BIOCLIMATISM IN ARCHITECTURE: AN EVOLUTIONARY PERSPECTIVE

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ABSTRACT

The well-known Darwinian evolutionary theory (1859) introduced natural selection as the most important mechanism of evolutionary processes at every level from biological systems, including species, individual organisms… to molecules, such as DNA or proteins. In architecture we observe similar evolution processes, which lead to the development of various architectural movements and concepts from common primitive living structures. Fundamentals of vernacular architecture have been used in bioclimatic architecture, which has gradually become the inspiration of various movements in contemporary architecture. The study points out that the development of bioclimatism in architecture has followed the pattern of a natural evolutionary process in which 'natural selection' is likely motivated by several factors, including resources and environment problems, and driven by different mechanisms including novel building design concepts and methods, new standards and codes, discoveries in building science and construction costs. This study is an effort aimed to clarify the evolution process of the bioclimatic approach in architecture over time and its influences on contemporary movements in architecture. The paper shows also that the evolutionary theory generated new scientific tools able to improve building design thanks to simulation-based optimization methods applied to building performances. Finally, this study investigates new motivations in the era of climate change whose effects are expected to introduce more challenges as well as more trends towards a sustainable built environment through the new concept of Eco-adaptive architecture.

Keywords: bioclimatic architecture, climate change, eco-adaptive architecture, evolution, evolutionary optimization, vernacular architecture.

1 INTRODUCTION

The well-known Darwinian evolutionary theory (1859) introduced natural selection as the most important mechanism of evolutionary processes, highlighting the importance of diversity at every level – from biological systems, including species, individual organisms… to molecules such as DNA or proteins. This theory states that all organisms now living on Earth can be traced back to a common ancestor (possibly a single-celled organism) living some 3.5 to 3.8 billion years ago [1]. Figure 1 gives a visual representation of the evolutionary process of life on Earth as a spiral [2]. Interestingly, it's likely that architecture has experienced a similar evolution process, which has led to the development of various architectural movements and concepts from a common primitive living structure. Although the Darwinian evolutionary theory (now the Modern evolutionary synthesis) is mainly used to explain the evolution and development of living organisms on Earth, we assume that development of architecture, especially the bioclimatic concept in architecture, can be explained by using the governing ideas of the evolutionary theory.

Bioclimatism is a design concept in architecture that takes into account the relationship between a building and its systems, its natural environment mainly through its (micro-)

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Figure 1: Visual representation of the history of life on Earth as a spiral [2].

climate and its occupants (especially in connection with human thermal comfort conditions). Following bioclimatism in architecture, building designs help achieve optimal comfort using preferably architectural elements and avoiding complete dependence on mechanical systems. The origin of the bioclimatic approach in architecture can be traced back to the design principles applied in most vernacular and traditional buildings all around the world. Vernacular/traditional architecture evolved over time, reflecting environmental, cultural, technological, and historical context of a specific location on which it was built [3]. Hence, knowledge on bioclimatism was accumulated from vernacular architecture during an 'evolutional' process. Bioclimatism in architecture is now considered a critical concept for achieving sustainability of modern buildings.

Studies using the evolutionary perspective to explain the development of architecture have been found elsewhere [4]. However literature on this subject is not very abundant, this article is therefore aimed to introduce and to discuss the idea of evolution in architecture through the following issues:

- To find a way to explain the development of architectural concepts by applying the idea of the evolutionary theory.
- To introduce a novel perspective about the development of architecture in the inter-relationship between human and climates: natural evolutionary perspective.
- To clarify present motivations and challenges of current architecture facing climate change so as to give predictions of the trend of bioclimatic architectural evolution.

Like most other studies related to evolution and biomimetics in architecture [4, 5], this study employed a **theoretical research method**, which is mainly relied on analysis of history of architecture, observation and comparison of processes and events. Hence, the result of this study will be interpreted qualitatively. It is also necessary to note that the focus of this study is the methodological aspect of designing architecture rather than the formal aspect of defining architectural styles (which was the focus of an earlier study [4]).

2 SIMILARITY BETWEEN THE DEVELOPMENT OF BIOCLIMATIC ARCHITECTURE AND A NATURAL EVOLUTIONARY PROCESS

From very simple architectural forms in the early days of the human society, architecture has undergone an 'evolution' for a long period of time, leading to a lot of architectural movements and methods as well as various architectural styles. We have found similarities between the process of the natural evolution and the process of the evolution of architecture, as presented in Table 1. These similarities found in Table 1 tend to indicate that the architectural

Table 1: Similarity between natural evolution and architectural evolution.

	Natural evolution (Modern evolutionary synthesis)	Architectural evolution	Examples of proofs or evidences
1st ancestor	A single-celled organism, living approximately 3.8 billion years ago	Primitive artificial living structures	Caves or huts as human shelters
Motivations	Limited sources of foods; Changes of the climate and environment; Competition to survive and to enhance reproduction	Exhausted natural resources; climate change, environmental pollution, ecological imbalance; Societal forces including technical, social and economic aspects, new style and ideology [4]	Energy crisis, global warming and higher requirements for qualitative living environments motivate currently a growing trend towards eco-friendly architecture.
Mechanisms	**Natural selection based on genetic mutations:** The process by which genetic mutations that enhance reproduction become more common in successive generations of a population.	'Wise choices' of builders is the first stage of evolution (similar to genetic mutation) resulting in **best practice examples** and higher expected building performances. **Novel building design concepts and methods** and especially **new standards and codes** are the main drivers of 'selection' in architecture.	Passive buildings and zero-energy buildings generated concrete examples of energy efficient buildings in Europe. Moreover, the Directive on Energy Performance of Buildings, EPB (Directive 2002/91/EC) induced recently, in the EU, a significant reduction of energy consumption in all new buildings [6].

(*Continued*)

	Natural evolution (Modern evolutionary synthesis)	Architectural evolution	Examples of proofs or evidences
Mechanisms	**Biased mutation:** The phenomenon by which two genotypes in the same position but with a different mutation probability have different chance of evolution.	**Construction costs** make a significant bias in the selection of various technical solutions for buildings responding equally to standards [7].	The **extremely rapid development** of double-flow ventilation coupled with a heat exchanger on the extracted air for very energy-efficient buildings in temperate climates comes from its high economic profitability.
	Genetic drift: The change in allele frequency from one generation to the next due to allele sampling error.	**Discoveries in building science** which make breakthrough advances in building design methods or building technologies.	The **invention of new technologies** (reinforced concrete, elevators…) or new methods (simulation-based design of buildings [8], adaptive comfort models [9], CFD applied to buildings [10, 11] and cities [12]) are changing the architecture.
	Genetic hitchhiking: If one allele in a particular haplotype is strongly beneficial, then other alleles in this haplotype become more common in the population.	**An influential architectural movement** makes other supplemental movements to become more popular.	**Significant values** of green architecture make eco-architecture, energy efficient architecture, and passive architecture… to become more common.
	Gene flow: The exchange of genes between populations and between species.	**Knowledge exchange** generates opportunities for architectural changes.	**Symbiosis of some existing architectural styles** results sometimes in new styles or new architectural forms.
Outcome	**Adaptation:** The process that makes organisms better suited to their living environment.	**Adaptation** in architecture is the process that makes buildings better suited to their climate and their natural and cultural environment.	**Colonial architecture** in South East Asia is an evidence of adaptation in architecture: Western architecture has changed to adapt to hot humid climates of these colonial countries.

(*Continued*)

Table 1: (*Continued*)

	Natural evolution (Modern evolutionary synthesis)	Architectural evolution	Examples of proofs or evidences
Outcome	**Co-evolution**: Evolution of one species causes adaptations in a second species, such as a predator and its prey.	**Co-evolution** between architecture and nature, urban planning or building technologies.	Different **town planning rules** imposed in terms of land use of urban areas induced different forms of urbanization in Europe [13].
	Co-operation: Co-evolved interactions between species involve mutual benefits, e.g. plants and mycorrhizal fungi that grow on their roots, aiding them in absorbing soil nutrients.	**The co-operation** of architecture with nature, urban planning or technology.	**Green roofs and facades** improve building performances while promoting biodiversity. The design of an eco-district facilitates the design of high environmental performance of buildings that enhance also the environmental performance of the neighborhood [14].
	Speciation: The process where a species diverges into two or more descendant species.	**Various architectural movements** are originated from an original one.	Passive buildings, nearly zero-energy buildings and green buildings have all resulted from the **bioclimatic approach.**
	Extinction: The disappearance of anentire species. Endangered species indicate the likelihood that it will become extinct.	**The disappearance** of an architectural movement, type of building or design method due to natural or cultural changes.	**The architectural heritage of everyday buildings** (vernacular housing, industrial buildings, etc.) is often demolished at large scales except when protected by heritage protection regulations.

trends associated with formalism often faded into insignificance quickly. Meanwhile those associated with the function of the building, the climate, the natural and societal conditions often exhibit stronger vitality and last longer. This principle is entirely consistent with the rules of the natural evolution: the form of an organ is often defined by its function and its environment.

3 EVOLUTIONARY PROCESS OF THE BIOCLIMATIC APPROACH IN ARCHITECTURE

Although the term 'bioclimatic architecture' first appeared in the mid-20th century, we believe that design methods based on bioclimatic principles were established much earlier and were applied to vernacular and traditional architecture of many regions over the world

[15]. These methods were developed by 'trial and error' and maintained by word of mouth. Until the year 1930s, these methods were summarized into scientific publications [16–18] and further developed to improve their efficiency. Table 2 explains the architectural evolution towards and from bioclimatism in architecture.

In the era of computer-aided design, the bioclimatic design method has moved into a new period, with advanced design techniques and accurate control of building performances through simulation-based design of buildings and smart technologies. Key steps of the development stages of bioclimatic design from empirical methods to analytical methods and computational modeling methods are introduced in Table 3.

From vernacular and traditional architecture, thanks to the leapfrog development of the bioclimatic design method, designers can now create high-performance buildings, zero-energy buildings or green buildings with respect to different environmental criteria. Especially, with the support of optimization methods in building performance simulation, many rigorous design goals become easier to realize than ever. Simulation-based optimization methods allow designers to save 10% to 30% of the building energy consumption through passive design solutions (depending on many factors, including climate types) [20].

4 EVOLUTIONARY THEORY AS A METHOD IN BUILDING DESIGN

Today, people apply the principles of natural evolution into the development of scientific tools to improve the performance of products, including building design and construction. During the year 1960s, genetic optimization models have become an optimization method which has been widely acknowledged later [22]. Genetic algorithms became particularly common after the study of John Henry Holland in 1975 [23]. Evolutionary algorithms are now used to solve multidimensional problems as well as to optimize system operations [24, 25] and they are proved to be more efficient than other optimization algorithms. Figure 2 illustrates the principle of genetic optimization and its correspondence with human evolution.

Optimization method using genetic algorithms are being studied and applied to the design of green buildings or energy efficient buildings, providing remarkable improvement of their performance [27–29]. The genetic algorithms have several advantages, including easy programming, powerful search capability compared with other algorithms. The search ability of the genetic algorithms is capable to solve problems with discontinuous objective functions and/or problems with multiple minima; thus they are used more commonly than other optimization techniques [30]. The only obstacle of using the evolutionary algorithms is to integrate them into design programs or software for professional use and to simplify their usage to an acceptable level. Until then, we believe that architectural design based on optimization will create a major revolution in architecture.

5 REDEFINING THE BIOCLIMATIC APPROACH: CHALLENGES EMERGING FROM CLIMATE CHANGE

Relying on the evolutionary theory, climate change is seen has a driving force of future architectural evolutions. This section tries to analyze and predict future outcome of the evolutionary process of the bioclimatic approach in architecture.

The bioclimatic approach, as defined by Olgyay [16], takes into account three disciplines complementary to the architectural design. '*The first step is to define the measure and aim of requirements for human comfort. For this, the answer lies in the field of biology. The next is to review the existing climatic conditions, and this depends on the science of climatology. Finally, for the attainment of a rational architectural solution, the engineering sciences must*

Table 2: The architectural evolution towards and from bioclimatism.

Architectural trend or period	Adaptation features of architecture	Time
Prehistoric architecture	Simplest forms of climatic adaptation in architecture, e.g. using locally available material to build shelters or living in caves to avoid predators/bad weather.	Prehistoric age
Vernacular architecture	Architecture have some adaptations to local natural and social conditions [15].	Evolved along the history
Bio-inspired architecture and technologies	Culminating in an organic style inspired by nature, adapting to local environments and conditions.	From the late 19th and early 20th centuries up to present time, beginning from the works of Antoni Gaudí
Organic architecture	A philosophy of architecture which promotes harmony between human habitation and the natural world, reducing the need of using energy and resources.	The term organic architecture was coined by Frank Lloyd Wright (1867–1959) – one of the four most influential architects of the 20th century [4].
Bioclimatic architecture	**Passive design solutions adapt to climatic conditions to create indoor comfort, satisfying better demands of building occupants.**	**Since mid 20th century**
Passive and low energy architecture	Employing advanced design techniques to build more energy efficient and more comfortable buildings. This trend has partly evolved towards creating zero-energy buildings.	Since 1980s
Green buildings	Buildings respectful for their natural environment and strictly controlling their environmental impacts through the building's entire lifecycle, while maintaining good indoor comfort for occupants.	Since the end of 20th century
Sustainable architecture	Meeting the needs of present generations without compromising the ability of future generations to meet their needs while balancing environmental, social and economic issues in the building design.	The future

Table 3: Three major bioclimatic design methods in an evolutionary order.

	Empirical method	Analytical method	Computational modeling method	
			Simulation	Optimization
Estimated effective period	Until the year 1950s	1930 – present	1990 – present	2000 – present
Design objectives	Human comfort and health	Human comfort and health	Human comfort and health; energy; environmental impact	Human comfort and health, energy saving, environmental impact
Comfort assessment method	Rules of thumb	Building bioclimatic chart [16–19]	Standards and codes (thermal comfort models, natural lighting codes, IAQ codes, green building rating tools)	Standards and codes (thermal comfort models, natural lighting codes, IAQ codes, green building rating tools)
Climate analysis method	Observation	Discrete statistical weather data	TMY, TRY, DRY… weather files	TMY, TRY, DRY… weather files
Performance verification method	Trial and error	Monitoring and comparison	Numerical simulation	Numerical simulation + Optimization [20], uncertainty and sensitivity analysis [21]
Diagnostic method	Trial and error	Trial and error + monitoring and analysis	Numerical simulation	Numerical Optimization [20], uncertainty and sensitivity analysis [21]
Applications and outcomes	Vernacular housing, traditional building	Comfortable building	Energy-efficient building Comfortable building Ventilation systems	Zero energy building, Green building, sustainable building

be drawn upon'. Emphasizing great concern about the building energy issue, Hyde [31] has redefined 'bioclimatic' by introduce the term 'synergy' in which energy efficiency has been seen to center on the design of more efficient mechanical systems, in addition to the passive elements of the building and the occupants behavior, to engage in synergies that lead to an integrated solution. For example, combining new forms of technology at a larger scale will provide a mean of achieving zero energy targets in buildings. The bioclimatic approach is represented in Fig. 3 (adapted from [16]).

The design of bioclimatic buildings, which are well integrated in their natural environment, has evolved in recent decades towards green buildings design that generates a real

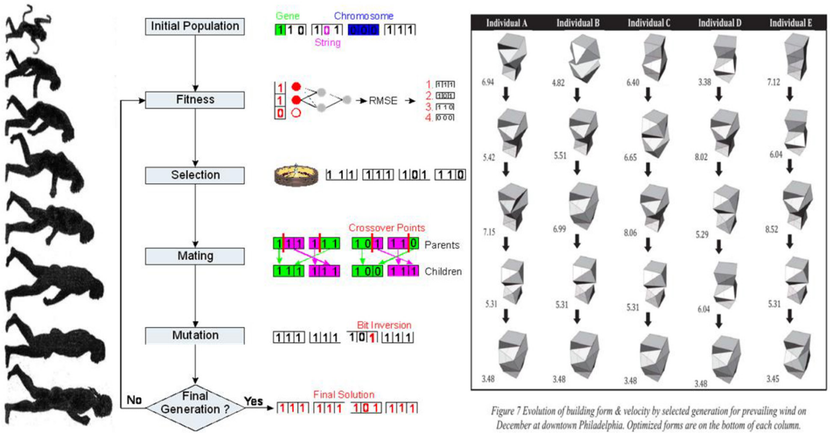

Figure 2: Building optimization by the genetic algorithm and comparing with the evolution of species [26].

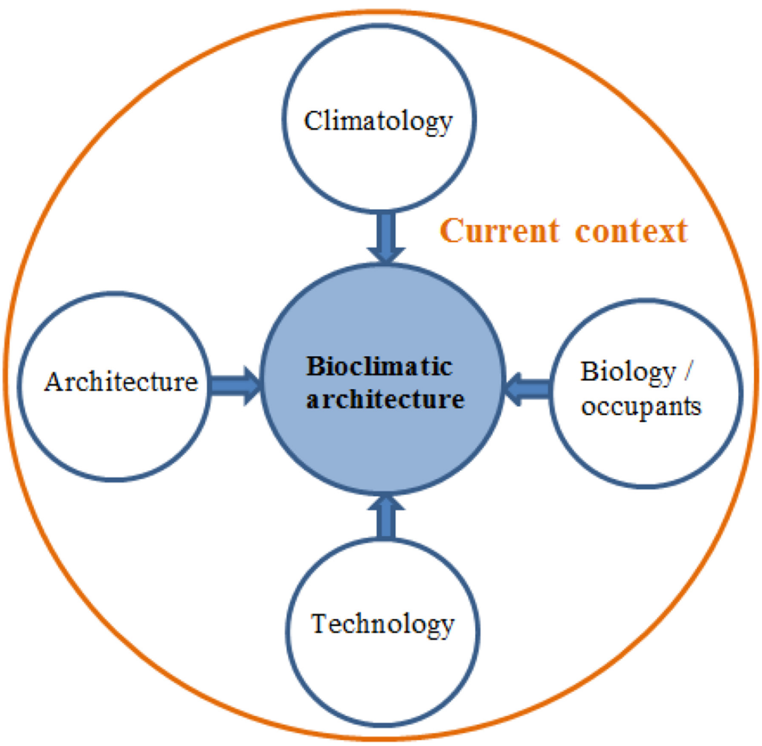

Figure 3: The bioclimatic architecture (adapted from [16]).

co-operation between architecture and its environment. Ecological architecture and green buildings refer to environmentally responsible buildings that are eco-friendly, resources-efficient and low producer of environmental impacts throughout the building's life-cycle. Figure 4 shows a representation of the ecological architecture that takes into account the

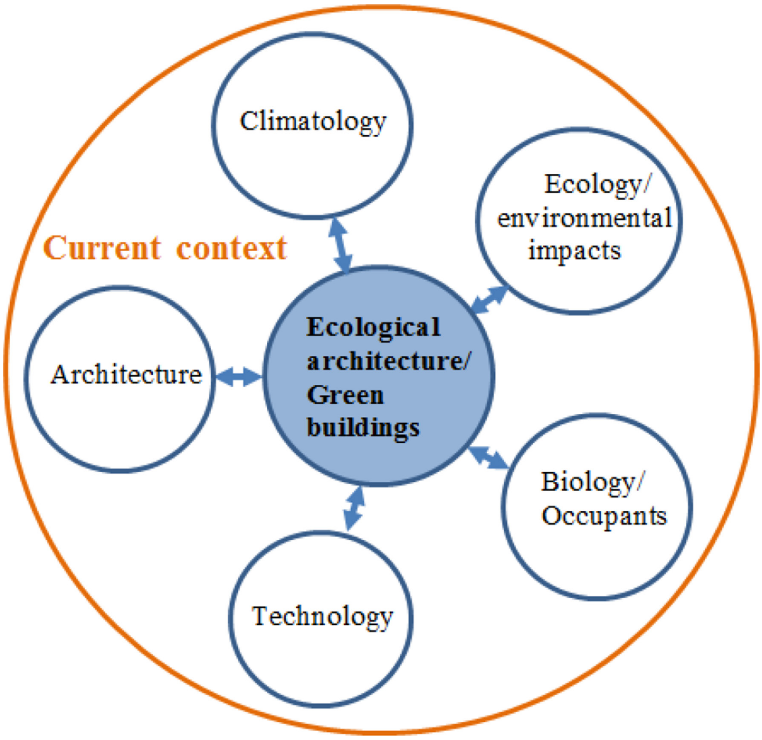

Figure 4: The ecological architecture or green architecture.

interrelationship between a green building and its microclimate, its natural environment, its occupants, its technological systems and its architectural design.

We are living in a period during which the climate change evolves more strongly than ever and generates adverse effects to humans. Buildings will face harsher and more changeable climatic conditions as well as environmental disasters (flooding, earthquake, etc.) that will occur more frequently. Architecture must now adapt to climate change. Therefore, the continued development of the bioclimatic approach in architecture undergoes a great change in which climate change will be one main driving force of this future architectural evolution.

The increase of greenhouse gas emission into the atmosphere is one main underlying cause of climate change and the building sector is one of the principal factors of these emissions. Thus, the magnitude of climate change will partially depend on the environmental performance of buildings and urban planning. Today, it is essential to take into account the changing nature of the environment. Architecture has to be more eco-friendly while it has also to adapt to changeable climatic conditions and to be resilient to environmental disasters.

For these reasons, in this paper we propose a new approach in architecture – the '**Eco-adaptive approach' –** as a new evolutionary step of the conventional "Bioclimatic approach". This new concept emphasizes the importance of the environmental dimension as a co-evolutionary design element: respectful integration into the natural environment and co-operation between architecture and nature are now becoming a compulsory requirement in building design but it is also necessary to design buildings that will adapt to changes in

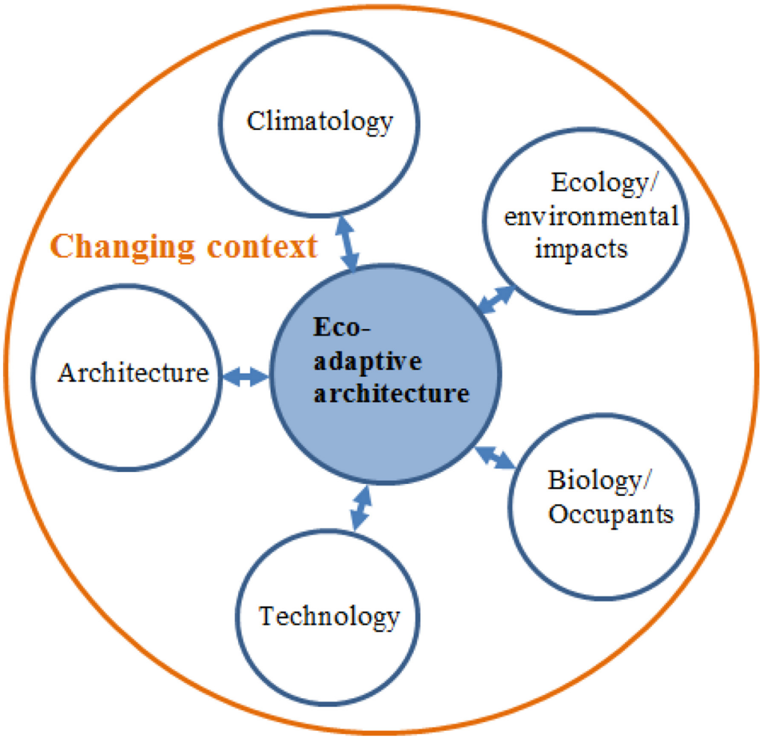

Figure 5: The eco-adaptive architecture.

their natural environment and that are resilient against natural disasters. Eco-adaptive architecture will be 'greener' but also more adaptable and resilient.

Figure 5 shows a representation of the eco-adaptive architecture that takes into account the co-evolution between an eco-adaptive building and its changing context, including its climate, its natural environment, its occupants, its technological systems and its architectural design. For example, technological operation of building systems should be able to adapt to climate changes: smart technologies may be used for data gathering in the building with an automatic adjustment of its operation but the building must also continue to function properly if its technological systems are put out of use due to a disaster.

Thanks to its co-operation and co-evolution with its environment, the eco-adaptive architecture will meet the environmental needs of present generations without compromising the ability of future generations to meet their environmental needs. Eco-adaptive buildings will thus help moving towards a sustainable architecture, which is likely to be the next step of the architectural evolution. Sustainable architecture requires achieving a further step balancing the environmental, social and economic issues of buildings design for the actual and future generations.

6 SUMMARY AND CONCLUSIONS

This paper proposes a new perspective of the development of bioclimatic architecture: the perspective of his natural evolution. We can apply evolutionary theory to explain the formation and extinction of some architectural movements. Through a comparative analysis and synthesis, this study has highlighted the perspective of the evolution of bioclimatic architecture over time. The study also showed that the theory of natural evolution has a certain role in the development of innovative bioclimatic design methods which allow designers to create greener buildings. In recent years, rapid climate change has become a new driving force for the architectural evolution. Finally, this paper proposes the '**Eco-adaptive approach'** as the next evolutionary step towards a more sustainable architecture thanks to its resilience and its ability to adapt to changes in its environment.

The research approach as well as the comparative analysis in this study could be the catalyst for further studies, and also generate helpful materials for teaching and learning architecture at school.

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