Exaptation as a Design Strategy for Resilient Communities

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> In King's College Chapel in Cambridge, for example, the spaces contain bosses alternately embellished with the Tudor rose and portcullis. In a sense, this design represents an "adaptation," but the architectural constraint is clearly primary. The spaces arise as a necessary by-product of fan vaulting; their appropriate use is a secondary effect. Anyone who tried to argue that the structure exists because the alternation of rose and portcullis makes so much sense […]. Yet evolutionary biologists, in their tendency to focus exclusively on immediate adaptation to local conditions, do tend to ignore architectural constraints and perform just such an inversion of explanation. *[1]*

Summary

The chapter focuses on the significance and the originality of the study of the exaptation as a possibility to extend the architectural design toward more sustainable approaches aimed at enforcing urban resilience. The use of exaptation's definition in architecture corroborates the heuristic value of the cross-disciplinary studies on biology and architecture, which seems even more relevant in times of global environmental crises. Exaptation will be described, in the chapter, as a functional shift of a structure that already had a prior but different function. In architecture, a functional shift of a structure that already had a function may apply to forms of decorations embedded in architectural

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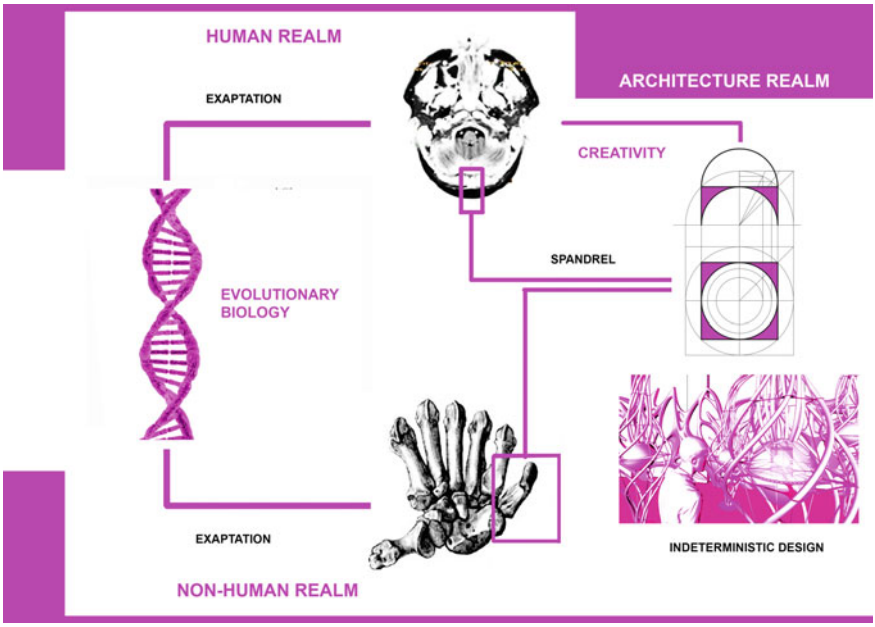
components and to both changes of function of tectonic elements and chance of use of the architectural space. In the final part of the chapter, informal architecture will be introduced as a representation of architectural exaptation.



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1 Introduction

Many scholars have focused on transdisciplinary studies involving biology and other disciplines, including glottology, economics, and technology [2, 3].

Despite the potential applications in design practice, there are no significant studies on the relationships between evolutionary biology and architecture if we exclude those on biomimicry.

Beginning with the comparisons, between the phenotypes of the human body, from classical to Renaissance architecture, then codified, for the first time in the primitive hut by Marc-Antoine Laugier [4–6], explorations on biomimicry have today reached high levels of interest, especially in the study of materials technology and bio-inspired technologies such as bio-robotics, and are also promoted by influential educators and scholars such as Neri Oxman [7].

The potential of bio-mimicry lies in the fact that in several cases, we are still far from being able to simulate what evolution by natural selection has produced in billions of years (e.g., photosynthesis). The limit of biomimicry, however, is that any architectural reference to biology stays on a phenotypical level and does not instead consider biology as a potential starting point for a paradigmatic change in the principles of design and its workflow, which, however, in times of global crises caused mainly by the way we design cities, may be necessary [8].

A more recent cross-disciplinary stream of research regards the introduction of autopoiesis in architectural computation design. The term autopoiesis, expressed for the first time by the Chilean Biologist Humberto Maturana, along with his colleague, the late neuroscientist Francisco Varela, is about the self-generating and self-maintaining systems, which influenced system thinking and cybernetics as well as computation architecture.

In this chapter, the interest in the relationship between the biology of evolution and architecture is attributable to the possible analogies between natural selection and architectural design, which could potentially corroborate the relevance of autopoiesis in architecture as an approach aiming at understanding the design process rather than its final product.

This analogy is also confirmed by the several definitions of biologists regarding the principles of evolution and adaptation [9], which, very often, are superimposable with those used by architects regarding systemic architectural design and sustainable projects.

However, despite the relevance of the relationships indicated in the premises, architecture is still considered an autonomous discipline for a large part of architectural theorists, and, generically, refers, in the most well-known history of architecture books, to a quite short timeframe, starting from the beginning of the Bronze Age, up to the present day.

In some cases, what happened before this period is ascribed rather to the field of archaeology, which only selectively is considered relevant for the growth of knowledge in the field of architectural design [10].

Biological and cultural evolution, on the other hand, in terms of only what concerns the relationships between *Homo sapiens* and the habitats, covers a period of at least 200,000 years, since we were born in Africa as a new species.

Also, in this case, the study of ecology shows that a wider time span allows to better measure the effects of global crises, such as climate change, highlighting how, therefore, the study of the biology of evolution offers opportunities for reading the futuristic scenario, more efficiently than those developed over the time of traditional urban studies. Coincidentally, according to Pringle, the extension of the research toward 200,000 years ago, allows us to discover the origin of human creativity and, therefore, its skill to design [11].

In fact, the reading of the evolutionary trends of the city, according to long times (what biologists and geologists call “deep time”), in the architectural perspective, but very short if interpreted in terms of the biology of evolution, exposes the design

to errors of interpretations on future trends, precisely on the basis of biology studies. This risk also includes other terms of a possible analogy between biology and architecture, such as the possible reading of the contemporary city in recapitulation form, meaning as such that contemporary cities are the pinnacle of a linear and progressive evolutionary process at the origin of which less advanced urban forms are found.

The limited heteronomy of research in architecture, therefore, in addition to a more limited time span research, has also led to overlooking theories already known instead in the biology, and already considered in other fields of research (archaeology), such as that of "niche construction": the recursive and constructive process by which organisms actively alter environmental states, thereby modifying the conditions that they, and other organisms, experience, and the frame of selective pressures in their environments [12–14]. This kind of selective pressures actively modified by human activities, as an evolutionary account of Anthropocene, has started to be relevant in architecture, quite recently, and mostly through a limited literature review including quite exclusively philosophical trends, such Tim Morton's Dark Ecology [15], rather than hard sciences. It could instead be assumed that the architectural interventions and the shaping of landscapes have long been true drivers of the human niche construction.

The transposition in the history of architecture of criticism of Ernst Heckel's doctrine that ontogeny recapitulates phylogeny [16] could in itself be another significant and original topic for the writing of a chapter.

Given the vastness of the possible analogies between evolutionary biology and architecture, however, the present one is dedicated to an initial study limited to the specificity of "exaptation" or functional shift, which, according to the following paragraphs, can become a key term in reading the cities in terms of resilience.

Consequently, late paleontologist Stephen Jay Gould's seminal work on exaptation will be the main reference of the study.

2 Exaptation Versus Adaptation in Architectural Design

Between the 1960s and 2000s, a relevant discussion took place in the field of biology fueled, above all, by Stephen Jay Gould, regarding the definition of the evolutionary mechanisms of adaptation.

This discussion, which explored a vast existing literature, from Williams [17] to Bock [18–21], resulted in a pivotal article by Gould and Elisabeth Vrba on exaptation [22]. With this text, the authors intended to challenge and extend the traditional taxonomy around the term of adaptation by highlighting that the same referred exclusively to that process through which the form follows a certain function, thus excluding from this process all those cases in which the forms (i.e., pre-existing structures) were subsequently co-opted by an adaptive function.

The two authors come to define aptation as the set of both of these processes (so, any structures or traits someway useful for the fitness), while exaptation concerns functional co-optation [22]. According to Pievani and Serrelli [23], two types of exaptation must be distinguished: 1) exaptation as a functional shift of a structure that already had a function (as in the case of the feathers of birds, which did not evolve for flight, but were already present and connected to thermoregulation and sexual selection functions; the same for fingers and limbs, already present before the ancestors of tetrapods lived permanently on land); 2) exaptation as the use of structures without any function (as in the case of the reuse of dismissed organs or the use of redundant portions of a system). Spandrels refer in particular to the second type.

Exaptation does not exclude adaptation but extends the taxonomy of the processes that contribute to the fitness of organisms and populations. It implies that the current function of a structure (an anatomical or behavioral trait) does not always coincide with its historical origin. The concept was first proposed by Charles Darwin in the sixth edition of *The Origin of species*, to explain the gradual evolution of organs of particular complexity.

Exaptation has so far had interesting applications in the study of the evolution of technologies, where in many cases, a new technology arises from the reuse and re-functionalization of previous tools [24], and the evolution of languages [25], while, in architecture, it has not yet been applied. The potential interest of this discussion by architects regards the fact that, as described by Gould and Vrba [9, 22], the definitions of aptation-adaptation-exaptation can be perfectly transferred in the field of design. Nevertheless, the two disciplinary areas have developed, autonomously, their own linguistic code, from which their respective taxonomies derive. A cross-disciplinary connection is useful when it has a heuristic value, that is, when using a concept from another discipline helps us to ask new fruitful questions in another discipline. It seems to us that exaptation meets this criterion very well, as argued below.

Thus, a transdisciplinary approach could potentially lead to a re-interpretation of the history of architecture through the meaning of function, associated almost exclusively with the rationalism of modern movements [26–30], taking into account the more articulated connotations deriving from biology, which might challenge the conventional architecture positions.

The introduction of exaptation in architecture could be one of these cases. In architecture, in fact all aspects concerning the use of buildings and spaces, not predicted by design, have been excluded from the paradigms of the design processes.

As happened in the field of biology, even for architecture, the absence of a definition does not mean that some forms of functional co-optation have not been detected.

According to Gould and Vrba [22], “taxonomies are not neutral or arbitrary hatracks for a set of unvarying concepts; they reflect (or even create) different theories about the structure of the world. As Michel Foucault has shown in several

elegant books (1965 and 1970, for example), when you know why people classify in a certain way, you understand how they think."

As with biology, by questioning the existing taxonomy, they were simply relegated to the realm of random facts, or read as aspects of a sociological or psychological nature, which had nothing to do with the project or design. According to different systems of thought, "What seems peripheral to us becomes central, and distinctions essential to us do not matter" [22].

Similarly, also in architecture "classifications are not passive ordering devices in a world objectively divided into obvious categories. Taxonomies are human decisions imposed upon nature—theories about the causes of nature's order. The chronicle of historical changes in classification provides our finest insight into conceptual revolutions in human thought. Objective nature does exist, but we can converse with her only through the structure of our taxonomic systems" [31].

Publications such as *Architecture without architects* [32], and *Toward a Critical Regionalism* [33] have emphasized alternative architectural paths to design mainstream. And they also proposed a re-interpretation of the link between architecture and archaeology, which corroborated the growing interest in informal and vernacular architecture.

However, the relevance of not foreseen uses in architecture has been considered as a criticism of the current design, often from a sociopolitical perspective, rather than an opportunity to extend the significance of architectural design itself.

According to the taxonomies of architecture, we define it as designing everything that implies a functional determinism: even when this determinism concerns the transformation of pre-existing structures born and developed for different uses. For example, the walls of the early Christian temple which are co-opted to become foundations of a new basilica, or when a house of a celebrity then becomes a museum.

All these transformations modalities, when performed consciously, therefore with determinism, even if the initial architectural design did not imply them, are alternatively indicated as regeneration, restoration, conservation, preservation, and functional adaptation, depending on the geographic context or the historical period, or the specific architectural discipline [34].

However, several forms of functional co-optation in architecture remain excluded from this presumed interpretation of determinism. For example, the phenomena of temporary appropriation of public space, which contributes to the resilience of the neighborhoods, concern the uses of space not planned in any conventional design [35].

According to the studies on the temporary appropriation of public space, the expansion toward unexpected uses, logically, increases the possibility of "survival" ("life cycle" in architecture) of those places, whilst the lengthening of this cycle is an essential condition to reduce the environmental impacts that are at the origin of the current environmental crisis [36].

Hence, the significance of these phenomena is due to the evident similarity with the mechanism of natural selection, which might help in understanding how to radically redefine the paradigms of design in times of climate change and ecological disruption. Natural selection never operates *ex nihilo* and does not produce new structures from zero, but by modifying the existing material, including the historical constraints it contains. So, exaptation shows us that every structure has an intrinsic transformative potential. Exaptation is an extension of the adaptative possibilities of organisms because it underlines flexibility and plasticity, as in the case of the human brain, a compendium of exaptations of neural areas and networks, or in the case of human DNA, 80% of which have no known function and act as a repertoire for possible reuses.

In these phenomena, as in many others, it is a question of giving a name to the ability of a project to allow functions and uses that were not expected, or predictable, before its realization. The projects have inherent potentials and unexpected reuses.

3 Spandrels: The Missing Link Between Architecture and Biology

The most surprising aspect of the lack of transdisciplinary studies linking the biology of evolution and architecture is Gould's use of an architectural metaphor to explain exaptation.

Gould even uses an architectural tectonic component ("spandrel") to define in biology the characteristic that is a by-product of the evolution of some other characteristic, rather than a direct product of adaptive selection:

> The great central dome of St. Mark's Cathedral in Venice presents in its mosaic design a detailed iconography expressing the mainstays of Christian faith. Three circles of 2 figures radiate out from a central image of Christ: angels, disciples, and virtues. Each circle is divided into quadrants, even though the dome itself is radially symmetrical in structure. Each quadrant meets one of the four spandrels in the arches below the dome. Spandrels-the tapering triangular spaces formed by the intersection of two rounded arches at right angles are necessary architectural byproducts of mounting a dome on rounded arches. Each spandrel contains a design admirably fitted into its tapering space. An evangelist sits in the upper part flanked by the heavenly cities. Below, a man representing one of the four biblical rivers (Tigris, Euphrates, Indus, and Nile) pours water from a pitcher in the narrowing space below his feet. The design is so elaborate, harmonious, and purposeful that we are tempted to view it as the starting point of any analysis, as the cause in some sense of the surrounding architecture. But this would invert the proper path of analysis. The system begins with an architectural constraint: the necessary four spandrels and their tapering triangular form. They provide a space in which the mosaicists worked; they set the quadripartite symmetry of the dome above. Such architectural constraints abound, and we find them easy to understand because we do not impose our biological biases upon them. Every fan-vaulted ceiling must have a series of open spaces along the midline of the vault, where the sides of the fans intersect between the pillars. Since the spaces must exist, they are often used for ingenious ornamental effect. [1]

Architectural constraints have a structural function, independent of their subsequent artistic and symbolic use. Although the use of the architectural term, spandrel, in biology has turned more than forty years old, the biological term, exaptation, vice versa, is absent in the architectural literature with the exceptions of few very recent papers by Furnari [37, 38] and Faulders [39].

The case studies explored by these authors have shown "that in design, like in biology, innovation-by-exaptation can be usefully contrasted to innovation-by-adaptation, which assumes evolution of the structure of a feature toward better function. In contrast, exaptation describes the unforeseen connection between an existing feature and a new function, different from the function for which the feature was originally designed or selected for" [38].

With exaptation, evolutionary thinking stresses the role of constraints in evolution. A constraint (physical, developmental, structural, and so on) is not just a negative limitation to change, but an opportunity to re-use something already there. Natural selection works in the economy: it is less costly to use a structure already existing, rather than to evolve it *ex nihilo*. This is also true for molecular evolution, when de novo genes evolved from already existing scraps of DNA without any previous function. Translated in architecture, therefore, exaptation will include all the overlooked forms of functionalization which are not design based. In this case, we mean, for design, the deterministic approach to design, which implies a specific use (function) attributed to architecture when in place.

Similar to what has happened in biology, a change in the taxonomy has implied a change in the perspective as well. The indeterministic forms of functionalization, in fact, seem much less collateral to the deterministic ones, once we decide to classify them.

The classification could include at least categories such as: (1) the functionalization of existing geomorphologies; (2) the re-functionalization of existing designed structures; (3) the integration of new functions to a certain architecture; (4) and the change of use.

Each category might consider a new functionalization that was not implied by the initial design or by the existing context. The re-functionalization might take place formally, through a conventional design, or informally.

The re-functionalization through a new set of deterministic designs has acquired sufficient dignity to be acknowledged and classified, mostly, during Romanticism, in which the historical and monumental significance of architecture has become a cultural value.

From the roots of the nineteenth century derive today's terms which span from the traditional "restoration", "conservation", and "preservation", to the more recent "adaptive reuse", "functional transformation", and "regeneration".

Surprisingly, considering that the impact, in terms of inhabitants and users, of informal architecture is equal to the formal one, none of the aforementioned terms includes the correspondent functionalization which takes place without a deterministic design process.

It could be said that, even without an adequate distinction with no nuances, these transformations or functionalizations could fall within a generic idea of informal architecture, according to Table 1.

4 Informal Behavior as a Form of Exaptation

Through the lens of biology studies, this part of the chapter is an initial discussion on the informal hypothesis as a form of exaptation, in opposition to the conventional perspective of informality as a result of urban environment deterioration.

According to Gould [31], taxonomies in biology can be affected by prejudices and may incur errors due to the identification of trends that, in reality, compared to a time period or to a larger population, turn out to be simple fluctuations:

> The common error lies in failing to recognize that apparent trends can be generated as by-products, or side consequences, of expansions and contractions in the amount of variation within a system, and not by anything directly moving anywhere. Average values may, in fact, stay constant within the system (as average batting percentages have done in major-league baseball, and as the bacterial mode has remained for life)—while our (mis) perception of a trend may represent only our myopic focus on rare objects at one extreme in a system's variation (as this periphery expands or contracts). And the reasons for expansion or contraction of a periphery may be very different from causes for a change in average values. Thus, if we mistake the growth or shrinkage of an edge for movement of an entire mass, we may devise a backwards explanation.

Apparently, this error can also be encountered in architecture. In fact, generically, the term "informal," associated with architecture, always has been overlooked if compared with the formal or deterministic perspective, even if, in terms of world population, the impacts of formal and informal settlements are equivalent [40].

There was a tendency to associate the informal exclusively with slums in the past. The United Nations, in fact, defines slums as settlements with inadequate access to safe water, sanitation, and other infrastructure, subject to structurally poor housing quality, overcrowding, and insecure residential status [41].

Today, a wider vision of informal architecture prevails, which also includes positive phenomena of temporary appropriation of public and semi-public space, which, thanks to an increased degree of diversity and inclusiveness, can be considered a measure of social sustainability of a certain settlement and resilience of those communities [35].

And, in fact, it is easy to re-read in some of these phenomena of positive adaptation, not foreseen in the urban design, those same characteristics of plasticity, functional opportunism, and resilience that, in biology, is subsumed in the term exaptation (type 1) and spandrel.

According to Lara-Hernandez, the informal behavioral patterns, which increase the resilience of public spaces, regard mostly commerce, leisure, sport, and worship. He has shown in his research, for example, how an obsolete telephone booth in central Mexico City can become a cooking space to prepare street food or how an

Table 1 This table, realized by the authors, is a first attempt to systematize the phenomena of exaptation in design with the aim of demonstrating the relevance of the non-deterministic approach in architectural design

Deterministic design (adaptation)	Indeterministic design (exaptation)/informal design							
Design based construction	Functionalisation of existing geomorphologies		Re-functionalisation of existing structures		Integration of function		Change of function	
Formal	Formal	Informal	Formal	Informal	Formal	Informal	Formal	Informal
I.e. Ville Savoye	I.e. Domus De Janas	Cave	Basilica (pre-existing structures)	Slums (Kenema)	San Marco Spandrels (?)	I.e. Borboletta (Figs. 1, 2 and 3)	Piazza Anfiteatro (Lucca)	Oases Documenta —Kassel

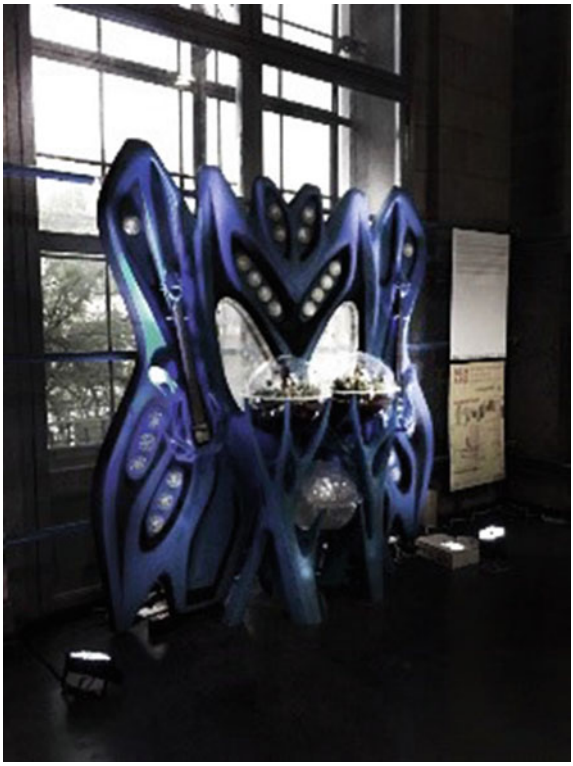

Fig. 1 Borboletta. Bienal Arquitettura. Buenos Aires, 2019 (Photo credit: Monad Studio)

occluded window becomes an altar [35]. Similarly, according to Khemri, a wall of Algiers' El Houma can become either an exhibition space or a place where it is possible to organize a community event within the context of a funeral or a wedding [42].

Despite these and many other informal resilience potentials, the reason for their underestimation remains to be asked and understood.

The prejudice toward informal architecture takes on the tones of mockery if we admit that, today, the first cause of the climate crisis lies in the way in which the formal city has been designed and developed.

In fact, ca. 40% of CO_2 emissions depend on the deterministic design in architecture [40], which, therefore, has shown its limits in overcoming a global crisis, such as the environmental one. Population growth and urbanization are the third major cause (after deforestation and invasive species) of the ongoing mass-extinction of biodiversity.

According to *Science*, over 50% of the world's population lives in urban environments and that implies unintended pressures on global ecology and humans [43]. Human intestinal microbial diversity declines with industrialization and life in urban contexts, giving a dramatic contribution to the rise of many modern diseases.

Fig. 2 Borboletta. Bienal Arquitettura. Buenos Aires, 2019. Borboletta is an architectural practice-based research which simulates the potential of the concept of spandrel in coexistence with non-human species. (Photo credit: Monad Studio)

The World Health Organization states that the impact of climate change on clean air, safe drinking water, and nutritious food supply will cause, between 2030 and 2050, "approximately 250,000 additional deaths per year, from malnutrition, malaria, diarrhea, and heat stress alone. The direct damage costs to health are estimated to be USD 2–4 billion per year by 2030," This will have major effects on informal settlements since "areas with weak health infrastructure—mostly in developing countries—will be the least able to cope without assistance to prepare and respond" [44].

Snyder et al. [45] stated that "these conditions are the perfect breeding ground for EVD (Ebola virus disease). Previous EVD outbreaks occurred in rural and geographically isolated communities. The presumed introduction of the virus to the slums of Kenema and Freetown in Sierra Leone has undoubtedly augmented its spread. Sierra Leone is urbanizing at a rate of 3% each year, and in 2005 more than 97% of its urban population lived in slums." The degradation of the ecosystems in which virus-reservoir animals live adds up, therefore, to urbanization with these characteristics: a lethal mix which, due to human activities, makes pandemic outbreaks much more likely.

Fig. 3 Borboletta. Bienal Arquitettura. Buenos Aires, 2019. Borboletta Research group: Alessandro Melis (Heliopolis 21); Eric Goldemberg & Veronica Zalcberg (Monad Studio); Francesco Lipari (OFL); Dzhumhur Gyokchepanar (University of Portsmouth); Jorge Cereghetti (UADE Labs). (Photo credit: Monad Studio)

All this does not exclusively concern the southern hemisphere and the slums, but the weakest fringes of Western society as well. Diane Yentel, president of the National Low Income Housing Coalition in the USA, reiterated the condition of the particular vulnerability of homeless people [46].

It is a paradox. If, on one hand, the organized city contributes to negative environmental pressure, on the other hand, it is the informal settlement that suffers most of its negative effects, though, sometimes, it is there that you can find creative and unexpected solutions regarding solidarity and special practices, such as the ones described in Mexican, Algerian, and many other forms of community resilience.

Nevertheless, we are usually faced with the unilateral idea that the informal city is the problem.

Once more biology, and Gould himself, may offer an interpretative hypothesis to understand why non-deterministic architecture is considered marginal.

Determinism can, in fact, be read as a manifestation of the creative, and even promethean power, which mankind attributes to its alleged privileged position on the evolutionary scale [31].

Gould's position is corroborated by Freud, according to whom the main revolutions in knowledge have led to the dethronement of human arrogance from Olympus of our cosmic certainties; from the Copernican revolution to the discovery of the unconscious, through Darwin's theory of evolution [47].

As has happened during the revolutions of heliocentrism, Darwinian evolutionism and the discovery of the unconscious in opposition to rationalism, today, it is the environmental crisis that dethrones humanity and brings it back to the margins of nature and, hopefully, within the ecosystem.

> "Much as we may love ourselves, *Homo sapiens* is not representative, or symbolic, of life as a whole. We are not surrogating for arthropods (more than 80 percent of animal species), or exemplars of anything either particular or typical. We are the possessors of one extraordinary evolutionary invention called consciousness—the factor that permits us, rather than any other species, to ruminate about such matters (or, rather, cows ruminate and we cogitate). But how can this invention be viewed as the distillation of life's primary thrust or direction when 80 percent of multicellularity (the phylum Arthropoda) enjoys such evolutionary success and displays no trend toward neurological complexity through time—and when our own neural elaboration may just as well end up destroying us as sparking a move to any other state that we could designate as 'higher'?"

This preliminary consideration by Stephen Jay Gould, in *Full House* [31], leads us to reflect on how much our society has been conceived to respond to a "superior" perception of ourselves, and, therefore, to last for a limited time. The city, conventionally planned, as the most "advanced" product of man's neuronal capacity, more than any of its other products, suffers from the poor resilience of this approach.

The COVID-19 pandemic showed all our vulnerability and the areas with the greatest (formal and informal) conurbations were clearly the most affected, because the virus exploits our sociability and density of movements, turning them against us.

Continuing in the transposition, why, therefore, do we continually portray the pitifully limited image of the human settlement, in the form of a conventional city, village, or other, which, instead, is nothing more than a brief episode in the life of vertebrates, as if it were the more advanced multicellular coexistence model? And why, then, are we fighting an environmental war to keep alive a form of settlement that inevitably seems to lead us to self-destruction?

According to Gould, we are "narrative creatures," and, as such, we seek directionality, a trend toward which to turn, even if this is not real. For these reasons, before building an idea of the city, we must build a new narrative that leads to an idea of humanity as an alternative to the current one, less privileged along a non-existent evolutionary single scale. We are a tiny branch in the great tree of biodiversity, as we dramatically discover each time during a pandemic.

It follows that the new paradigms of planning, in a crisis phase such as the present one, which presupposes a revolution in human thought, will imply a less "arrogant" vision of human settlements (cities?), as more advanced outposts of life on this planet.

The hypothesis of a new paradigm, however, does not imply renunciation of creativity, as a non-promethean position might imply. According to the paleoanthropologist Heather Pringle, in fact, the variability—intended as the proliferation of forms and artefacts without a predefined use—is at the origin of creativity. Diversity, in biology, is the fuel of any change. Art, technology, science, and all the expressions of creativity are a manifestation of associative thinking, activated when linear logic, which is the standard modality of survival, and its specialized and one-dimensional expressions in the urban realm are unable to respond to the crisis [11].

Thus, in the analogy between biology and architecture, the role of non-intentional nature, in the first case, is attributable to the designer, in the second.

Future cities, or rather the forms, today unimaginable of coexistence, will depart from the idea that architecture and nature are separate and equivalent conditions that are compared on a game table, sometimes in harmony, often in conflict.

> The chess-board is the world; the pieces are the phenomena of the universe; the rules of the game are what we call the laws of Nature. The player on the other side is hidden from us. We know that his play is always fair, and patient. But also we know, to our cost, that he never overlooks a mistake, or makes the smallest allowance for ignorance. [48]

This allegory, known as Huxley's chessboard, discussed in biology for some time, is still present, in the 70s in the famous diagram by M Scott Pegg, which accompanies the bestseller *The Road Less Travelled*. Here, we could say that, following the same idea of linear progress, we architects have built cities to this day.

In times of global environmental crisis, of anthropic origin, this apparent diversity of subject seems even more relevant, given that, in ecological terms, the hope is that man will overcome the projection of his role as an alternative to nature, as an entity emancipated from ecosystem dynamics [31].

Similarly, to the mechanisms described by evolutionary biology, the architectural spandrels imply variability of forms and their potential relationships with the environment, which allows nature to adapt to unpredictable environmental conditions. Exaptation means that a degree of structural redundancy is frequently functional, mostly in ever-changing and unstable environments. The most creative systems in nature (genomes, brains, and ecological networks) are all redundant. Conversely, functional specialization can be very risky in times of environmental change.

Therefore, the survival and balance of ecosystems also depends on architectural exaptations intended as an urban redundancy of forms and relationships which favor the adaptation to continuously changing environments.

As well as exaptation in evolutionary biology, informal architecture is an opportunity aimed at the resilience of the city bodies and could lead to redefining the paradigms of human coexistence and the urban fabric in times of global crises.

Without having the arrogance to provide a conclusive answer, the change of perspective raises a series of hypotheses, which, hopefully, will be the subject of further studies in the near future. For instance, what can we learn from informal behavioral patterns in terms of low consumption of energy and resources, and about coexistence with non-human species?

This position is, therefore, the consequence of the failure of the order-oriented approach to planning and the awareness of the end of an alleged heroic phase of exclusively deterministic colonization of the planet.

Thus, we expect that the architectural version of the sixth finger (the so-called panda's thumb) of the panda as well as the dinosaur feathers [23, 49] can be recognized in informal settlements and indeterministic architectures. Exaptation implies that each trait has not only a function, but a range of potential side-effects: exploring them, we open new evolutionary possibilities.

In conclusion, architectural exaptations can be considered a non-pre-organized way to colonize the biosphere, which in biologic terms, could also correspond to a non-anthropocentric way to do this.

5 Conclusions

In the chapter's introduction, we have underlined both the significance and the originality of the study of the exaptation as a possibility to extend the architectural design toward more sustainable approaches aimed at enforcing urban resilience.

Exaptation has been described, in the following paragraph, as a functional shift of a structure that already had a prior but different function. Examples of the aforementioned mechanism have included the feathers of birds, which did not evolve for flight, but were already present and connected to thermoregulation and sexual selection functions.

In architecture, a functional shift of a structure that already had a function may apply to forms of decorations embedded in architectural components, such as pinnacles, columns, capitals, beams, and other structures. The coexistence of narrative, symbolic, and aesthetical features together with structural functions are particularly present in gothic and classical architectures in ways in which it is sometimes difficult to distinguish what the primary intent was.

Although the coexistence of these aspects in architecture is well-known, the reading of its origin in a structural key, in the history of architecture literature, and in a narrative key, in the text of art history, respectively prevail, if compared with more syncretic and articulated perspectives.

As mentioned, the first attempt to systematize this matter was probably due to the tradition of architectural treats which, especially in the eighteenth century, indicate in the imitation of nature the origin of the forms, thus placing both structural and decorative reasons in the background.

At the center of the third chapter's paragraph, a second and complementary definition of exaptation, thus not alternative to the previous one, refers to the use of structures, called spandrels, without any function (as in the case of the reuse of dismissed organs or the use of redundant portions of a system).

This second definition, although more ambiguous in the transposition into architecture, given that the architectural example from which Gould draws inspiration for the term spandrel, could fall more easily in the first definition (spandrels have a previous function, a structural one), nevertheless offers greater hints of

current interest. It, in fact, can be reflected in non-deterministic and informal planning as an opportunity to increase the resilience of cities, since non-deterministic design does not exclude deterministic planning, in addition to which exaptation does not exclude adaptation, and, therefore, extends the taxonomy of the processes that give fitness to organisms.

The case of the Piazza Anfiteatro, in Lucca, could well-represent non-deterministic design as an extension of the adaptative possibilities of cities [50].

Just as a thumb of a panda, where the panda is the city, the middle age square grows on the abandoned and obsolete remains of the ancient Roman amphitheater (second century AD), which determined its elliptical closed shape, which perfectly fits for the use of workshops, commercial activities, and compact residential quarters, facing a central public space.

From the evolution of the Piazza Anfiteatro clearly a non-deterministic design approach emerges, one which implies that the current function of a structure does not always coincide with its historical origin, while explaining the complexity of city evolution.

As a consequence of further generative role of constraints, the elliptical space, cleaned of medieval superfetations, became the ideal location for the nineteenth-century market designed by the architect Lorenzo Nottolini, required by the economic and social needs of the rise of the bourgeois city. A constraint became an opportunity.

Although not explicitly referable to the theoretical framework of the exaptation studies, attempts to rethink design paradigms in an adaptive key, through transdisciplinarity, have not been missing, albeit marginalized by the mainstream of architectural autonomy.

Among these, a pivotal role should be attributed to radical movements (during the Sixties and Seventies in the Twentieth century) and, especially, to the Japanese Metabolists and Austrian Radicals. Although unconsciously, the Oases of Haus Rucker Co., presented for the first time at Kassel's Documenta, represent a surprising insight into the possibilities of using exaptation to design in an ecological key. Fueled by the constraints of the limit of the planet's resources, as described for the first time by the Club of Rome (1972), some of those ideas, now almost half a century old, have achieved acknowledgment only today [51], when the consequences of the environmental crisis have become indisputable.

The last paragraph, before the conclusion, focuses on informal architecture as a representation of architectural exaptation.

Despite its great potential, if we exclude the experiences of practices like Urban Think Tank, Teddy Cruz, Giancarlo Mazzanti, and Alejandro Aravena / Elemental, the study of the informal has often been underestimated by architectural criticism.

In these architectures, and especially in Aravena's Quinta Monroy plan (2004), the flexibility and plasticity potential of non-deterministic design has been emphasized by their authors, although a social and solidarity reading of the informal phenomenon has prevailed over the biological analogy, according to which the city could become a compendium of networks.

In conclusion, the use of exaptation's definition, in architecture, raises a few significant questions regarding the evolution of the cities, which corroborate the heuristic value of the cross-disciplinary studies on biology and architecture, which seems even more relevant in times of climate change and global crises.

Exaptation means that a degree of structural redundancy is frequently functional, mostly in ever-changing and unstable environments. The most creative systems in nature (genomes, brains, and ecological networks) are all redundant. Conversely, functional specialization can be very risky in times of environmental change.

Exaptation implies that each trait has not only a function, but a range of potential side-effects: exploring them, we open up new evolutionary possibilities.

Limiting the design to responses to conventional mottos such as "Form follows function" or "Less is more," can be a risk as well.

Thus, in order for architecture to become an opportunity from a problem, it should respond to design paradigms in which redundancy and variable diversity of structures reflect (and enrich) functionalism.

According to this interpretation, the failure of a planned function, due to physical, developmental, and structural constraints, does not necessarily have to be interpreted negatively for the future of the city. It can also be an opportunity to re-use a structure designed for an obsolete function, to respond to unexpected constraints. Like natural selection, the city should work in terms of economy: it is less costly to use a structure already existing, rather than to build it from scratch.

Planners, therefore, will increasingly have to ask themselves which design tools can guarantee greater redundancy and flexibility in the design of cities, rather than aiming at a set of functions for future urban visions with specialized functions, such as those of the traditional "zoning," which, besides being proven wrong, did not allow conversion of the structures into new more virtuous uses.

If diversity, as in biology, is the fuel of any change, a minimalist perspective, based on homogeneity and standardization, unlike what was assumed by the orthodox rationalism of the Modern Movement positions, could, therefore, appear less functional today than we have ever imagined.

Core Messages

- The most creative systems in nature are redundant.
- Exaptation is a functional shift of a structure that already had a prior but different function.
- Structural redundancy is frequently functional, mostly in ever-changing and unstable environments.
- Both in biology and architecture, the redundancy of structures contributes to the resilience of a system in times of environmental change.
- Architecture should respond to design paradigms in which redundancy and variable diversity of structures reflect functionalism.

- The failure of a planned function of a city can be an opportunity to re-use a structure designed for an obsolete function, to respond to unexpected constraints.

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