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Natural and Architectural Convergence: A Model of Nature-Based Strategies in the Architectural Design Domain

Chra Hunar Ahmed [1,*] and Hoshyar Qadir Rasul [2]

[1] Department of Architecture, College of Engineering, Salahaddin University, Erbil 44002, Iraq
[2] Department of City Planning Engineering, College of Technical Engineering, Sulaimani Polytechnic University (SPU), Sulaymaniyah 46001, Iraq; hoshyar.rasul@spu.edu.iq
* Correspondence: chra.ahmed@su.edu.krd; Tel.: +964-0750-7066002

Abstract: Nature is the major source and basis for architectural design. It is beyond human ability to create the same unlimited changes and dimensions. One of the key actors in minimizing negative impacts on nature and the environment is the architect. Due to the different uses of nature in architectural design and the interdisciplinarity between the approaches and aspects of nature, this study aimed to explore the contributions of nature-based strategies to the architectural design domain and identify the comprehensive relationship between nature and architecture. Through using logical argument, the nature-based strategies of architectural design were classified according to four categories of architectural design principles in a predicted model. For testing and validating the model, one strategy, which included nine nature-based approaches of architectural design with 23 aspects, was evaluated, and the scopes of the approaches were identified. VOSviewer was used for data analysis, and the survey questionnaire method was used for the focus group of architects to evaluate Erbil City's architectural design. In this survey, 328 responses were received, which were ranked using the four-point Likert scale (most of the time, some of the time, seldom, and never), and the *t*-test from SPSS software was used to compare the approaches of the selected nature-based strategy. The passive design was the only approach with a positive value from the *t*-test (3.805) with a *p*-value of 0.000. Among these 23 evaluated aspects, natural ventilation received the highest mean value (1.91).

Keywords: nature; architectural design; nature-based strategies; nature_architecture model

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1. Introduction

The environment provides common prosperity that belongs to everyone, and it is intended for everyone; thus, everyone has a role to play in preventing local and global climate changes [1]. Environmental issues began to have an increased prominence on the global agenda in the early 1990s, as the public's knowledge of the effects of unchecked climate change was growing; it is now obvious that creating a connection between architecture and the environment is crucial [2]. The connection between the natural environment and architecture has always been essential, and many architects have recognized the necessity of creating a link with the surrounding environment throughout history and have taken steps to achieve this connection through their works [2]. From the oldest cave homes and crude huts built completely of natural materials to the towering skyscrapers of our century, made up of manufactured grids of glass, steel, and concrete, there have always been diverse relationships between architecture and nature [3].

The symbol is the analogy between natural and architectural homology, in which architecture is a symbolic imitation of nature, and there is a great endeavor to recognize the language of nature via harmonic and symmetric arrangements in architecture. The symbolic concept refers to obtaining goodness, fairness, beauty (aesthetic), and ethics [4]. Ecological thinking is the acknowledgment of the dynamic unity between nature and architecture,

the respect for what is already there, and the associated openness to other people [5]. Regarding nature, the form and functional arrangement are significant elements to help reduce the building's negative effects on the environment and are the most practical and cost-effective connection for improving building efficiency, performance, and feasibility [6]. Many solutions, questions, and complaints have been proposed regarding the connections and relationships between nature and architecture; the number of historical examples illustrates the relationship between nature and architecture in the past. Today's architecture has advanced beyond the spiritual, symbolic, and aesthetic uses of natural forms to an extremely sophisticated approach to bioinspired performance-based building designs. The incorporation of biological systems, biological processes, and natural science are all innovative applications of the strategies of bio-inspiration approaches of architectural design [7]. Today's most developed technologies at micro- and nano-scales provide us with a better understanding of new sources of knowledge, inspirations from nature, and natural functions in architectural design, such as the strategies used by animals and plants to adapt to their surrounding environment without having any negative impact on ecosystem [8,9].

Nature can inspire us: First is visual inspiration, which includes forms, shapes, and patterns in nature. Second, conceptual inspiration involves obtaining a grasp of natural processes. Third, computational inspiration involves the environment's computing processes and our capacity to mimic them [10]. Architectural shapes inspired by nature are one of the three strategies of interaction between nature and architecture; the others include architectural forms that are solidly associated with the context of landscapes, and architectural shapes that are characterized by natural materials. There are always admirable and perfect regulations between man, nature, and architecture [11]. The architecture components that inspired from nature are; the type of materials including programmable, bio-reactor, and mechanical materials; the elements of building behavior, including structure, materials, interior elements, building systems, and building envelopes. Additionally, building behavior targets, including efficient materials, efficient structures, indoor air quality, energy efficiency, water efficiency, air quality, visual comfort, and thermal comfort [12], with acoustic comfort as one of the proper design considerations for efficient structure design [13,14]. The use of nature-inspired materials in bio-engineering and architectural design was inspired by these biological materials that were difficult to harvest in bulk, and toxic in their direct applications, such as hair, bone, and nacre. The nature-inspired materials have the characteristics of multifunctional abilities with reliability and high mechanical resilience in different scales of implementations and their functions are similar to the functions of natural materials [15]. Brick technology can successfully incorporate fractal geometries and waste materials to produce environmentally friendly solutions with improved structural and acoustic characteristics. Ground-recycled tire rubber and fractal-shaped cavities can be combined to create hollow concrete bricks that are lightweight, acoustically efficient, and environmentally friendly. This has led to the development of increased mechanical strength, structural effectiveness, and sound absorption of buildings [16]. Moreover, inspiration from natural mechanisms will help in solving problems in different fields; for example, the overflow behavior in the mechanisms of surface wetting properties in microstructure control led to methods to control macroscale liquid dynamics [17]. Whereas the designer and architects aspire to learn from nature and to drive an optimum solution from it, nature has mastered how to most efficiently obtain a multifunctional structure. The majority of the current works are an imitation of a form in nature, in which the simulations and digital tools are used in the application of complex structures [18]. For architectural design and building construction nature has been the main source of inspiration in different ways and for different degrees of complexity. Le Corbusier, in his Modulor, incorporated the rules of the Fibonacci series to control building dimensions at a very simple level based on the distribution of plant petals [19]. According to Pohl, the inspiration from nature must be well abstracted inside of the context of an interdisciplinary imitation, rather than the direct interpretations. Thus, understanding the biological principles, searching for them, and transferring them to solving design problems are not simple tasks for architects [20].

The relationship between nature and architecture in the previous studies was more focused on a single phrase or simple categorizations; no research studies have structured the comprehensive relationship between nature and architecture. Therefore, the main aim of this study was to predict a comprehensive model of the strategies of nature inspirations according to the architectural design principles.

1.1. The Study Background

1.1.1. Architectural Design Principle

Architecture, distinct from construction-related fields, is the art and practice of designing and building. Architecture is a discipline that satisfies both functional and expressive needs, and it serves both humanistic and aesthetic goals [21]. According to the Roman architect and engineer Marcus Vitruvius Pollio, what represents architecture are firmatis (strength), which must be strong and in good condition; utilitas (utility), which should be beneficial and practical for the users; and venustatis (beauty), which should be pleasant and positive for everyone [22]. From Vitruvius' representation of the principles of architectural design, different models were proposed; function, form, and meaning are the three dominant principles of architectural design, and the secondary principles are context, modality, and will, which are an application of views of Vitruvius: function (utilitas), construction (firmitas), and aesthetics (venustas). On the one hand, construction falls under the secondary principle of modality, which is derived from the dominant principles of form; on the other hand, aesthetics does not belong to the dominant principle of meaning but rather to the secondary principle of will [23]. In the same manner, the model of function–form–meaning is a major part of architectural design: function is analogous to an idea or representation; form is analogous to an object or medium; and meaning is analogous to an interpretation and communication. One of the advantages of this model is that it can be used as a guide to explain the mutual and harmonious relationship among principles of architectural design, shown in Figure 1 [24].

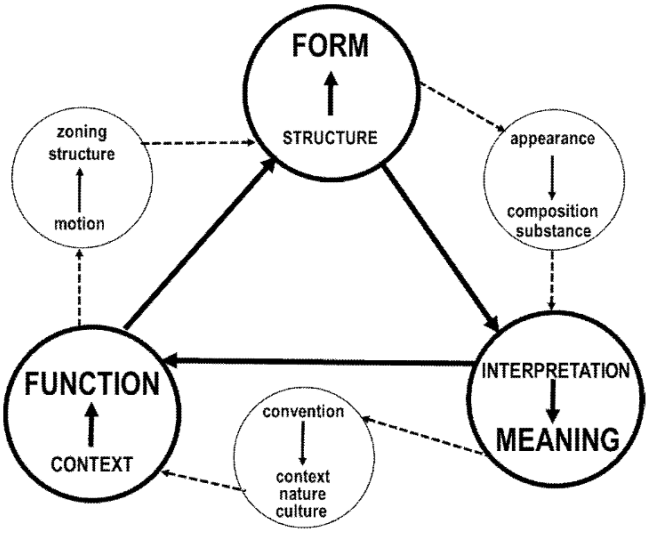

Figure 1. The three main aspects of architectural design (function–form–meaning). Reproduced from Ref. [24].

The three domain principles involved in the idea and philosophy of architectural design are space, structure, and enclosure, in which space involves certain activities and functions, the structure consists of any technological applications, and enclosure is the real form of the building. Movement (motion) in space-time is the means through which the combination of the mentioned three principles is achieved [25]. Any emphasis on architectural design should be directed toward these three crucial principles of function, construction, and form; the form from this model depends on geometric order [26]. So,

the summarized main principles of architectural design domain were form, function, and concept which illustrated in Figure 2.

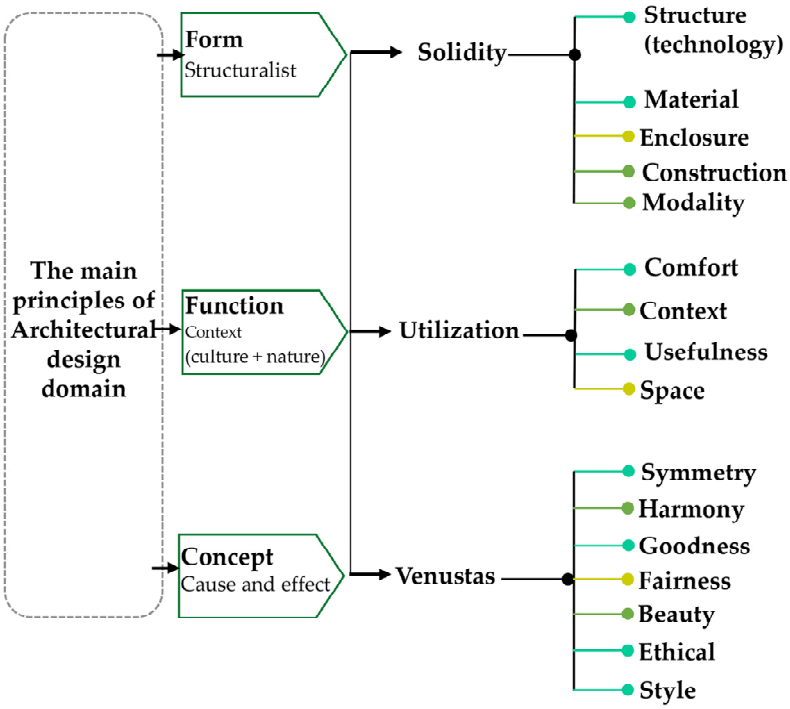

Figure 2. The summarized principles of architectural design based on the literature.

1.1.2. Nature-Based Strategies of Architectural Design

A strategy is a plan created to accomplish a certain goal [27]. Design strategy is a systematic regulation of approaches to improve solutions and obtain particular goals [28]. Aspect can be viewed as a specific component or element of an environment, concept, issue, etc. [29]. The various aspects of nature have had an impact on architecture, with biology having been increasingly included in the activities of the design process [30]. The environmental design strategy aspects include consideration of how to encourage positive engagement with buildings and environments [31]. Nature-based strategies are interdisciplinary and complex, so architects should understand the process of framing natural inspirations in design, in addition to improving our knowledge, behaviors, and sustainable thinking by taking advantage of rich sources of nature [32].

Intelligence and the ability to save energy, be self-sustaining, and efficiently use resources are the most well-known strategies of natural systems [33,34]. The building orientation, shading devices, cost efficiency, and natural ventilation of buildings are the common aspects of a sustainable design approach. They related to computational inspirations; in more detail, using a passive solar design approach, the building will receive solar radiation in the winter while solar radiation is blocked during the summer by using shading devices [35]. The visual, conceptual, and computational inspirations are the three main contributions of nature to architectural design. These approaches of architectural design, which relate to nature, can be classified according to these three inspirations. The common approaches of nature-based inspirations in architectural design from the literature are compiled below:

1. The approaches of computational inspirations:

Bioclimatic architecture

When discussing the mechanisms of the interaction between the environment and architecture, we consider the interaction between a structure's systems and its surroundings, particularly through its "microclimate", e.g., ensuring thermal comfort levels for its

occupants/users. Building designs that adhere to bioclimatic architecture enable higher levels of comfort by using appropriate architectural components and avoiding a total reliance on mechanical systems. The bioclimatic approach to architecture originated from the design principles seen in the large majority of regional and traditional structures around the world [36]. The first use of bioclimatic architecture in the form of a blueprint was used by Olgyay in 1950 to 1953 as nature-inspired strategies in architectural design [37].

Green architecture

A construction approach known as "green architecture" or "green design", which has existed since the 1950s [38], seeks to reduce the negative effects on both the environment and human health. By using eco-friendly building materials and construction techniques, the "green" architect or designer seeks to protect the water, air, and soil [39,40].

Eco-design

Eco-design is a philosophy as well as a strategy of design. It entails incorporating regulations throughout a service's or a product's lifecycle. Predicting and reducing harmful environmental effects (from the manufacturing, use, and disposal of products) is the primary objective of eco-design. Eco-design also maintains a product's quality level following its recommended use [41]. In addition, the ecological strategic approach takes into account the physical mechanisms, such as water and energy [42]. By maintaining or improving the material and social circumstances that affect people's health and the environment over time without going beyond the ecological capacities that support them, we supposedly practice sustainability [43]. Thus, eco-design is a return to the sustainability concept, and it appeared in the first wave of the modern movement in 1962 [44].

Passive design

Passive design as another environmental strategy may be helpful in the advancement of sustainability in a healthy built environment since passive construction is an excellent approach to conserving energy for sustainability [45]. The first use of passive design was in the middle of the 1970s [46], and it makes use of breezes and sun while simultaneously blocking out unwanted heat and cold [47].

Sustainability

The building's shape, positioning, construction method, and its relationship to the topography are of prime significance for environmentally conscious architectural codes in a building to result in sustainable architecture. Sustainable construction practices include minimizing maintenance costs using forethought, recycling, ensuring building energy efficiency, conserving water, and reducing material waste [48]. As a philosophical and comprehensive concept, it was used after the Brundtland report in 1987 [49].

Eco-efficiency

Eco-efficiency is the combination of the economy and environment, which are two dimensions of sustainability pillars; it is a type of sustainability system that includes socio-economic, eco-efficiency, and socio-ecological indicators [50], as shown in Figure 3.

Eco-friendly

The key philosophy of eco-friendly, "earth-friendly", or "environmentally friendly" is "in danger of being lost. Healthier living for all the inhabitants and plants will be provided, and it will be equal to "going green" and "sustainability". The most common characteristics of eco-friendly designs are the conservation of natural resources such as water and energy, reducing pollution of water, air, and soil, providing bio-diversity, respecting the ecosystem, reducing the negative impact on humans and the environment, and using recyclable materials [51].

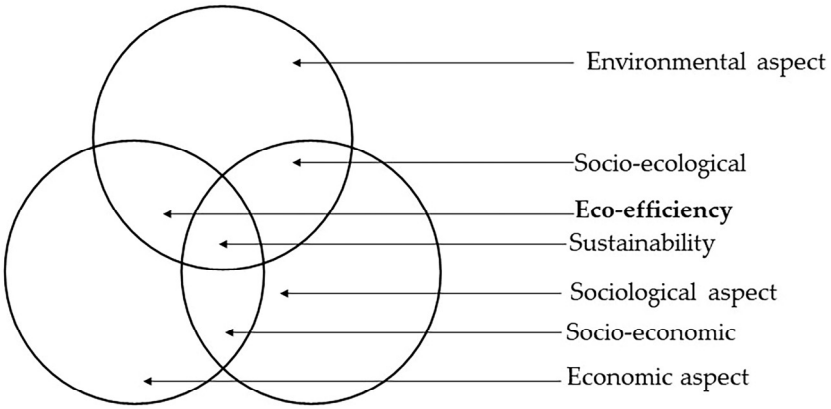

Figure 3. The position of eco-efficiency in the three pillars of sustainability, adapted from Ref. [50].

Cradle to Cradle

Cradle to Cradle was developed in 1990 by William McDonough and Michael Braungart; it can be characterized as an invention that takes into account the quality of the materials, water, air, biodiversity, enhancement of natural sun rays, and the processes for reusing, recycling, and recovering [52].

Zero Energy Buildings

Buildings are crucial in creating plans for sustainable development since they have a significant impact on global energy and carbon emissions. Introduced in the early 2000s [53], the popularity of zero-energy buildings (ZEBs) has grown recently; several countries have chosen or are considering establishing ZEBs as their future building energy objectives to address difficulties with the depletion of the energy supply and the degradation of the environment. "ZEBs are buildings that produce and use an amount of energy that is exactly equal to their annual needs" [54].

2. The approaches of visual inspiration:

Geomorphic architecture

Buildings with geomorphic architecture are those that are inspired by nature, take their symbolism from a natural process, offer an experiential equivalent to that found in nature, fit into the natural contour of the land, and are combined with the landscape to form a single entity, or are partially or entirely earth-sheltered [55].

Zoomorphic design

Zoomorphic refers to human-made forms that resemble animals in shape or appearance. Since the beginning of time, artists have manufactured zoomorphic designs by incorporating non-animal forms with characteristics inspired by animalistic forms [56].

Anthropomorphic design

Anthropomorphism is the imitation of the human form as a symbol and metaphor. "The idea of the relationship of the body and architecture is an analogy that had been with us in one form or another forever" [57].

Biomorphic design

Biomorphic architecture refers to a direct conception that is affected by the organic forms of the human body, animals, and plants [58].

Biomorphology is the study of the structure and organization of living organisms and the organs, tissues, and cells that make them up. Structural morphology "refers to functional design in technology and functional anatomy in biology", and micromorphology is the examination and characterization of the shape of small details, which is a genuine great resource for useful forms [59].

3. The approaches of conceptual inspirations:

Evolutionary architecture

This process progresses from abstraction, which includes concept and design derivation, using concretization, which concentrates on translating the concepts into design components and aspects to be combined into the overall product design. Similar to what was proposed, the framework approach alternates between divergence and convergence [60].

Metabolic architecture

The catabolic and anabolic processes of the body's systems are described by metabolism, a movement that emerged and was inspired by biological metaphor and genetic design. It was a response to environmental disasters, human catastrophes, and natural disasters like earthquakes and tsunamis [61].

Parametric architecture

How the dimensions relate to one another is the definition of parametric design. It was later expanded to create parametric modeling, which is the representation of geometric relationships based on computational methods [62].

Regenerative architecture

Intelligent limits, incorporating entire system designs, intelligent structure, the community's perspective, and the appropriate ecology are the most crucial regenerative architecture principles [63].

4. The combination:

Organic architecture

According to Louis Sullivan, the concept of "organic" in architecture refers to a broad approach that includes ideas like organisms, functions, growth, development, shape, and structure [64].

Bionic architecture

The key premise of bionic architecture is learning from nature for the sake of technology or understanding nature with the aid of technology. This means that bionic is a word that was created by combining "biology" and "technology" [65].

Biomimicry

Biomimicry is a strategy for sustainable development. In its broadest sense, it imitates or draws creative inspiration from nature's systems, ideas, procedures, and functions to construct a long-lasting future [66].

Biophilic architecture

The core principle of biophilic architecture is the process of integrating nature's characteristics into the built environment or giving life to buildings, known as biophilic design. It relates to human health, human well-being, physiological advantages, and performance enhancement [67]. The aesthetic preference for the complex geometric properties of natural scenes can also be found in the building's artificial structures, which the parameters of natural scaling hierarchy and of either fractal graphics or of ornaments will increase the visual organization if the relationship between them was interesting it will positively impact on both physical and mental health [68]. Using the strategies of fractal fluency of nature in the building design will have a positive impact on aesthetic experience and physiological stress reduction of the observers, such as fractal floor patterns, fractal window shades, and fractal solar panels will have to improve salutogenesis [69]. Additionally, the utilization of urban space will be more attractive by using the integrations of multiple fractals, biophilia, and traditional architecture, and it affects the user experience by providing the aesthetic value of visual urban perception, which encourages walkability, natural navigation with positive effects on health and well-being [70].

Thus, computational inspirations, visual inspirations, conceptual inspirations, and a combination of them are used as nature-based strategies for systematic regulations of these approaches of architectural design related to nature. These nature-based strategies have a convergence relationship with the dominant principles of architecture: function, form, and concept. In a way that the computation of nature has been used in the functional principle of architecture, the visual appearance of nature has been used in the formal principle of architecture, the concept of nature has been used in the idea and conceptual principle of architecture, and it was the same for the combinations between them.

2. Materials and Methods

2.1. Data Analysis

Through reviewing the existing literature on the nature inspirations of design and the most common theories of architectural design principles, nature's contributions to architectural design were identified. Nature-based strategies in architectural design were classified into four categories: form, function, concept, and combination. This study predicted a model of nature's contributions to architectural design based on these four named categories. Moreover, this research was focused on a functional nature-based strategy for testing and validating the model. VOSviewer was used to construct a set of criteria and key aspects of a functional nature-based strategy involving nine approaches (bioclimatic architecture, green architecture, eco-design, passive design, sustainability, eco-efficient design, eco-friendly design, cradle-to-cradle, and zero energy buildings), whose aspects are related to environmental behaviors.

On 21 December 2021, 450 research articles from Scopus were accessed that are related to nine selected approaches; they were analyzed using the VOSviewer (https://www.vosviewer.com/ accessed on 13 December 2021), a program for visualizing and creating bibliometric networks. These networks can be built utilizing citations, co-citations, bibliographic coupling, or co-authorship relationships, and they can contain journals, researchers, or individual articles. To create and display co-occurrence networks of significant phrases taken from a body of scientific literature, VOSviewer additionally provides a text or keyword mining capability [71]. The data were scanned before entering into this software tool, including the title and the abstract of the articles. The search keywords were related to "aspects", "environmental behaviors target or environmental strategies", and "architectural design". The outcome included the aspects of occurrences of these selected approaches.

The size of the circles is illustrated according to the number of occurrences of each aspect; the summarized aspects include temperature, thermal comfort, saving, energy performance, air, heat, envelop, light, insulation, energy demand, window, natural ventilation, orientation, cooling, opening, performance evaluation, waste, environmental pollution, natural resource, life cycle assessment, greenhouse gas emission, CO_2 emission, carbon emission, fossil fuel, consumption, renewable energy, wind, and reuse. As shown in Figure 4.

The six categories shown as different colors were classified according to the user's desire. These aspects were edited into 23 main aspects of architectural design targets because they contained repetitions, and some of them consisted of only one word. Simulation is not used for finding and rating systems, but it was the most common method of evaluating environmental behavioral targets in architecture [72]. In this research, because of the large number of approaches (9) and their aspects (23), a survey questionnaire was used to evaluate their contribution to Erbil City's architectural design. Erbil (Hawler in Kurdish), the largest city in Iraqi Kurdistan, has been consistently inhabited for 6000 years [73]. Climate change and the problems of natural resource decline are the main reasons for its selection as the setting for the survey questionnaire.

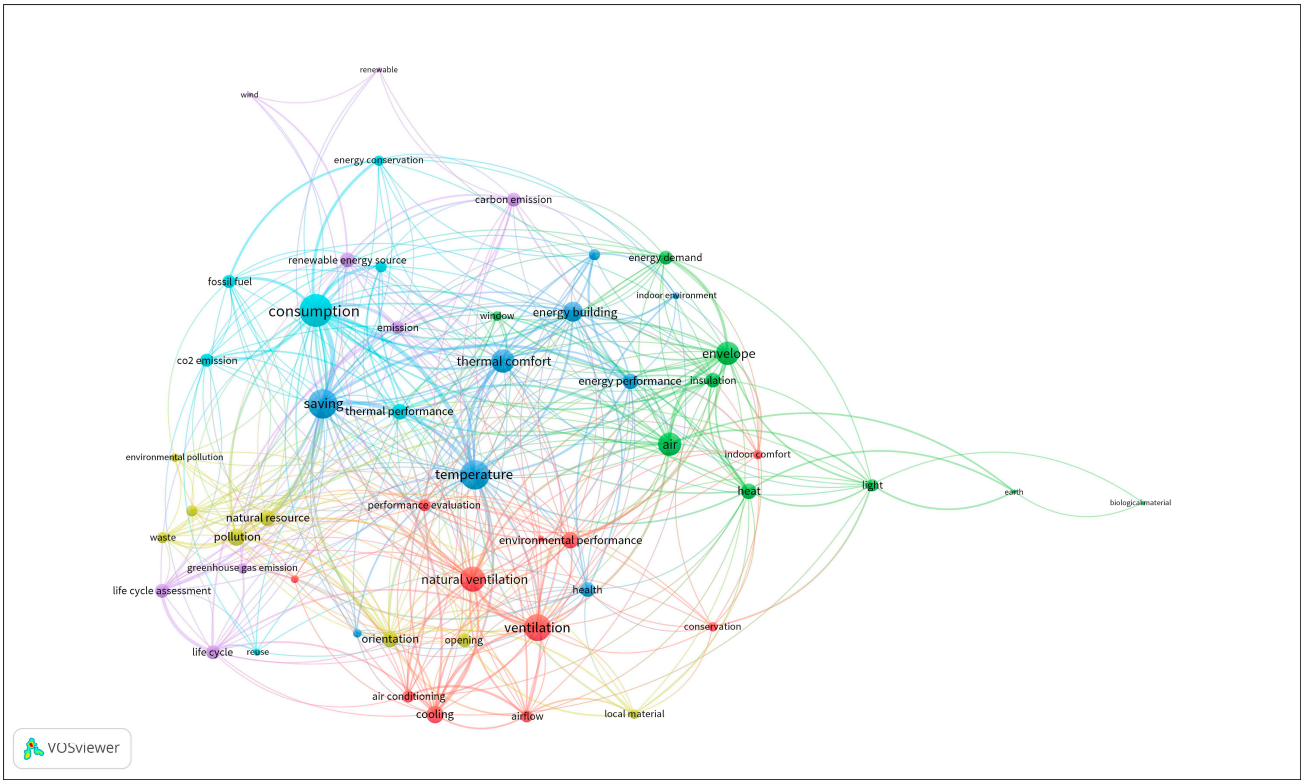

Figure 4. The "aspects" and "environmental behaviors target or environmental strategies" and "architectural design" as keywords in the VOSviewer analysis.

2.2. Evaluation (Survey Method)

Between December 2022 and March 2023, a face-to-face survey questionnaire and online survey tool "Google Forms" in English and Kurdish were prepared for the focus groups of architects who have designed projects in Erbil City, as shown in third step in Figure 5. The data on the participants obtained from the Kurdistan Engineers Union showed that the number of architects in Erbil City was 2060 on 31 December 2022, and the number of architecture office buildings was 93, most of which were visited during the survey. From the survey, the architects could choose from the 23 aspects, the ones that they regarded as important in their designs, and rated the aspects according to a four-point Likert scale (most of the time, some of the time, seldom, and never). A total of 328 responses were obtained from this survey, and the responses from never to most of the time were assigned a value from zero to three. The data were imported into SPSS version 25 and Excel 2018, and the results were described as numbers, percentages, means, and standard deviations (SD). The *t*-test was used to compare means between the approaches of functional nature-based strategy in Erbil City's architectural design.

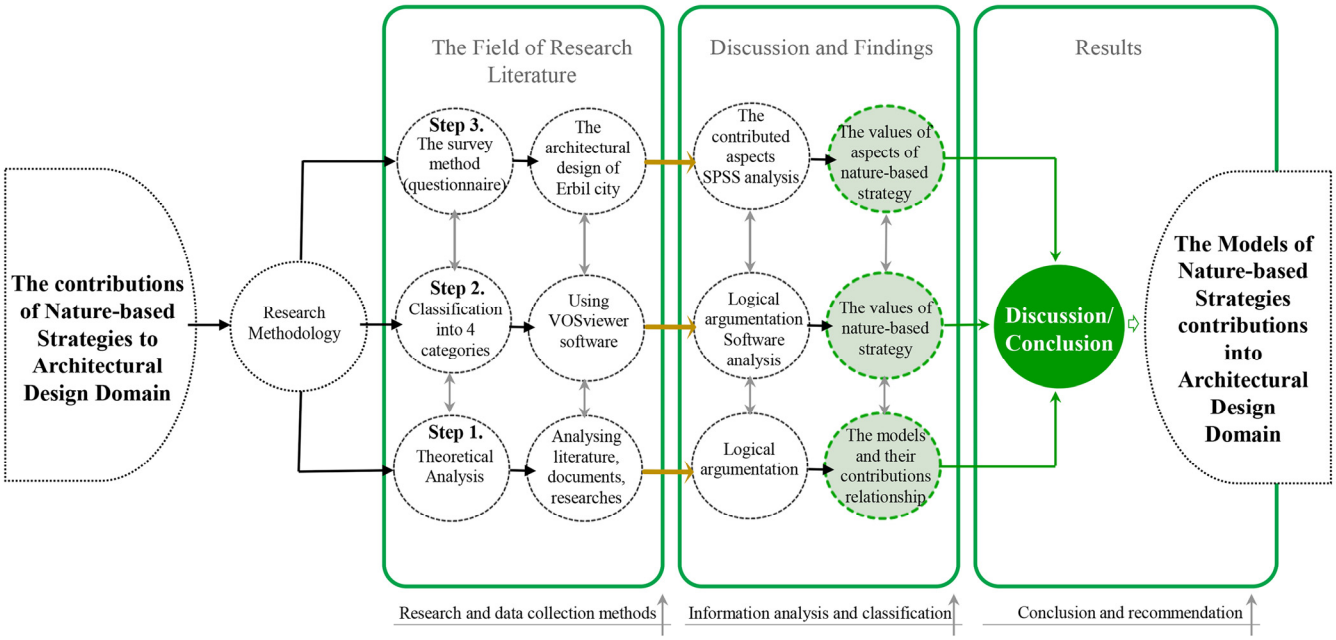

Figure 5. The diagram of levels and steps of the research methodology.

3. Results

3.1. Results of Literature Analysis

3.1.1. Nature-Based Strategies in Architectural Design

Using the literature on nature-based strategies and the dominant architectural design principles, the structure of nature's contributions to architectural design was illustrated in a diagram (Figure 6). The nature-based strategies, their approaches, and the aspects were divided into the four main architectural design domains (function, form, concept, and combinations of these principles).

From the diagram, bioclimatic architecture, green architecture, eco-design, passive design, sustainability, eco-efficient design, eco-friendly design, cradle-to-cradle, and zero-energy buildings were assigned as the functional nature-based strategy of architectural design because they are dependent on natural environmental behaviors. The approaches of zoomorphism, geomorphic, anthropomorphism, and biomorphism were assigned as the formal nature-based strategy of architectural design because they are dependent on the formal imitation of nature. In addition, the approaches of metabolic architecture, evolutionary design, parametric design, and regenerative architecture were assigned as the conceptual nature-based strategy of architectural design because their designs are based on conceptual inspiration from nature. The approaches of organic architecture, bionic architecture, biomimicry, and biophilic design were assigned as the combined nature-based strategy of architectural design because, in these approaches, nature contributed to more than one principle of design. The functional nature-based strategy of architectural design (Figure 7) was the main topic of this research.

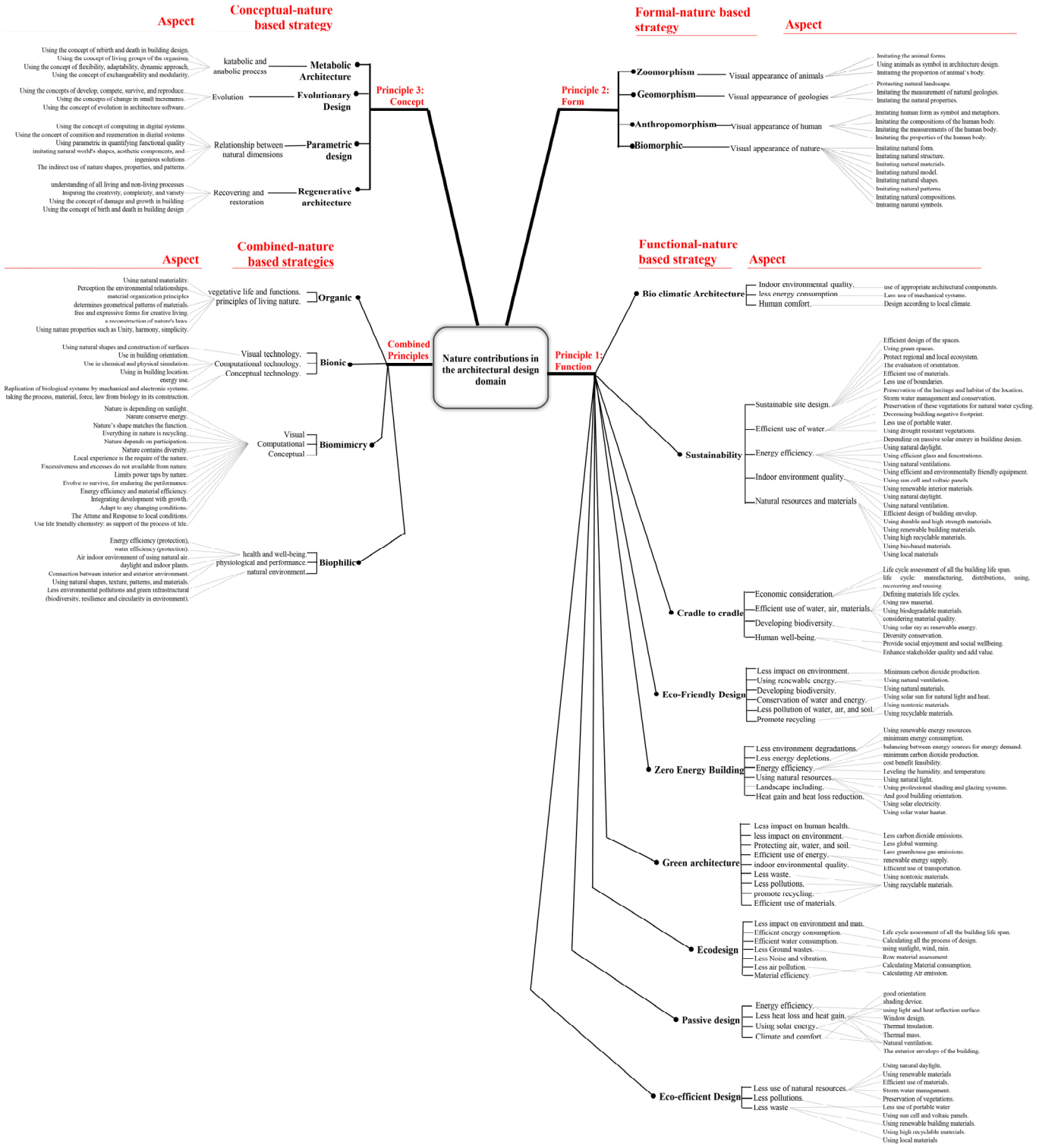

Figure 6. The diagram of nature-based strategies within architectural design principle.

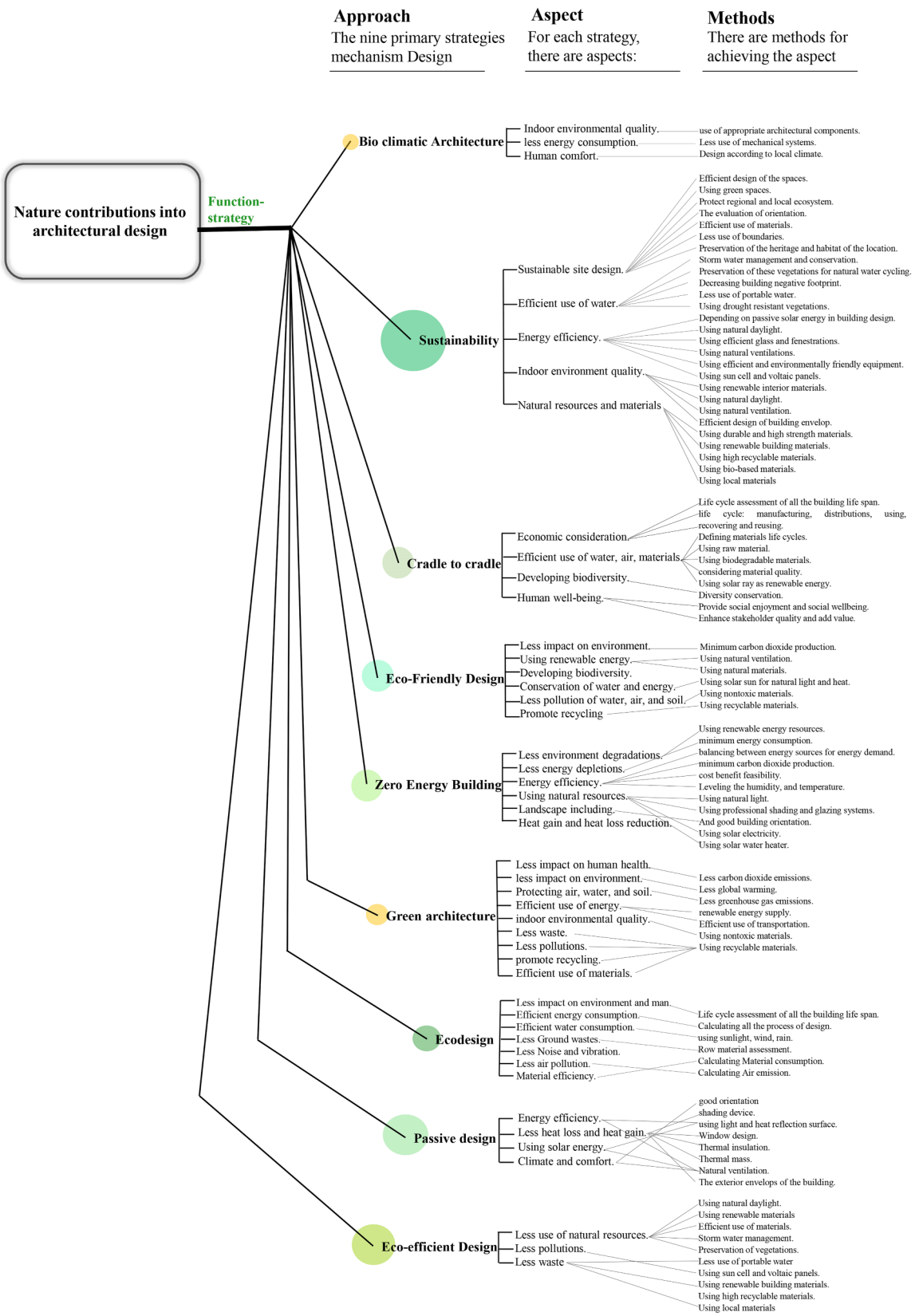

Figure 7. The structure of aspects and the approaches of a functional nature-based strategy of architectural design.

After classifying the nature-based strategies according to the four architectural domains (function, form, concept, and combination), seven options of the models were

extracted from this classification in Figure 8. which were arranged into point, linear, and comprehensive relationships between the nature inspirations and architectural principles. The models of nature inspirations include function, form, concept, function-form, function-concept, form-concept, and function-form-concept models.

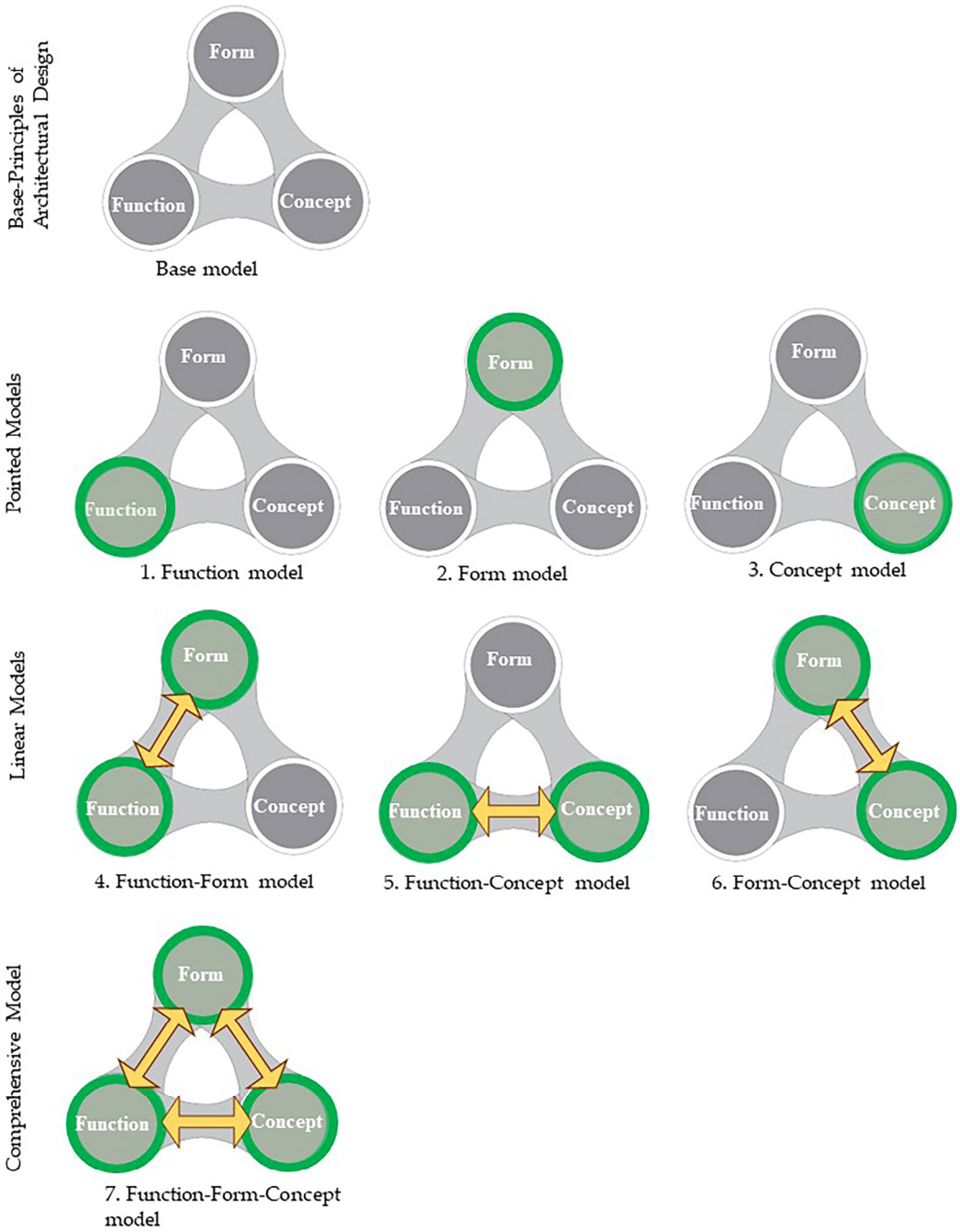

Figure 8. The models of nature-based strategies converge to the architectural design principles.

3.1.2. Predicted Nature–Architecture Model

The general model of the relationship between nature and architecture, which is in the form of a pyramid, was divided into three levels of contributions: the first level (the base of the pyramid) contained the name of nature-based strategies, including functional strategy, formal strategy, conceptual strategy, and combined strategy; the approaches were in the second level, and the aspects were in the third level of the pyramid. All the levels were

divided according to the principal contributions; the top of the pyramid was left for future development, as shown in Figure 9.

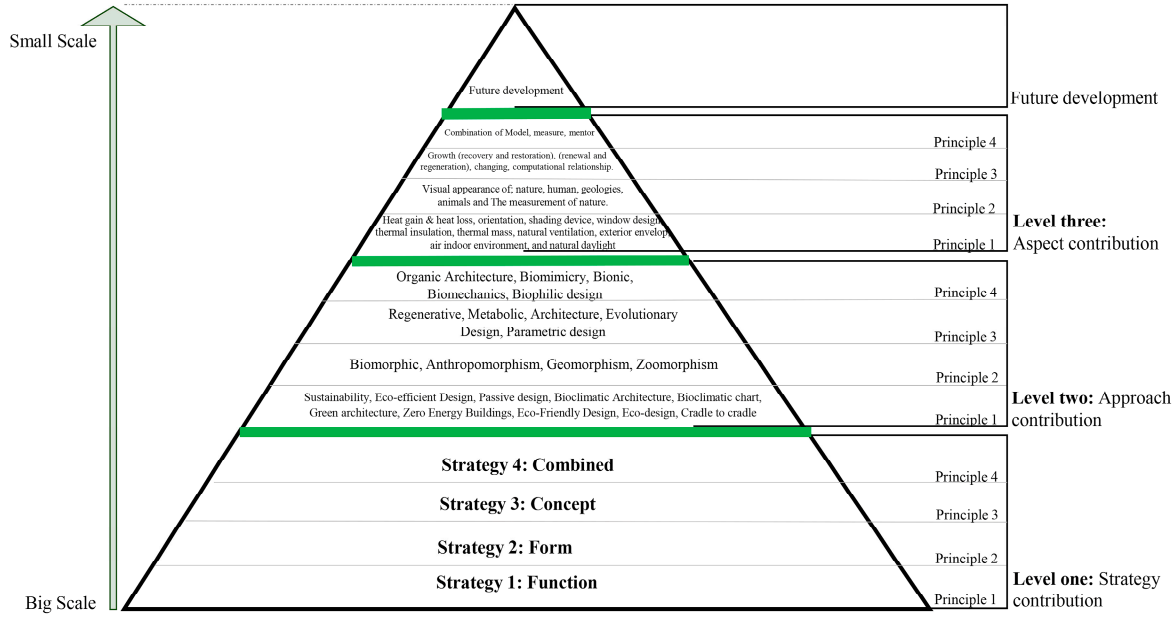

Figure 9. The model of the relationship between nature and architectural design.

3.1.3. Functional Nature-Based Strategy of Architectural Design

According to literature on the functional nature-based strategy of architectural design the key philosophy of each approach was listed in Table 1. Which it revealed the main differences between them.

Table 1. The key philosophies of a functional nature-based strategy of architectural design.

No.	Approach	Key Philosophy
1	Sustainability	Balancing environment, social, and economic factors [74]
2	Eco-efficient design	Economic and environmental maintenance [50]
3	Passive design	Climate and comfort (less heat loss and heat gain) [45]
4	Bioclimatic architecture	Adaption to the local climate [36]
5	Green architecture	Reduce effects on the environment and human health [39,40]
6	Zero energy buildings	Self-sufficient buildings (energy efficiency and renewable energy generation) [54]
7	Eco-friendly design	Earth-friendly, environmentally friendly, in danger of being lost [51]
8	Eco-design	A design according to the ecological process [41]
9	Cradle to Cradle	Less negative impact (life cycle of product: manufacturing, distribution, usage, recovery, and reuse) [52]

Next, the most common aspects of each approach are listed in Table 2, with the hierarchy of importance for each aspect appearing for each approach. For instance, for passive design, energy efficiency, heat gain, and heat loss are more significant than other aspects of the other approaches.

Table 2. The aspects of a functional nature-based strategy of architectural design.

Approach		Aspect
Functional strategy:		
1	Bioclimatic Architecture	Improved indoor environmental quality Less energy consumption Human comfort [75]
2	Green architecture	Less impact on human health Less impact on the environment Protect air, water, and soil Efficient use of materials Efficient use of energy Indoor environmental quality Less waste Less pollution Promote recycling [38]
3	Eco-design	Less impact on the environment and humans Efficient energy consumption Efficient water consumption Less ground wastes Less noise and vibrations Less air pollution Material efficiency [44]
4	Passive design	Building orientation Window design Thermal mass Heat gain and heat loss Natural ventilation Thermal insulation [76] Performance of acoustic insulation [13,14]
5	Sustainability	Sustainable site design Efficient use of water Energy efficiency Improved indoor environment quality Natural resources and materials [77]
6	Eco-efficient Design	Less use of natural resources Less waste Less pollution [50]
7	Eco-Friendly Design	Less impact on the environment Using renewable energy Developing biodiversity Conservation of water and energy Less pollution of water, air, and soil Promote recycling [51]
8	Cradle to cradle	Economic consideration of building construction Efficient use of water, air, and materials Developing biodiversity [52]
9	Zero Energy Buildings	Less environment degradation Less energy depletion Energy efficiency Using natural resources Inclusion of landscape Heat gain and heat loss reduction [54]

The scope of sustainability was larger than the scope of the other approaches in functional nature-based strategy when examining their main key philosophy and aspects, and it was located in the middle of the timeline of the development of these approaches, as shown in Figure 10. The other approaches are models of sustainability; thus, it is possible to argue that sustainability is the fundamental functional nature-based strategy of architectural design.

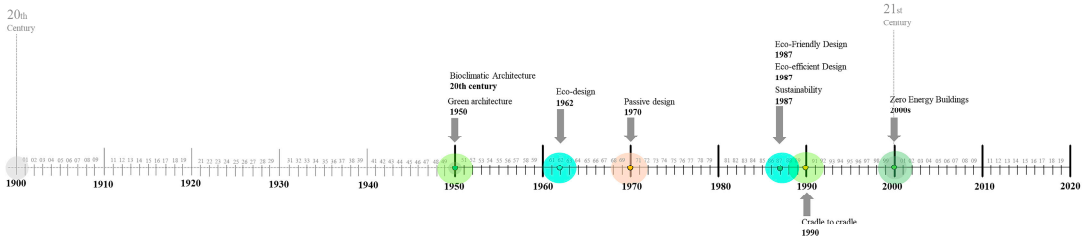

Figure 10. The timeline of the approaches of a functional nature-based strategy of architectural design.

3.2. Results of Survey

The evaluation of the functional nature-based strategy's contribution to architectural design was conducted via a questionnaire in Table 3. It was completed by 328 architects, a response rate of 63%. All the participants worked in Erbil City consultant offices, and the majority were male (81.10%), and 89.3% were architects who had a bachelor's degree in architectural design. The responses were coded as 0, 1, 2, and 3, and the aspects were arranged as A1–A23. The mean of all aspects was 1.3348 with an SD of 0.37604, and they were ranked from 1 (1.91) to 23 (0.44).

The highest means were obtained for questions A13, A14, A8, and A11 (1.91, 1.87, 1.86, and 1.82). Meanwhile, the lowest means were obtained for questions A23, A22, A3, and A2 (0.44, 0.76, 0.80, and 0.82) as shown in Figure 11. At the same time, the highest deviations, measured in standard deviations (SD), were found in questions A8 (SD 1.09), A13 (SD 1.04), A18 (SD 1.03), and A7 with A10 (SD 0.99). The smallest SDs were obtained for questions A23 (SD 0.67), A1 (SD 0.71), A2 (SD 0.74), and A22 (SD 0.83).

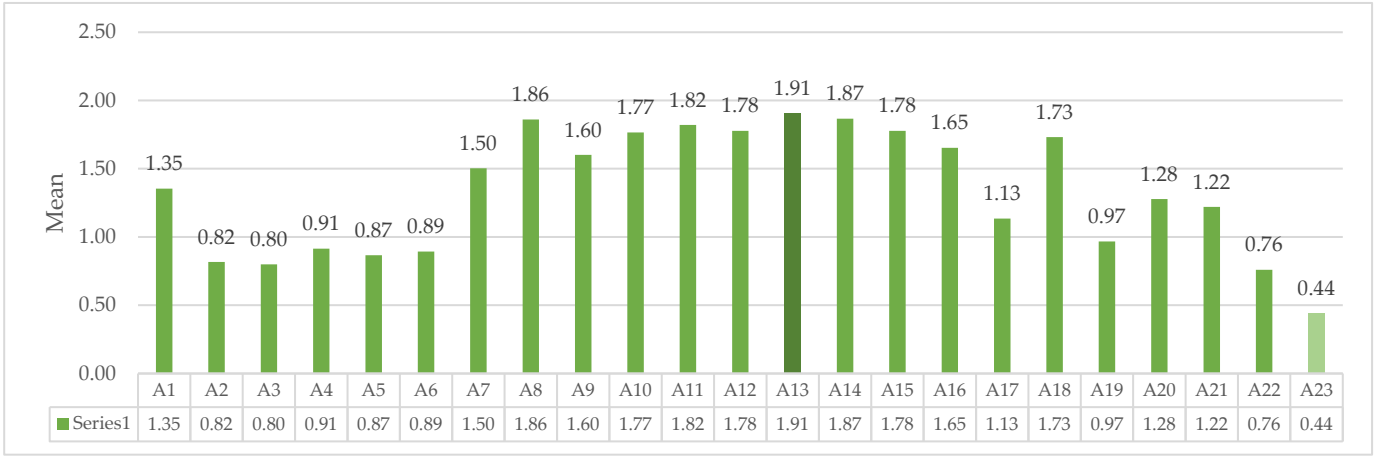

Figure 11. The ranked means of the 23 aspects of the functional nature-based strategy based on survey responses.

Table 3. The statistics of nature's contributions in a functional strategy of architecture design (n = 328) and 23 aspects of the approaches of this strategy.

The Aspects of Functional Strategy	Never		Seldom		Some of the Time		Most of the Time		Mean	%	Rank	SD
A1 Collecting all the information about the local climate	38	11.6%	143	43.6%	140	42.7%	7	2.1%	1.35	45.1	12	0.71
A2 Pollution (greenhouse gas emission, CO_2 emissions) effects on humans, environment	118	36.0%	160	48.8%	42	12.8%	8	2.4%	0.82	27.2	20	0.74
A3 Recycling waste material during construction	152	46.3%	107	32.6%	52	15.9%	17	5.2%	0.80	26.6	21	0.89
A4 Recycling wastewater during the construction process	137	41.8%	99	30.2%	75	22.9%	17	5.2%	0.91	30.5	17	0.92
A5 Recycling waste material during the demolition process	154	47.0%	80	24.4%	78	23.8%	16	4.9%	0.87	28.9	19	0.94
A6 Recycling wastewater during construction	139	42.4%	98	29.9%	78	23.8%	13	4.0%	0.89	29.8	18	0.90
A7 Calculating heat gain and heat loss	45	13.7%	146	44.5%	64	19.5%	73	22.3%	1.50	50.1	11	0.99
A8 Good orientation	54	16.5%	59	18.0%	94	28.7%	121	36.9%	1.86	62.0	3	1.09
A9 Shading device according to solar radiation	47	14.3%	108	32.9%	102	31.1%	71	21.6%	1.60	53.4	10	0.98
A10 Window design according to solar radiation	38	11.6%	94	28.7%	103	31.4%	93	28.4%	1.77	58.8	7	0.99
A11 Thermal insulation materials	20	6.1%	94	28.7%	139	42.4%	75	22.9%	1.82	60.7	4	0.85
A12 Calculations for thermal mass materials	32	9.8%	92	28.0%	121	36.9%	83	25.3%	1.78	59.2	5	0.94
A13 Natural ventilation	36	11.0%	84	25.6%	83	25.3%	125	38.1%	1.91	63.5	1	1.04
A14 Exterior envelops of the building	20	6.1%	101	30.8%	110	33.5%	97	29.6%	1.87	62.2	2	0.91
A15 Indoor air environment	31	9.5%	86	26.2%	136	41.5%	75	22.9%	1.78	59.2	6	0.91
A16 Using local materials	28	8.5%	133	40.5%	92	28.0%	75	22.9%	1.65	55.1	9	0.93
A17 Using renewal materials	85	25.9%	133	40.5%	91	27.7%	19	5.8%	1.13	37.8	15	0.87
A18 Using natural daylight	38	11.6%	114	34.8%	74	22.6%	102	31.1%	1.73	57.7	8	1.03
A19 Using voltaic panels	106	32.3%	152	46.3%	45	13.7%	25	7.6%	0.97	32.2	16	0.88
A20 Calculating cost reduction	72	22.0%	127	38.7%	95	29.0%	34	10.4%	1.28	42.6	13	0.92
A21 Life cycle assessment of design	94	28.7%	101	30.8%	100	30.5%	33	10.1%	1.22	40.7	14	0.97
A22 Using the passive system	145	44.2%	133	40.5%	34	10.4%	16	4.9%	0.76	25.3	22	0.83
A23 Balancing between the energy source and energy demand	211	64.3%	93	28.4%	20	6.1%	4	1.2%	0.44	14.7	23	0.67

Question wording: A. Please rate if you have regarded these aspects during the design of your project regarding nature contributions. If these aspects were regarded from all the project's designs, it was most of the time. From some of the project's designs, it was some of the time. It was seldom, if the aspect rarely used in the design projects. Additionally, it was never as if they have never been included in any project design. The values are: most of the time = 3, some of the time = 2, seldom = 1, and never = 0.

The functional nature-based strategy of architectural design was coded as (Fun.), the nine selected approaches were coded as (App.No), and the aspects of the approaches were identified as sub-numbers for the approaches, as shown in Figure 12.

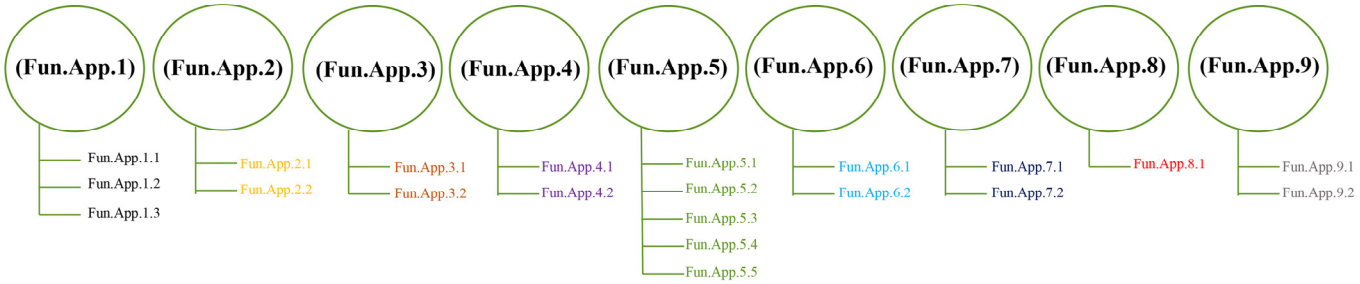

Figure 12. The symbols of a functional nature-based strategy of architectural design, with their approaches and aspect numbers.

Due to the small differences between the approaches of green architecture, eco-design, eco-efficient design, and eco-friendly design, one mean was considered for these four approaches, and there were similarities between these aspects in the questionnaire, as shown in Table 4. These included the calculation of the impact of the building on its surroundings, including humans, the environment, the ecosystem, and the economy; their mean was 0.858. The lowest mean score was for zero-energy buildings (0.723), and the highest score was for the passive design (1.611); all the approaches of functional nature-based strategy had negative values on the *t*-test except the passive design (3.805). Therefore, there were highly significant differences between these approaches of a functional nature-based strategy of architectural design, and their *p*-values were smaller than 0.05, as shown in Table 5.

Table 4. The symbols of the questions for each aspect of the functional nature-based strategy of architectural design are grouped into nine approaches and 23 aspects.

No.	Approach	Symbol of Approach	Number of Aspects	Symbol of Aspect	SD
1	Bioclimatic architecture	(Fun.App.1)	3	A1-A15-A22	0.71-0.91-0.83
2	Green architecture	(Fun.App.2)	2	A2-A3-A4-A5-A6	0.74-0.89-0.92-0.94-0.90
3	Eco-design	(Fun.App.3)	2	A2-A3-A4-A5-A6	0.74-0.89-0.92-0.94-0.90
4	Passive design	(Fun.App.4)	2	A7-A8-A9-A10-A11-A12-A13-A14-A15-A18-A19-A22	0.99-1.09-0.98-0.99-0.85-0.94-1.04-0.91-0.91-1.03-0.88-0.83
5	Sustainability	(Fun.App.5)	5	A3-A4-A5-A6-A8-A9-A10-A11-A12-A13-A14-A15-A16-A17-A18-A19-A22	0.89-0.92-0.94-0.90-1.09-0.98-0.99-0.85-0.94-1.04-0.91-0.91-0.93-0.87-1.03-0.88-0.83
6	Eco-efficient design	(Fun.App.6)	2	A2-A3-A4-A5-A6	0.74-0.89-0.92-0.94-0.90
7	Eco-friendly design	(Fun.App.7)	2	A2-A3-A4-A5-A6	0.74-0.89-0.92-0.94-0.90
8	Cradle to cradle	(Fun.App.8)	1	A20-A21	0.92-0.97
9	Zero energy buildings	(Fun.App.9)	2	A19-A22-A23	0.88-0.83-0.67

Table 5. The statistical calculations of means of a functional nature-based strategy of architectural design.

Mean Name	Approach	Symbol	*n*	Mean Value	Theoretical Mean	Std. Deviation	*t*-Test	*p*-Value	Sig.
Mean1	Bioclimatic architecture	(Fun.App.1)	328	1.297	1.500	0.485	−7.591	0.000	HS
Mean2	Green architecture Eco-design Eco-efficient design Eco-friendly design	(Fun.App.2) (Fun.App.3) (Fun.App.6) (Fun.App.7)	328	0.858	1.500	0.642	−18.102	0.000	HS
Mean3	Passive design	(Fun.App.4)	328	1.611	1.500	0.528	3.805	0.000	HS
Mean4	Sustainability	(Fun.App.5)	328	1.417	1.500	0.411	−3.660	0.000	HS
Mean5	Cradle to cradle	(Fun.App.8)	328	0.989	1.500	0.755	−12.256	0.000	HS
Mean6	Zero energy buildings	(Fun.App.9)	328	0.723	1.500	0.659	−21.368	0.000	HS

4. Discussion

Starting from the selected aspects for the questionnaire design, the mean of these aspects ranged from relatively low (0.44) to very high (1.91); the lowest mean was "balance between the energy source and energy demand", followed by "using passive systems" (0.76) and "using voltaic panels" (0.97). The highest mean score was for "natural ventilation", which was interesting for the architects of Erbil City; the response rate selections were 11.0% never, 25.6% seldom, 25.3% some of the time, and 38.1% most of the time. It was the same result as the responses of the study by Kujundzic et al. (2023), in which the highest rate of relevance (68.75%) was obtained for natural ventilation [78]. To compare the rate of contributions between the approaches of functional nature-based strategy, a *t*-test was used. Only passive design had a positive value (+3.805), which means that nature contributes to Erbil City architecture via the passive design approach Figure 13. The difference between this study and the other related studies is that, in this study, the strategy was identified as the outcome with a group of evaluated approaches, whereas in the other studies, the researcher selected an approach before starting the research and without giving a critical reason.

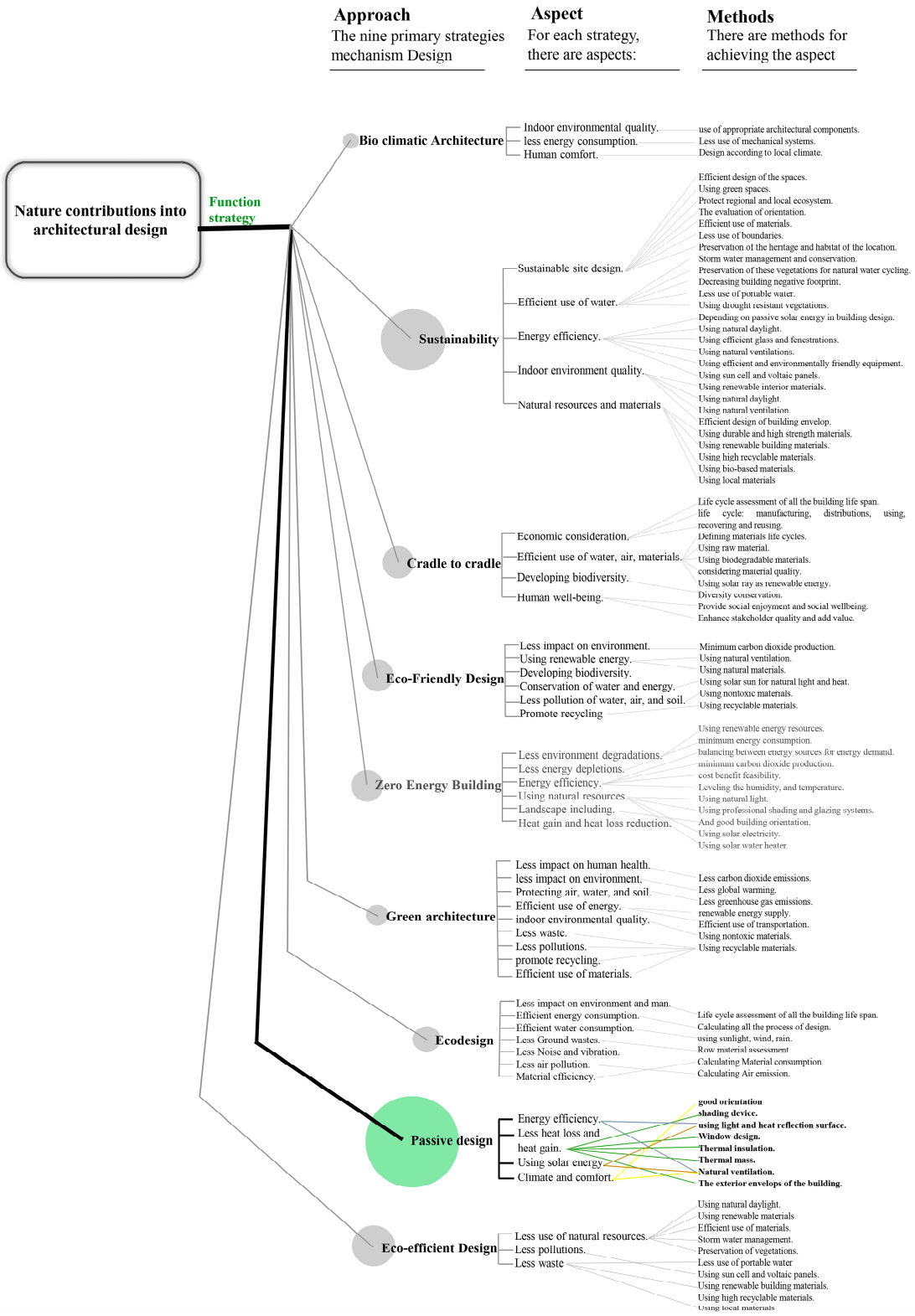

Figure 13. The result of the evaluated functional nature-based strategies that contributed to the architectural design of Erbil City.

5. Conclusions

For the sake of having environmentally friendly buildings, this study researched nature's contributions to architectural design and predicted a model for structuring the relationship between nature and architecture. The model is based on four categories

(function, form, concept, combination) of nature's inspirations to the architectural design principles, with seven options (function, form, concept, function_form, function_concept, form_concept, and function_form_concept) using three levels (strategy, approach, and aspect). Most of the approaches of nature-based strategies of architectural design have their significant aspects and different models in nature. Among these approaches, the scope of sustainability was higher than the scope of the other approaches in a functional nature-based strategy of architectural design.

To test and validate the model, 23 aspects were evaluated, which were extracted from nine approaches to architectural design in Erbil City. The model of relationship between nature and architecture in Erbil City's architectural design is based on the approach of passive design, as shown in Figure 14. The mean score of most of the aspects of passive design had the highest values, except for the use of voltaic panels, which had low values related to the lack of use of passive systems in Erbil City. The client requirements also have a negative impact on the low values of other aspects and approaches of functional nature-based strategy. The classifications of the approaches of architectural design into nature-based strategies will help designers use them in the four different architectural design principles; the complexity and interdisciplinarity of nature and its approaches will be less confusing. Additionally, placing these nature-based strategies of architectural design with their approaches and aspects in a predicted model will provide a clear picture for researchers to select proper approach for their research studies. Additionally, they can predict more levels smaller than the aspects of the relationship between nature and architecture

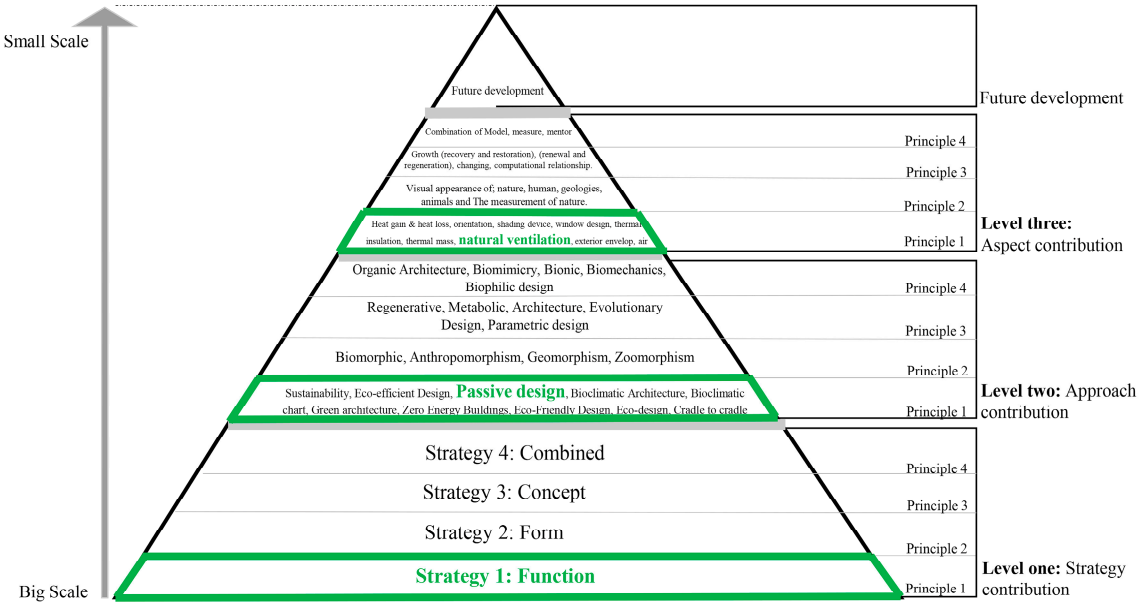

Figure 14. The model of the relationship between nature and architectural design in Erbil City identified using a functional nature-based strategy.

There is a group of functional nature-based strategies to solve the problems of the functional architectural principle. In addition, there is a group of formal nature-based strategies to solve the problems of the formal architectural principle and a group of conceptual nature-based strategies to solve the problems of the conceptual architectural principle, and the same applies to their combinations.

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and H.Q.R.; visualization, C.H.A.; supervision, H.Q.R.; project administration, H.Q.R.; funding acquisition, C.H.A. All authors have read and agreed to the published version of the manuscript.

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References

1. Pope Francis Encyclical Letter Laudato si'. In *The Holy Father Francis on Care for Our Common Home*; Vatican Press: Vatican City, Italy, 2015; p. 184.
2. Emekci, Ş. Using Nature in Architecture: A Perspective from Antoni Gaudi. *Eur. J. Sci. Technol.* **2022**, 87–91. [CrossRef]
3. Adams, D.J. *Organic and Inorganic Functionalism*; SteinerBooks: Hudson, NY, USA, 1995; pp. 40–41.
4. Portoghesi, P. *Nature and Architecture*; Skira: Milan, Italy, 2000; ISBN 88-8118-658-6.
5. Couvelas, A. Bioclimatic Building Design Theory and Application. *Procedia Manuf.* **2020**, *44*, 326–333. [CrossRef]
6. Xu, B.; Yuan, X. A Novel Method of BP Neural Network Based Green Building Design—The Case of Hotel Buildings in Hot Summer and Cold Winter Region of China. *Sustainability* **2022**, *14*, 2444. [CrossRef]
7. Imani, N.; Vale, B. (Eds.) *Biomimetic Buildings: Copying Nature for Energy Efficiency*; MDPI: Basel, Switzerland, 2022; ISBN 978-3-0365-5402-0.
8. Fratzl, P.; Weinkamer, R. Nature's Hierarchical Materials. *Prog. Mater. Sci.* **2007**, *52*, 1263–1334. [CrossRef]
9. Deyaa Abdul Jalil, D.W.; Ali Hasan Kahachi, H. The Implementation of Nano-Biomimicry for Sustainability in Architecture. *J. Eng. Sustain. Dev.* **2019**, *23*, 25–41. [CrossRef]
10. Arciszewski, T.; Kicinger, R. Structural Design Inspired by Nature. In *Proceedings of the AICC 2005*; George Mason University: Rome, Italy, 2005.
11. Sposito, A. Architecture and Nature. *Int. J. Archit. Art Des.* **2017**, *9309*, 3–10. [CrossRef]
12. Aamer, H.S.; Hamza, A.F.; Khairy, M.; Ghonimi, I. Biomimicry as a Sustainable Design Methodology for Building Behaviour. *Eng. Res. J.-Fac. Eng.* **2020**, *46*, 191–201. [CrossRef]
13. Glean, A.A.; Gatland, S.D.; Elzeyadi, I. Visualization of Acoustic Comfort in an Open-Plan, High-Performance Glass Building. *Buildings* **2022**, *12*, 338. [CrossRef]
14. Taghipour, A.; Sievers, T.; Eggenschwiler, K. Acoustic Comfort in Virtual Inner Yards with Various Building Facades. *Int. J. Environ. Res. Public Health* **2019**, *16*, 249. [CrossRef]
15. Gu, G.X.; Su, I.; Sharma, S.; Voros, J.L.; Qin, Z.; Buehler, M.J. Three-Dimensional-Printing of Bio-Inspired Composites. *J. Biomech. Eng.* **2016**, *138*, 021006. [CrossRef]
16. Sambucci, M.; Sibai, A.; Fattore, L.; Martufi, R.; Lucibello, S.; Valente, M. Finite Element Multi-Physics Analysis and Experimental Testing for Hollow Brick Solutions with Lightweight and Eco-Sustainable Cement Mix. *J. Compos. Sci.* **2022**, *6*, 107. [CrossRef]
17. Zhou, S.; Jiang, L.; Dong, Z. Overflow Control for Sustainable Development by Superwetting Surface with Biomimetic Structure. *Chem. Rev.* **2023**, *123*, 2276–2310. [CrossRef]
18. Pathak, S. Biomimicry: (Innovation Inspired by Nature). *Int. J. New Technol. Res.* **2019**, *5*, 34–38. [CrossRef]
19. Finsterwalder, R. (Ed.) Form Follows Nature. In *Form Follows Nature: A History of Nature as Model for Design in Engineering, Architecture and Art*; Birkhäuser: Basel, Switzerland, 2015.
20. Pohl, G.; Nachtigall, W. *Biomimetics for Architecture & Design Nature—Analogies—Technology*; Springer: Berlin/Heidelberg, Germany, 2015; ISBN 9783319191195.
21. Collins, P.; Gowans, A.; Ackerman, J.S.; Scruton, R. Architecture | Definition, Techniques, Types, Schools, Theory, & Facts | Britannica. Available online: https://www.britannica.com/topic/architecture (accessed on 2 April 2023).
22. Jesberg, P. Marcus Vitruvius Pollio. In *Vom Bauen zwischen Gesetz und Freiheit*; Springer: Berlin/Heidelberg, Germany, 1987; pp. 29–33.
23. Capon, D.S. *Architectural Theory: The Vitruvian Fallacy*; John Willey & Son: New York, NY, USA, 1999; ISBN 0471979465.
24. Salura, P.; Fauzy, B. The Ever-Rotating Aspects of Function-Form-Meaning in Architecture. *J. Basic Appl. Sci. Res.* **2012**, *2*, 7086–7090.
25. Ching, F.D.K. *Architecture: Form, Space, and Order*; John Wiley & Sons: New York, NY, USA, 2007; ISBN 0471752169.
26. Krier, R. *Architectural Composition*; Academy Editions: London, UK, 1991; p. 346.
27. Strategy Noun—Definition, Pictures, Pronunciation and Usage Notes | Oxford Advanced American Dictionary at OxfordLearnersDictionaries.Com. Available online: https://www.oxfordlearnersdictionaries.com/definition/american_english/strategy (accessed on 13 April 2023).

28. Harper, J. What Is Design Strategy? (And 5 Steps To Define Yours) | Indeed.Com. Available online: https://www.indeed.com/career-advice/career-development/design-strategy (accessed on 16 July 2023).
29. Aspect Noun—Definition, Pictures, Pronunciation and Usage Notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.Com. Available online: https://www.oxfordlearnersdictionaries.com/definition/english/aspect (accessed on 13 April 2023).
30. Chayaamor-Heil, N. From Bioinspiration to Biomimicry in Architecture: Opportunities and Challenges. *Encyclopedia* **2023**, *3*, 202–223. [CrossRef]
31. Mary Ann Steane, K.S. *Environmental Diversity in Architecture*, 1st ed.; Steane, M.A., Steemers, K., Eds.; Routledge: Oxfordshire, UK, 2004.
32. Olia, S.; Habib, F.; Shahcheraghi, A. Exploring the Place of Nature Strategies in Architecture Design Process towards Nature and Built Environment Symbiosis. *Creat. City Des.* **2023**, *5*, 70–84.
33. Verbrugghe, N.; Rubinacci, E.; Khan, A.Z. Biomimicry in Architecture: A Review of Definitions, Case Studies, and Design Methods. *Biomimetics* **2023**, *8*, 107. [CrossRef]
34. Austin, M.C.; Garzola, D.; Delgado, N.; Jiménez, J.U.; Mora, D. Inspection of Biomimicry Approaches as an Alternative to Address Climate-Related Energy Building Challenges: A Framework for Application in Panama. *Biomimetics* **2020**, *5*, 40. [CrossRef]
35. Zebari, H.N.; Ibrahim, R.K. Methods & Strategies for Sustainable Architecture in Kurdistan Region, Iraq. *Procedia Environ. Sci.* **2016**, *34*, 202–211. [CrossRef]
36. Nguyen, A.T.; Reiter, S. Bioclimatism in Architecture: An Evolutionary Perspective Bioclimatism in Architecture: An Evolutionary. *Des. Nat. Ecodyn.* **2017**, *12*, 16–29. [CrossRef]
37. Barber, D. The Thermoheliodon. *ARPA J.* **2014**. Available online: http://arpajournal.net/wp-content/uploads/2014/05/Barber_The-Thermoheliodon.pdf (accessed on 13 June 2023).
38. Coma Bassas, E.; Patterson, J.; Jones, P. A Review of the Evolution of Green Residential Architecture. *Renew. Sustain. Energy Rev.* **2020**, *125*, 109796. [CrossRef]
39. Madhumita, R. *Importance of Green Architecture Today*; Jadavpur University: Kolkata, India, 2008.
40. Ragheb, A.; El-Shimy, H.; Ragheb, G. Green Architecture: A Concept of Sustainability. *Procedia-Soc. Behav. Sci.* **2016**, *216*, 778–787. [CrossRef]
41. Cradle to Cradle: Remarking the Way We Make Things. Available online: https://youmatter.world/en/definition/definition-eco-design-examples-definition/ (accessed on 28 May 2023).
42. Lan, M. Create a Harmonious Environment Together of Ecological Architecture Design Method. *Procedia Environ. Sci.* **2011**, *10*, 1774–1780. [CrossRef]
43. Clift, R. Forum on Sustainability. *Clean Prod. Process.* **2000**, *2*, 67–70. [CrossRef]
44. Keulartz, J.; Korevaar, G.; Future, O.C. Environmental Design 1. *Encycl. Environ. Ethics Philos.* **2009**, *1*, 327–329.
45. Li, B.; Guo, W.; Liu, X.; Zhang, Y.; Russell, P.J.; Schnabel, M.A. Sustainable Passive Design for Building Performance of Healthy Built Environment in the Singnan Area. *Sustainability* **2021**, *13*, 9115. [CrossRef]
46. Watson, D. *Bioclimatic Design Research BT—Advances in Solar Energy: An Annual Review of Research and Development*; Böer, K.W., Ed.; Springer: Boston, MA, USA, 1989; pp. 402–438, ISBN 978-1-4613-0837-9.
47. Cairns Regional Council. Sustainable Tropical Building Design: Guidlines for Commercial Buildings. *Wetlands* **2011**, *48*, 6.
48. Tascı, B.G. "Sustainability" Education by Sustainable School Design. *Procedia-Soc. Behav. Sci.* **2015**, *186*, 868–873. [CrossRef]
49. Brundtland, G.H. Our Common Future: Report of the World Commission on Environment and Development. *Can. J. Public Health* **1987**, *78*, 366–367.
50. Sidkar, S.K. Sustainable Development and Sustainability Metrics. *AIChE J.* **2003**, *49*, 1928–1932.
51. Holzer, D. What Does Eco-Friendly Mean? Available online: https://homeguides.sfgate.com/ecofriendly-mean-78718.html (accessed on 1 April 2023).
52. McDonough, B.W.; Braungart, M. *Cradle to Cradle: Remaking the Way We Make Things*, 1st ed.; North Point Press: New York, NY, USA, 2002; ISBN 0865475873.
53. Panagiotidou, M.; Fuller, R.J. Progress in ZEBs—A Review of Definitions, Policies and Construction Activity. *Energy Policy* **2013**, *62*, 196–206. [CrossRef]
54. Li, D.H.W.; Yang, L.; Lam, J.C. Zero Energy Buildings and Sustainable Development Implications—A Review. *Energy* **2013**, *54*, 1–10. [CrossRef]
55. Burger, E. Geomorphic Architecture: Multifamily Residential Design Solutions. *Tunn. Undergr. Space Technol.* **1987**, *2*, 287–297. [CrossRef]
56. Coates, M.; Brooker, G.; Stone, S. *The Visual Dictionary of Interior Architecture and Design*; AVA Publishing: Worthing, UK, 2009.
57. Campbell, M. *An Architectural Prognosis: Greek Medicine & Architecture*; Carleton University: Ottawa, ON, Canada, 2007.
58. Aldersey-Williams, H. *Zoomorphic: New Animal Architecture*, 1st ed.; Laurence King Publishing: London, UK, 2003; ISBN 978-1856693400.
59. Petra, G. *Biomimetics in Architecture (Architecture of Life and Buildings)*; Petra Gruber, J.L., Ed.; Springer Wien: New York, NY, USA; Vienna Institute of Technology: Vienna, Austria, 2011; ISBN 9783709103319.
60. Liu, Y.-C.; Chakrabarti, A.; Bligh, T. Towards an 'Ideal' Approach for Concept Generation. *Des. Stud.* **2003**, *24*, 341–355. [CrossRef]
61. Schalk, M. The Architecture of Metabolism. Inventing a Culture of Resilience. *Arts* **2014**, *3*, 279–297. [CrossRef]

62. Dİno, İ.G. Creative design exploration by parametric generative systems in architecture. *METU J. Fac. Arch.* **2012**, *1*, 207–224. [CrossRef]
63. Littman, J.A. *ScholarWorks @ UMass Amherst Regenerative Architecture: A Pathway beyond Sustainability*; University of Massachusetts: Amherst, MA, USA, 2014.
64. Senegacnik, M.Z.; Kuzman, M.K. Interpretations of Organic Architecture. *Prostor* **2014**, *2*, 290–301.
65. Nachtigall, W. Bau Und Klimatisierung. In *Bionik*; Springer: Berlin/Heidelberg, Germany, 2002; pp. 147–171.
66. Badarnah, L. Form Follows Environment: Biomimetic Approaches to Building Envelope Design for Environmental Adaptation. *Buildings* **2017**, *7*, 40. [CrossRef]
67. Makram, A.; Ouf, T.A. Biomimetic and Biophilic Design as an Approach to the Innovative Sustainable Architectural Design. In Proceedings of the AR-UP 2019: Third International Conference of Architecture and Urban Planning, Cairo, Egypt, 14–16 October 2019; pp. 509–518.
68. Lavdas, A.A.; Schirpke, U.; Schirpke, U. Aesthetic Preference Is Related to Organized Complexity. *PLoS ONE* **2020**, *15*, e0235257. [CrossRef]
69. Taylor, R.P. The Potential of Biophilic Fractal Designs to Promote Health and Performance: A Review of Experiments and Applications. *Sustainability* **2021**, *13*, 823. [CrossRef]
70. Brielmann, A.A.; Buras, N.H.; Salingaros, N.A.; Taylor, R.P. What Happens in Your Brain When You Walk Down the Street? Implications of Architectural Proportions, Biophilia, and Fractal Geometry for Urban Science. *Urban Sci.* **2022**, *6*, 3. [CrossRef]
71. VOSviewer—Visualizing Scientific Landscapes. Available online: https://www.vosviewer.com/ (accessed on 24 May 2023).
72. Naboni, E. Environmental Simulation Tools in Architectural Practice. The Impact on Processes, Methods and Design. In Proceedings of the PLEA 2013—29th Conference, Sustainable Architecture for a Renewable Future, Munich, Germany, 10–12 September 2013; pp. 1–6.
73. Ibrahim, R.I.; Mushatat, S.A.; Abdelmonem, M.G. Erbil. *Cities* **2015**, *49*, 14–25. [CrossRef]
74. Chavalittumrong, P.; Speece, M. Three-Pillar Sustainability and Brand Image: A Qualitative Investigation in Thailand's Household Durables Industry. *Sustainability* **2022**, *14*, 11699. [CrossRef]
75. Bugenings, L.A.; Kamari, A. Bioclimatic Architecture Strategies in Denmark: A Review of Current and Future Directions. *Buildings* **2022**, *12*, 224. [CrossRef]
76. Mahar, W.A.; Verbeeck, G.; Reiter, S.; Attia, S. Sensitivity Analysis of Passive Design Strategies for Residential Buildings in Cold Semi-Arid Climates. *Sustainability* **2020**, *12*, 1091. [CrossRef]
77. USGBC LEED Credit Library | U.S. Green Building Council. Available online: https://www.usgbc.org/credits (accessed on 10 June 2023).
78. Kujundzic, K.; Stamatovic Vuckovic, S.; Radivojević, A. Toward Regenerative Sustainability: A Passive Design Comfort Assessment Method of Indoor Environment. *Sustainability* **2023**, *15*, 840. [CrossRef]