YRSB19

iiSBE Forum of Young Researchers in Sustainable Building

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Conference Proceedings

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YRSB19 – iiSBE Forum of Young Researchers in Sustainable Building 2019
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Foreword

In an UN report Our Common Future, written by Brundtland Commission in 1987 is stated "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". It is clear that nowadays young people represent near future generation which could be threatened by global changes on the Earth.

28 years later (in 2015) UN adopted the Resolution: Transforming our world: the 2030 Agenda for Sustainable Development. This Agenda is a plan of action for people, planet and prosperity and should stimulate action up to 2030 in areas of critical importance for humanity and the planet. The principal goal is to end poverty, protect the planet and ensure prosperity for all.

There are specified 17 Sustainable Development Goals with 169 associated targets which are integrated and indivisible and balance three dimensions of sustainable development: economic, social and environmental. These new goals and targets came into effect on 1 January 2016 and guide the actions up to 2030. It is expected, that all stakeholders, all of us, will work to implement the SDGs Agenda within own countries and at the regional and global levels, considering national specifics and priorities.

These goals, targets and proposed solutions should be widely discussed in international group of experts, considering global measure of the problem and consequently regionally specific situation. Young researchers can bring new ideas on how to contribute to sustainable development targets.

YRSB19 – Young Research Forum on Sustainable Building is organized for the third time together with CESB19 conference. The idea to organize Young Research SB conference as a satellite event has been initiated and developed in iiSBE – International Initiative on Sustainable Built Environment.

We appreciate that doctoral students, as well as young researchers, who already finished their doctoral studies, can present their scientific achievements and discuss their approaches with colleagues from other teams and universities from different countries. The interaction will help to improve their research and create new cooperation, networks and friendships across the borders.

The proceedings consist of 26 papers from 21 countries presented on YRSB19 conference held on July 1st 2019 at the Faculty of Civil Engineering, Czech Technical University in Prague.

We would like to thank all the authors of the papers presenting results of their work in the field of sustainability. We also want to thank to Czech Technical University in Prague, Faculty of Civil Engineering for the support. A special thank is addressed to all members of the organizing committee. All above mentioned help and support were necessary for successful organization of the conference and publishing of the proceedings. We hope that it will help in dissemination of sustainable building techniques into everyday construction practice and will thus contribute to solution of SDG targets specified in 2030 Agenda for Sustainable Development.

We hope that conference YRSB19 will contribute to enhancement of knowledge in the field of sustainable buildings and built environment considering changing natural, as well as socio-economic situation in the world.

In Prague in May 2019

Petr Hájek
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The Innovative Approach of Biomimetica and its Application to Sustainable Retrofitting of Existing Buildings

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Abstract

In recent decades, elements and technological systems inspired by the natural world have become more widespread in architecture and construction industry, in order to improve the energy efficiency and thermal behavior of buildings. The best known example are green facades, increasingly used to improve the energy efficiency of new buildings and the bioclimatic comfort of urban settlements. Through biomimetic studies, innovative solutions are being proposed, from the use of living biological systems (e.g. bio-reactive facades) for climate control to new natural materials (e.g. metal-sensitive wooden sheets) that react directly to external factors such as light, heat, humidity, opening and closing without the use of energy or mechanical aids. All these systems contribute to improving the energy efficiency of both buildings and the urban system in which they are located. The contribution aims to examine technological solutions based on biomimetic methodology, to assess their applicability in the retrofitting of existing buildings.

Keywords: *biomimetic, energy efficiency, retrofitting*

1 Introduction

Biomimicry' is a subject that has recently entered the world of architecture and building construction, as a result of the need to improve the comfort of buildings and to optimize the energy performance and behavior of buildings in cities, thanks to the help of nature. One of the main innovators of biomimicry is the American Janine Benyus, founder of the Biomimicry 3.8 Institute in Missoula, Montana, with the book "*Biomimicry: Innovation Inspired by Nature*". [1]

In her book she describes in detail how science is studying the best ideas of nature to solve the most difficult challenges of our millennium. *"Biomimicry opens an era based not on what we can extract from nature, but on what we can learn from it. This shift from learning about nature to learning about nature requires a new method of investigation, a new set of lenses and, above all, a new humility.".*

Biomimetics is a branch of technology that is used in multidisciplinary fields: biomimetic architecture is therefore only one of these branches. Biomimetic architecture is a contemporary architectural philosophy that seeks solutions for sustainability in nature, not by replicating natural forms, but by understanding the rules that govern them. Over the decades, the field of biomimicry has shifted from looking at nature as a form to a more functional vision, trying to replicate its processes and systems.

Moreover, two main levels of analysis can be identified: the study of the behavior of the individual organism or of a part of it, and the study of the ecosystem in which it is inserted, with the modes of exchange and collaboration that are triggered in the process. There are therefore many variations in reference to architecture: the use of vegetable elements integrated in buildings, the application of a technology, derived from nature, that is applied to buildings or parts of them, the definition of architectural forms that reproduce behaviors of vegetable or animal organisms, and so on. There is the possibility for architects to learn more deeply from nature and to use biomimetic materials and technologies in better buildings in the near future.

2 Biomimicry for architecture

As far as architecture is concerned, there is a movement called 'Living Architecture' [2], which focuses on the integration of natural elements and processes with the building. These processes are manifold and include, for example, the collection, storage and filtration of water, the exploitation of sun and wind energy, water microfiltration processes and nutrient treatments. To implement the idea of a living organism in a building, the system must be seen as a complex system, in which all parts interact and combine to form a whole. Consequently, the technological elements must be thought of as parts that interact with the natural ones. Biomimetic architecture includes this branch of 'Living Architecture' as it focuses on understanding the systems and processes of natural forms. This understanding can be used in two different ways: the first finds an example in nature and imitates it in a new project, while the second finds in nature the example that best suits the design needs.

The concept of Living Architecture is important because, among all the benefits, it considers the positive effects on health deriving from contact with living systems in the built environment. [3]. The Living Architecture tradition was born in Berkeley, California, with Christopher Alexander as the main protagonist and from there many followed in his footsteps [4].

The levels of a biomimetic analysis are different depending on the purpose of the study. "*Integrating the understanding of the functioning of the living world and ecosystems into architectural and urban design is a step towards the creation and evolution of radically more sustainable and potentially regenerative cities*". [5]. Zari also stresses the importance of human beings as decision-makers, in fact he says: "Human beings are undoubtedly effective ecosystem engineers, but they can gain valuable insights by observing how other species are able to change their environment while at the same time creating a greater capacity for life in that system.”

3 Urban sites and Vertical Green Walls

The best known and most used example of Living Architecture's biomimetic approach is green facades, which are increasingly used to improve the sustainability and efficiency of new buildings and, at the same time, improve the bioclimatic comfort of urban settlements. According to recent studies, Green Walls Systems (GWS) help buildings become more energy efficient and reduce carbon emissions. They also mitigate the Urban Heat Island (UHI) effect as facades absorb and filter rainwater, reduce pollution and act as carbon receptors. These systems, if properly designed, also preserve the biodiversity of the city's plants and animals, acting as attractive oases for many species. We briefly describe the main benefits of a green façade in an urban system.

3.1 Urban Heat Island

The urban heat island effect is defined as a metropolitan area or place within a city that has a higher temperature than the surrounding environment; in particular, (in full "urban heat island") an urban area that has a higher temperature, due to the generation of heat by vehicles, emissions due to the energy consumption of the buildings present, and the absorption of sunlight by surfaces that overheat such as asphalt roads or facades and roofs of buildings. This problem has long been documented [6] and its effects on the environment are not negligible. Much of this heat comes from overheating the multitude of dark surfaces in urban areas, which consequently radiate the accumulated solar energy. Numerous studies show that vegetation reduces this effect and the negative impacts that this phenomenon has on the quality of life, for example for life comfort inside of the buildings or health problems for children or oldest people during hot summers. Mitigation strategies of urban heat islands, such as trees, vegetation and green roofs or walls, are the subject of extensive research and generally offer benefits throughout the year.

3.2 Re-use and storage of rainwater

A critical issue in highly urbanized areas is the collection and removal of rainwater, especially in the event of particularly violent events. Green walls, but above all green roofs, naturally absorb and filter rainwater. The water can also be filtered and recycled for non-drinking uses, for example to irrigate the facades themselves. Vegetation has micro-filtering elements, such as roots and microorganisms that use and remove pollutants from the water. Excess water is then eliminated through the process known as evapotranspiration. In recent years, the combined use of vertical green structures and green roofs has increasingly been adopted as a "bioclimatic" project to integrate (or partially replace) urban drainage systems, with studies on the effectiveness of green systems for rainwater collection. Most always consider the combination of green roof and vertical facade and not just the Green Wall System. [7]

3.3 Indoor Air Quality

According to modern scientific research [8] indoor environments can be ten times more polluted than the outdoor environment, due to the gradual release of substances contained in building materials: this is known as "*Sick Building Syndrome*". A major study [9] states that the person spends, on average, more than 90% of their time at home. During this period people suffer the consequences of indoor air pollution which includes: toxic emissions such as formaldehyde, VOC, trichloroethylene, carbon monoxide, benzene, toluene, xylene, xylene and countless others [10]. The solution to the problems listed below can be found in plants. As the vegetation grows, it absorbs greenhouse gases from the atmosphere and stores them in their tissues. According to a study [11] all plants absorb and clean the air of pollutants, the effectiveness depends on the species, some are more efficient than others, and on the quantity of plants. A green wall can contain more than a thousand plants: they all filter the air and create oxygen. The use of GWS indoors also brings many benefits for users, as it raises the level of perceived comfort.

3.4 Biodiversity

Modern cities and cultivated land have greatly reduced the biological diversity present on planet Earth. A possible remedy can be found in the Living wall systems (LWS) which can be considered as a replica of vertical natural habitats. According to a study published in the journal Global Ecology and Conservation [12] the potential of LWS is enormous. The outer living walls can be seen as mini ecosystems: the incorporation of such a variety of plant species attracts many organisms and insects such as butterflies, bees, ladybirds and hummingbirds. *"Cities must become a key player in global efforts to conserve and restore biodiversity. At the same time, if the goal of urban design is to create or adapt cities so that they support people's well-being, the support and regeneration of urban biodiversity must be integrated into decision-making and design interventions."* [13]

3.5 Building protection

A green wall acts with a dual function: in summer it is a sort of barrier that protects the building from solar radiation and heat, thus limiting the use of energy required by the use of cooling systems. In winter, on the contrary, the walls and the substrate provide an additional layer of insulation that further isolates the building from the cold. These characteristics of LWS act to reduce the carbon footprint of a building [14], reducing temperature fluctuations in the casing. The green wall panels and the outer shell are separated by a layer of air that allows the building to "breathe". The system is very similar to rain shielding technology, which keeps rain away from the building while allowing moisture to escape. Covering an exposed vertical surface with a green wall protects it from precipitation and wind, harmful UV rays and corrosive acid rain.

3.6 Financial Added Value

The green improves the visual, aesthetic and social aspects of an urban area and, in addition to improving health and quality of life, also has a strong influence on the economic value of a building or a neighborhood [15]. Today, people are looking for healthy green spaces where they can live, even in the city. The trend confirms this research, in fact, prices are rising precisely for homes or offices in complexes that have more green space. This is a long-term investment and the initial costs of implementation should not lead to underestimate the long-term returns and profits not quantified in purely economic terms, in the implementation of the green.

3.7 Reduction of energy consumption

It has been shown that the temperature of an exposed surface of a green wall is significantly lower than the temperature it would reach if it were made of plaster or cladding panels. [15]. Research has shown that, for example, in humid Hong Kong climates, they can achieve a maximum temperature drop of 8.4 °C [16]. On the contrary, in the summer period, the effect of shading leads to important savings. According to a study by the National Research Council Canada [17] the shading effect of vertical green systems reduces the energy used for cooling by about 23% and the energy used by fans by 20%, resulting in an 8% reduction in annual energy consumption. This is also partly due to the process known as transpiration. Plants cool the surrounding environment slightly. With each additional plant this increases and therefore a green wall, with hundreds of plants, can reduce the temperature of a room from 3 to 7 °C [18]. According to a study conducted by the University of Seville [19] the cooling effect of the living wall was demonstrated, with an average reduction of 4°C compared to room temperature, even if in warmer conditions maximum decreases of 6°C were observed. During the winter, some living wall systems serve as additional insulation. There is an additional layer of air between it and the wall that reduces the amount of heat that escapes and the cold air that enters. Vertical green layers reduce also wind speed by stagnating around building facades.

3.8 Health and Well-being

Urban greenery is recognised as a remedy to stress reduction in a large number of publications and research documents confirming its benefits [20]. Three important factors that are highlighted [21] are: a) distance, the closer open green spaces are to one's home, the more often one visits them; b) time, spending time outdoors in open urban green spaces seems to be the most important factor influencing stress levels; c) accessibility, a home with direct access to a green courtyard or its own garden seems to be the optimal situation. The use of Vertical Green Walls on tall buildings, can be the first factor, brings close to homes or offices plant elements, with careful design can also make them accessible and attractive.

3.9 Aesthetic Improvement

When visiting the botanical gardens, walking in a park or walking through a forest, it is easy to see that nature has created a wide variety of colors, textures, patterns and sizes. Using this diversity and incorporating many plant species you can create works of art. Architect Luciano Pia has created a building that is living and green art, in his 25Verde. The example of a biomimetic approach to design that created a surprising result: the architect used the knowledge of botanists in the selection of plant species and integrated them harmoniously inside and outside the building complex. Designing a green wall that is different, captivating, intriguing and simply a pleasure to look at is a complex task. It requires strategic planning, in-depth knowledge of countless plant species, a strong eye for design.

3.10 LEED Credits

Considerations on the design of green and living walls are discussed in USGBC courses[22]. Vertical Green Wall design can be used to earn additional LEED® credits. LEED® (Leadership in Energy and Environmental Design) is an internationally recognized green building certification system. The use of this type is very important for the environment and the agency promotes it with extra LEED® credits. Using Living Wall System directly qualifies 2 credits and helps you earn another 30 points.

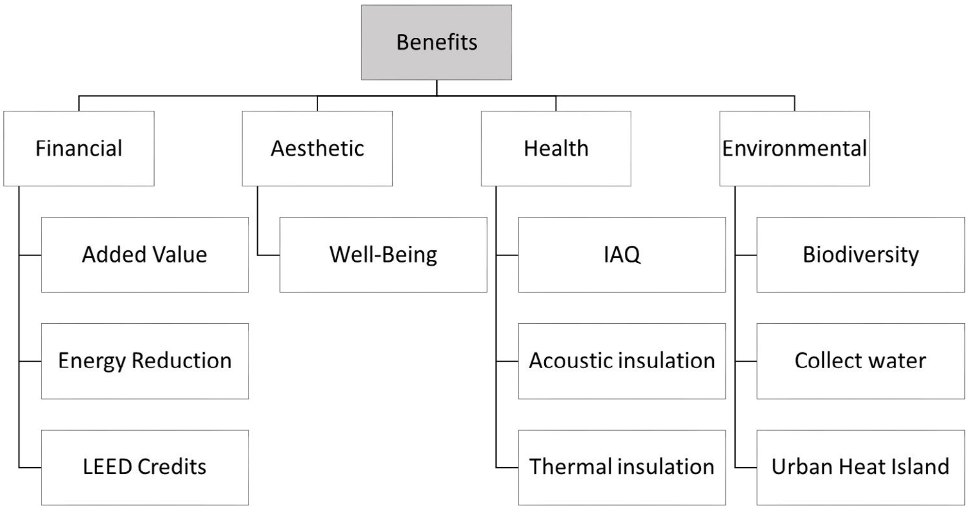

Fig. 1 *Overview of the benefits of using the Vertical Green Wall*

4 Biomimetic solutions evaluation method for retrofitting

There are several biomimetic solutions that can be used for retrofitting buildings in urban settings, to limit the criticality of urban areas and introduce the advantages listed above. The subdivision has been set according to: integrated vertical greening systems integrated in the architectural envelope, vertical greening systems juxtaposed with the perimeter wall of a building, external greening system.

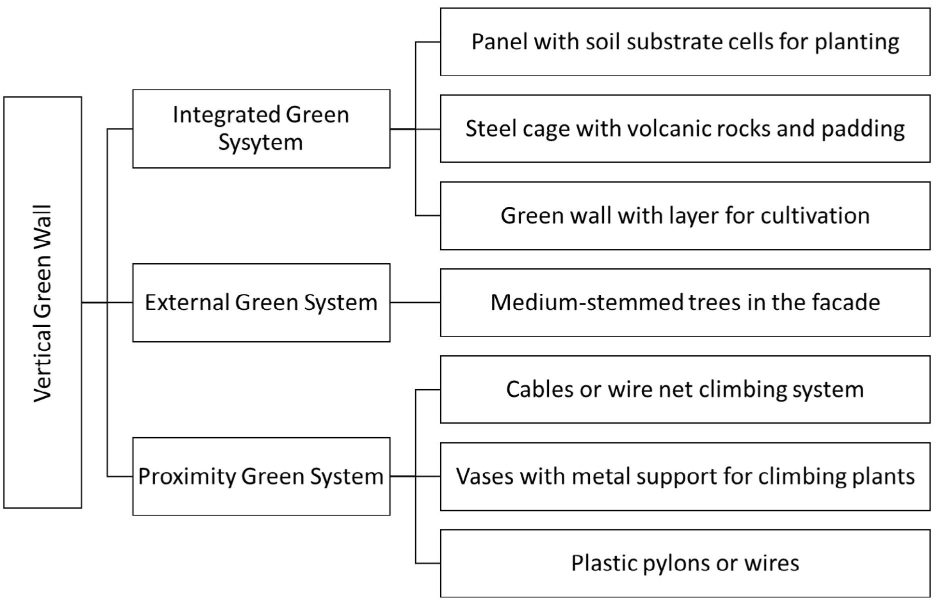

Fig. 2 *Overview of Vertical Green Wall*

4.1 Integrated Green System

Integrated systems of total or discontinuous vegetable coating of the facades of a building can be realized with different technologies: Panel with soil substrate cells for planting, Steel cage with volcanic rocks and padding, Green wall with layer for cultivation.

Fig. 3 *Panel with soil substrate cells for planting*

Fig. 4 *Steel cage with volcanic rocks and padding*

Fig. 5 *Green wall with layer for cultivation*

This type of living wall differs from the climbing facade in many respects but the fundamental is that they have roots for their nourishment in a special support and not in the ground. The walls are self-sufficient vertical gardens that are fixed to an independent frame either outside or inside a building. There are two ways to grow these walls: the soil-based substrate is the traditional way, while hydroponic growth is a more advanced technique that does not use the soil to provide the necessary nutrients to the plant but water [23]. From a functional point of view, compared to the adjoining green façade, most of these systems require a more complex design, as it is necessary to consider a greater number of variables, such as: the involvement of more layers, attention to the mechanism of water and nutrients, the supporting materials. [24]. The hydroponic system brings a new level of sustainability through intelligent water management and stable system dynamics. Plants are generally contained within discrete panels that contain an inert culture medium. Plants take root and anchor in the growing medium and each row of panels is irrigated and fertilized using precise pressure compensated drip technology. Careful attention must be paid to the design phase of the system. This is a delicate operation because the parameters of the site (location, appearance, adjacent characteristics) must be taken into account.

4.2 External Green System

The external systems contain some very significant interventions carried out in Italy in recent years. They consist of placing medium-sized plants on the various floors of the building in order to create the effect of a forest that develops vertically.

Fig. 6 *"Bosco Verticale" Arch. Stefano Boeri – Milano (IT)*

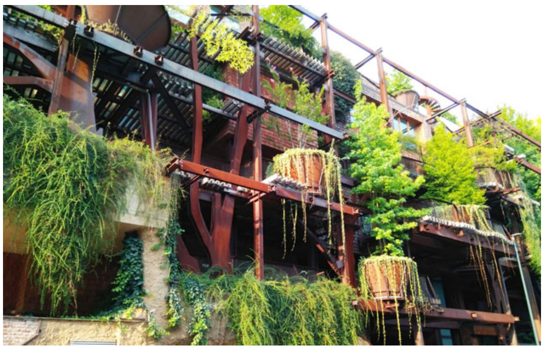

Fig. 7 *"25verde" building. Arch. Luciano Pia – Torino (IT)*

The system is particularly complex because it is necessary to have very large pots, therefore large areas and structures that support the weight of earth and trees. The positioning is outside, on balconies or terraces, and often there is a dedicated support structure. The images (Fig. 6 and Fig. 7) of Stefano Boeri's "Vertical Forest", which won the "Best Architecture in the World 2015" award, and Luciano Pia's "25verde" are reported, a striking example of how nature can be integrated with living systems, increasing the quality of life of the inhabitants.

4.3 Juxtaposed Green System

The juxtaposed systems of total or discontinuous vegetable coating of the facades of a building can be realized with different technologies: Cables or wire net climbing system, Vases with metal support for climbing plants, Plastic pylons or wires. The system uses climbing plants, or cascading plants, depending on the choice of the effect you want to give the facade and provides very simple and lightweight elements to be mounted as a support for growth. These are either modular panel nets, or plastic nets that can be adapted to the required surface or metal cables fixed to the main façade but detached from it to create a second external surface. The cables on the green facades are designed to encourage faster growth of climbing plants with thicker and denser foliage. Wire nets are often used to support slow-growing plants. This system is quite flexible and has a better degree of design applications than cables. Technologically, they work in the same way. Both systems use high-strength steel cables, anchors and additional equipment. [25]. The concept takes up what already happens naturally in many historical buildings, where climbing plants, such as ivy or wisteria, completely cover some facades, giving shows of colors and green movements.

Adaptability and lightness are the main features of these systems that offer significant advantages: protect the facade from sunlight, filter light and act as sunshades in summer, reduce overheating inside the rooms, bring the green near the windows of houses and offices. Depending on the plant species chosen, the system may change over the course of the seasons. With deciduous plants, the behavior is reversed in the winter seasons, allowing the sun's heat to reach the façade and enjoy the free heat storage.

Fig. 8 *Cables or wire net climbing system*

Fig. 9 *Vases with metal support for climbing plants*

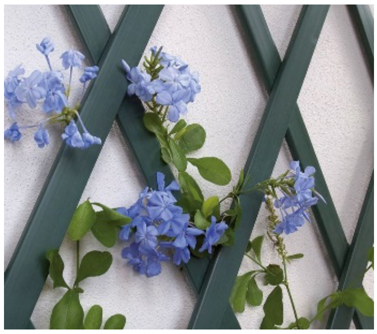

Fig. 10 *Plastic pylons or wires*

All these systems contribute to improving the energy efficiency of both buildings and the urban system in which they are located. This survey of technological solutions based on biomimetic methodology could be used in the retrofitting of existing buildings. The Vegetable Shading System improves the energy performance of the building but the design depends on the solar path based on the orientation, location in the urban context and available space. Often these solutions are used together, depending on the type of facade and the final effect that the designer wants. A summary table proposes some reflections based on some parameters: easy installation, modularity of the system, light control, strength and durability.

Tab. 1 *Comparison between different Vertical Green Wall solutions*

Vertical Green Walls		**Easy installation**	**Modularity of the system**	**Light control**	**strength and durability**
IGS	Panel with soil substrate cells for planting	✓	✓	✗	✓
	Steel cage with volcanic rocks and padding	✗	✓	✗	✓
	Green wall with layer for cultivation	✗	✓	✗	✓
EGS	Medium-stemmed trees in the facade	✗	✗	✓	✓
JGS	Cables or wire net climbing system	✓	✗	✓	✗
	Vases with metal support for climbing plants	✓	✓	✓	✗
	Plastic pylons or wires	✓	✗	✓	✗

We have chosen to give a score from 0 to 3 to classify the different solutions proposed, in order to give a useful tool to the designer for the most correct choice. Point are assigned strictly related to the technology analyzed before, in term of other factors determining the choice of the most suitable technology. Four main problems are discussed: the availability of water, the availability of land for planting, the level of biodiversity allowed by the chosen system, the area that can cover the solution.

Tab. 2 *Scale of use of the different factors (water, soil, biodiversity, area) according to the solutions illustrated*

Vertical Green Walls		**Water**	**Soil**	**Biodiversity**	**Area**
IGS	Panel with soil substrate cells for planting	2	0	3	2
	Steel cage with volcanic rocks and padding	2	0	3	3
	Green wall with layer for cultivation	3	2	2	3
EGS	Medium-stemmed trees in the facade	3	3	3	3
JGS	Cables or wire net climbing system	2	3	1	1
	Vases with metal support for climbing plants	2	1	1	2
	Plastic pylons or wires	2	3	1	1

5 Conclusions

The analysis aims to provide a useful tool for designers in order to help them choosing the best technology according to the building and to the intervention area. The scores assigned are the result of the analysis of biomimetic technologies related to the context in which they can be installed, taking into account the main aspects that the various types of vegetation and planting require. Although, the support and advice of a botanist is essential because the choice of species and the compatibility between them ensures the durability of the entire system over time.

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This research is inspired by the thesis of Elio Fetolli, who dealt with the project of redevelopment of a building located in Turin, with technologies related to biomimicry. We would like to thank Elio and Prof. Carlo Caldera, one of the thesis advisor.

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