolutionary circuit, where human populations influence the idoneity of technological and industrial systems and, through these, they may affect biological and socio-cultural evolution (Gallino, 1987, p. 186).

The (technological) survival of the fit: an exemplary case

The Darwinian world demonstrates that optimality in nature is not the primary effect of a design, but only the epiphenomenon or secondary consequence of the struggle for survival. In addressing the principle of imperfection in nature, Gould (1991) hypothesized that valid implications can be drawn from this biological theme for other historical systems, e.g. for the products of technology,

Is the evolution of some technological solutions rigidly conditioned by human intentionality or (instead) is it the epiphenomenon of contingent causes?

On the dominance of a technological solution as an effect of contingency, and not as the result of a progress towards absolute technological optimality, Basalla (1991) analyzed the case of the historical competition that took place between engines for the automobile, from which the gasoline engine emerged as the winning competitor.

At the beginning of the twentieth century it was not foreseeable that the internal combustion engine would impose itself on steam engines and electric ones.

Basalla (1991) reports that in the year 1900, in the United States, over four thousand cars were produced, whose vast majority was equipped with steam or electric engines, while those with gasoline did not reach a thousand. Yet, only a few years later, the defeat of the electric and steam models was absolute: at the 1905 New York car show, gasoline-powered cars were seven to one compared to other types.

Why was the petrol engine a winner? Its brilliant survival compared to its competitors, although documented, is not easily explained in terms of absolute competitive advantage. At the very beginning of the twentieth century, in fact, each of the propulsion systems had advantages and disadvantages, and no real technological superiority could be assessed.

The electric car appeared as the direct descendant of the gig: silent, easy to start and drive, it was unrivaled in terms of simplicity of construction and maintenance: electric motor, batteries, a simple gear system. Starting from 1894, when the production was started, the electric car had great advantages even if it was not without defects, including the high cost, the slowness, the limited autonomy, the batteries to be recharged about every fifty kilometers (hence the need to install service stations for charging batteries, without however solving the problem of long-distance travel). Precisely the limited range of action of these vehicles motivated their initial use for the urban transport of goods.

Steam cars, which continued to be produced throughout the 1920s, also enjoyed great popularity at the turn of the century. Similar to petrol engines from an aesthetic point of view, they were not as noiseless as the electric ones but had lower prices and maintenance costs and were able to move without difficulty on all kinds of roads thanks to the power of the engine. However, they were far from perfect: the limited range of action was a drawback, the steam was not condensed to be reused and the water supply had to be very frequent. A further problem was the time needed to produce steam for the first run of the day, although the waiting time was soon optimized in a few minutes.

The first gasoline cars, in turn, had obvious disadvantages at the beginning: starting the engine involved the contribution of muscle strength; the ignition, lubrication and transmission mechanisms had a certain technological complexity; the exhaust gases were harmful and the car noise unpleasant. The considerable autonomy, which made it a reliable means of transport, was certainly an advantage.

However, the survival and subsequent dominance of the petrol engine was not the result of the rational evaluation of advantages and disadvantages: at the beginning of the century such an *ex ante* evaluation was not possible.

The real competitors were actually the steam engine and the petrol one: while in fact the electric car immediately appeared penalized by the problem of batteries, the competition between the steam engines and the petrol ones was so tight that today we could perhaps have steam cars if chance and contingency had not decided otherwise.

Laszlo (1986) points out that the gasoline engine prevailed over the steam engine for reasons unrelated to criteria of energy efficiency: between the Stanley steam vehicle and the Otto four-stroke engine, the former was unpredictably beaten by a random and unpredictable event: a United States ordinance which, in connection with an outbreak of foot and mouth disease in livestock, required the elimination of water tanks intended for supply along the roads (Laszlo, 1986, p. 100). Considerations related to the nineteenth-century aura of steam further came into play to disadvantage steam cars, as steam was still identified as the driving force of railway locomotives, a social imaginary of the previous century rather than of impending modernity. After all, the manufacturers of steam cars did little to help change this negative image, nor were they able to promptly integrate into production those technical improvements that would have made steam cars more accepted by the market.

On the decline and abandon of the steam engine solution, Basalla (1988) reports that when in 1914 Henry Ford went to visit the Stanley workshops, which then produced 650 cars a year, he produced as many examples of his “T” model in a single day. At the same time that Stanley’s skilled workers were slowly manufacturing and refining a small number of steam hand made cars, Ford’s unskilled workers were mass-producing thousands of cars on the assembly line. Shortly after the end of the war, the Stanley Company closed its doors: it had failed to beat the competition from the inexpensive Detroit-made automobile (Basalla, 1988). Regarding the causes of the dominance of the petrol car, even the considerations regarding its absolute efficiency do not appear to be decisive: if it is true that a car with a petrol engine travels more kilometers per liter of fuel than its rival (Basalla, 1988), it is also true that the diesel engine is more efficient than the petrol one. Therefore it could to be asked why it was not the latter who definitively established itself as the dominant. If this has not happened and if the petrol engine has definitively won in the competition for survival, it is not for mere technical or economic reasons, but for a complex of systemic conditions. Once obtained a dominant position in the market, the manufacturers have exploited this fit solution without investing, if not limitedly, in alternatives. The winning competitor was not the absolute best, but only the one who for contingent reasons proved to be fit according to conditions given in the *milieu associé*.

The resumption of the electric motor, almost a century later, due to changing contextual conditions, witnesses the opening and emergence of renewed chances for past adapters.

Micro-reversibility and macro-irreversibility of technological processes

The history of living organisms testifies of a process of constant divergence of its evolutionary branches, while in technological evolution also convergent ramifications are allowed: the technology tree can unite technological descendants, recover reversible technological pasts, exhume interrupted or only apparently abandoned evolutionary branches (as the resumption of the electric car shows).

From a strictly genealogical perspective, the reversibility of technological progress is therefore not only possible but an ordinary event: e.g. the convergence of already existing devices in innovative patents; the recovery of technological knowledge from the past; the abandonment and intermittent resumption of certain technical solutions; the renewed interest in previous technological solutions that prove to be suitable for new applications in new technological or social contexts.

But if we move from the genealogical "linear" prespective towards a systemic dimension, this reversibility appears to be strongly compromized, so much so that it is practically impossible for the wheel of technological change to turn backwards.

The cycles of dominance of a limited number of technologies in fact involve the development of socio-economic infrastructures largely and rigidly determined by those same technologies: therefore, if the return to previous technologies is theoretically possible, systemic relations make it in most cases an unworkable hypothesis. There is indeed resistance on the part of society to adopt technological solutions that are incompatible with systemic conditions.

The general irreversibility of technological innovation, although not a principle, can therefore roughly correspond to the irreversibility of natural systems evolution.

The recognition of the common irreversibility also brings with it a rethinking of the meaning of progress. The peaceful observation that "whatever the nature of a technological revolution, it always proceeds from hoe to plow and never in the opposite direction" (Laszlo, 1986, p. 99) does not mean that all the best innovations are adopted or that those adopted are based on criteria of absolute optimality: contemporary times clearly testifies to which extent many technological choices are often dictated by factors extraneous to the concept of optimality but functional to forms of relative efficiency, as shown for example by the diffusion or dominance of technological solutions favored by merely contingent factors.

The recognition that any technological innovations adopted by society represent a certain degree of progressive improvement does not therefore mean that progress always goes towards the better, but instead it testifies to the forms of resistance of society to adopt solutions incompatible with the contingent systemic conditions.

If a scale of progress common to technological and natural systems can be identified, its trait is complexity: technological systems, like natural systems, demonstrate a tendency to develop increasingly complex relationships between components and to create reciprocal and extensive forms of interdependence.

Open conclusions: towards evolutionary interactions

In mature industrialized societies the process of diversification of artefacts has assumed the proportions of an accelerated and constant mechanism, with ever new objects and products destined on the one hand to replace others, on the other hand to coexist in a proliferating assemblage.

A first order of considerations about the constant process of artefact variety generation provides a dual interpretation, assuming that "variety" and "real diversity" may constitute two different indicators, the first functional to a genealogical yardstick and the second to a systemic vision.

If we limit our reflection to the evolution of the lineages of industrial products, we can witness a process of increasing variety that is constant, rapid, uninterrupted: from the initial prototype, the history of an industrial product is often the multiplication of countless variations. But if one moves from the scale of the lineages of the phenotype to the systemic one, it will be observed that the innumerable variety of artificial products may also corresponds to a considerable but much more limited number of types, or fundamental anatomical designs. A certain degree of stereotypy, that is a reduction of the variety to a limited number of basic models, would then seem conceivable also for artefacts. On the other hand, it is widely recognized that in the start-up and experimentation phase of a new industrial product, or of a patent, there is a certain taxonomic disorder, with many starting designs destined to be selected with respect to contingent situations that will determine the survival of only one or few suitable solutions.

The idea of a maximum initial disparity in the development of prototypes of industrial products can be reflected in the relationship between the nature of radical and incremental innovations: the few dominant models or types that survive the initial decimation would admit only long series of incremental innovations, which make it difficult to intervene over time with radical innovations on the dominant design level.

As a second order of refelections, we also observe that an evolutionary approach suggests the consideration of the elementary interactions between product populations.

We may derive from the fundamentals of ecology (Odum, 1953) that basic interactions between pair of species include competition (one species has an inhibitory effect on the other); commensalism (one species has an accelerating effect on the growth of another); predation (the predatory species has an inhibitory effect on the predated species which in turn accelerates the growth of the former).

Among these elementary interactions, the only one which deserved formalized theories is competition, largely developed –for instance– by the economic studies of perfect or imperfect competition between companies, or about the process of competition by the Schumpeterian entrepreneur (Saviotti & Metcalfe, 1991, p. 17).

The competition processes that a revised evolutionary aproach outlines tend to move away from the classic themes of perfect or imperfect competition or the advantages allowed by innovation processes. The competitive advantage can be rather understood as the speed of reaction and adaptation to contextual changes.

The evolutionary approach, while mantaining the theoretical horizon of competition as a powerful metaphor, virtually extends less explored interactions, such as commensalism, functional to describe the processes through which new products accelerate the development of populations of complementary products.

To complete these observations, it is possible to remind that whether we consider the classic competition between products, or the selection between production systems, or the survival of technological trajectories, these processes are traditionally evoked against the concrete background of market laws and dynamics. However, the *external environment* for products

or technologies is also an effective *milieu*, that is a set of conditions and factors, causes, chances and contingency, which can act jointly by evolutionary or selective mechanisms.
This actual environment often assumes the connotations of the ecological *niche*, presenting itself as both the set of physical conditions (given resources and natural limits in which the production of the artificial takes place) and the set of relationships between the various components of the system, none of them to be considered isolated, all of them being simultaneously the object and subject of the evolution of the other, in a process of reciprocal co-adaptation or mismatch.
What the evolutionary metaphor points out is that man made products can not be isolated from their *milieu*, each of them being at the same time subject and object of the other's evolution, according to a constant process of successful or failing reciprocal adaptation. New interactions are open wide for investigation from the product design angle: from symbiosis between families of products to commensalism for product populations, along with the idea of symbiotic designs for products or commensalism properties that could affect –positively or negatively– product strategies for the future, within the horizon where no artefacts or product designs can be conceived as evolving in isolation.

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Resumen: Los conceptos evolutivos pueden tener un gran atractivo al estudiar la cultura material y sus objetos diseñados. De hecho, existe una sólida tradición en el uso de analogías biológicas para comprender los diseños, como ocurre en el campo de la biónica, donde la simulación de procesos vitales aboga no solo por un enfoque de naturaleza puramente cognitiva sino, más bien, por un programa operativo permitiendo la traducción de isomorfismos entre organismos vivos y tecnología en soluciones de diseño efectivas. De manera más general, las ciencias naturales ofrecen un aparato extraordinariamente rico para aplicar analogías a los dominios de las ciencias de lo artificial. Pero, ¿cuán ampliamente aplicables son las metáforas darwinianas? ¿En qué medida los conceptos darwinianos de variación y selección proporcionan herramientas teóricas significativas en la innovación de productos? ¿Qué pueden aportar al análisis de los diseños de productos? Para ello, este estudio toma la forma de una revisión de la literatura sobre enfoques evolutivos para el análisis del cambio tecnológico, junto con una serie de interpretaciones sobre las analogías entre la evolución natural y la dinámica de generación de variedades de productos.

Palabras clave: Analogías biológicas - Teorías evolutivas - Metáforas darwinianas - Darwinismo tecnológico - Genealogías de productos - Variedad de productos - Evolución de artefactos

Resumo: Os conceitos evolucionários podem ter grande apelo no estudo da cultura material e seus objetos projetados. Na verdade, existe uma tradição robusta no uso de analogias biológicas para entender projetos, como ocorre no campo da biônica, onde a simulação de processos vitais preconiza não apenas uma abordagem de natureza puramente cognitiva, mas, sim, um programa operativo permitindo a tradução de isomorfismos entre organismos vivos e tecnologia em soluções de design eficazes. De maneira mais geral, as ciências naturais oferecem um aparato incomumente rico para analogias a serem aplicadas aos domínios das ciências do artificial. Mas quão amplamente aplicáveis são as metáforas darwinianas? Até que ponto os conceitos darwinianos de variação e seleção fornecem ferramentas teóricas significativas para a inovação de produtos? O que eles podem acrescentar à análise de projetos de produtos? Para tanto, este estudo assume a forma de uma revisão da literatura sobre abordagens evolutivas para a análise das mudanças tecnológicas, juntamente com uma série de interpretações sobre as analogias entre a evolução natural e a dinâmica de geração de variedades de produtos.

Palavras chave: Analogias biológicas - Teorias evolucionárias - Metáforas darwinistas - Darwinismo tecnológico - Genealogias de produtos - Variedade de produtos - Evolução de artefatos