

Article

The Role of Building-Integrated Greenery Systems in Building Sustainability Rating Systems

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Abstract: Building rating systems allow for the evaluation of environmental buildings' impact throughout their lifecycle, thereby enabling improved design. The integration of vegetation into building envelopes, through green roofs and facades, provides multiple benefits that enhance the sustainability of a built environment. In arid climates, Building-Integrated Greenery Systems (BIGSs) contribute to energy savings and the improvement of the urban environment through evaporative cooling. However, the maintenance of these green systems requires efficient water use. This study thoroughly reviews six selected building sustainability certifications to determine the extent to which BIGSs are considered in the certification process. The findings indicate that BIGSs are not yet well integrated directly into these certifications. While the certifications recognize the biophilic effects on users and contributions to sustainable construction, they often overlook scientifically proven benefits such as acoustic insulation and urban noise reduction. This study highlights the importance of updating certification frameworks to fully incorporate the diverse advantages of BIGSs, especially in enhancing indoor environments and achieving energy savings.

Keywords: nature-based solutions; green roof; green facade; sustainability certification



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1. Introduction

The building sector is one of the industrial sectors that most impacts the environment due to its significant consumption and extensive use of raw materials, contributing to approximately 50% of global carbon emissions [1], and it represented nearly 40% of the global energy demand in 2023 [2]. On the one hand, throughout the life cycle of a building, large quantities of materials, water, and energy are consumed, and an estimated 3 billion tons of construction waste are generated worldwide [3]. On the other hand, many pollutants are generated, usually related to manufacturing processes and the deposition of materials [4]. Moreover, water quality is substantially degraded, necessitating considerable efforts to return it to the environment at an acceptable quality level [5].

The impacts occur at all stages of a building's life cycle: (a) extraction of raw materials, (b) manufacturing and transport of construction materials, (c) building construction, (d) use and maintenance phases, (e) demolition, and (f) landfill deposition or recycling. Figure 1 illustrates these impacts throughout the life cycle [6].

With the aim of reducing the environmental impact of the building sector, building sustainability certifications have been developed, which allow the environmental impact of a building to be analyzed throughout its life cycle. Also known as green rating systems, these are methodologies for assessing the sustainability of buildings, and they primarily consider the following features: (1) site, (2) water, (3) energy, (4) comfort and safety, (5) materials, and (6) outdoor quality [7,8].



Figure 1. Life cycle of a building [6].

The use of building certifications can benefit cities by promoting the development of buildings that offer more than just livable spaces. These buildings can also be energy-efficient, reduce negative impacts, and improve the urban environment. One example of a certification program is Leadership in Energy and Environmental Design (LEED), which declares in its mission and vision that “certified buildings can save money, improve efficiency, reduce carbon emissions, and provide healthier environments for people” [9]. Certifications provide different frameworks around the world for creating highly efficient and cost-saving buildings that can bring new solutions for the urban environment while also helping investors achieve their Environmental, Social, and Governance (ESG) goals.

With the aim of achieving the highest score in sustainability certifications during the building design phase, architects and engineers seek construction systems that provide the necessary benefits to obtain the specified credits in the different categories of the certification systems.

Among others, the systems integrating vegetation into the building envelope, primarily green roofs and facades, provide multiple benefits at both the building and city scale [10].

At the building scale, Building-Integrated Greenery Systems (BIGSs) provide thermal insulation and energy savings [11–15], enhance indoor thermal comfort, contribute to the acoustic insulation of a building [16–20], protect building materials from climatic influences, and increase the value of the properties by improving their appearance and aesthetics [21]. At an urban scale, most commonly demonstrated benefits include the following: a reduction in the urban heat island effect [22,23], control of stormwater runoff [24–28], support for biodiversity in the city [29–33], purification of air and runoff water [34–40], a reduction in urban noise and urban agricultural production, and an improvement in public health through biophilia effects [41–43].

Green roof and facade systems are fully developed and regulated, and they are increasingly being used as an architectural option. There are international standards, such as the Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) guidelines [44], which regulate the technical aspects of these innovative construction systems. Additionally,

there are multiple platforms and professional associations linked to the BIGSs sector, such as the World Green Infrastructure Network (WGIN) [45] and greenroofs.com [46]. It can be stated that the BIGS sector is fully consolidated worldwide.

The benefits of BIGSs have been widely studied and discussed in a quantitative manner, establishing significant sustainability benefits in various urban environments [10]. This work aims to specify the most relevant benefits in the context of arid or semi-arid climates that align with the aspects to be measured in sustainable construction certification processes.

In arid and semi-arid climates, the strategy of integrating vegetation into the built environment poses a significant challenge and generates contradictions for decision makers. On the one hand, re-naturalizing the built space by incorporating vegetation contributes to the improvement of the urban climate, largely due to evaporative cooling. Additionally, these systems are known to contribute to the capture of rainwater. On the other hand, survival of the vegetation requires water consumption, which can present a significant challenge for urban managers.

In the study conducted by Mousavi et al., 2023 [47], the focus was directly on semi-arid climatic conditions and on addressing the optimization of residential buildings to improve energy efficiency and comfort. In semi-arid climates, where temperature control and efficient energy use are critical due to high temperatures and climatic variability, the focus on optimizing the building envelope is particularly relevant for enhancing sustainability and quality of life.

Although the study performed by Robbiati et al., 2023 [48] focused on green roofs as a solution to mitigate climate change and enhance biodiversity, their work's applicability in arid and semi-arid climates is noteworthy. In these regions, green roofs can provide thermal insulation, reduce cooling loads in buildings, and contribute to water management by capturing precipitation, although the selection of plants and irrigation systems must be adapted to water scarcity conditions.

In the study conducted by González-Méndez and Chávez-García, 2020 [49], the design of technosols (a group of soils with properties dominated by their technical origin) to support vegetation systems in urban environments can be especially useful in arid and semi-arid climates, where natural soils may not be sufficient to sustain vegetation. This research is relevant for improving green infrastructure in cities in these areas, promoting the creation of green spaces that help mitigate the urban heat island effect and improve air quality.

In the research study of Abdeen and Rafaat, 2024 [50], interior green walls can have a significant impact on air quality and thermal comfort in any climate, but in arid and semi-arid climates, where building cooling is a major challenge, these systems can offer additional benefits in terms of thermal insulation and improvements of the indoor microclimate.

Reyes et al., 2016 [51] studied the efficiency of green roofs with varying substrate depths and roof layers, finding important implications for arid and semi-arid climates. Green roofs in these regions can effectively reduce indoor temperatures, improve energy efficiency, and reduce the need for artificial cooling.

Carlucci et al., 2023 [52] focused on evaluating and monitoring a green wall in a semi-arid Mediterranean climate. Their research addressed the lack of field data and plant selection guides for green walls in such climates. They provided a comparative analysis between a living modular green wall and a reference facade without vegetation. Results indicate a significant decrease in air temperature (up to 8 °C), a reduction in sound pressure (up to 5.1 dB), and a consistent increase in relative humidity behind the green wall. Additionally, thermography revealed surface temperature differences of up to 27 °C, demonstrating the greater cooling efficiency of walls with higher leaf area density. This study provides evidence that green walls can protect building facades from solar radiation and high temperatures, reducing energy requirements for space cooling, which is crucial in semi-arid climates where heat management and water conservation are critical.

In summary, for arid and semi-arid climates and environments, studies have suggested that BIGSs primarily contribute to energy efficiency due to the thermal insulation they provide and their ability to retain rainwater. Additional benefits in these climates include improvements in biodiversity and enhanced indoor climates, which increase comfort sensation. However, the focus for arid or semi-arid environments remains on water retention and energy efficiency.

The incorporation of BIGSs can significantly contribute to improving the outcomes of building sustainability assessments, either directly or indirectly. The benefits of BIGSs can assist investors in selecting projects with substantial sustainable impacts. To make informed decisions, it is important to quantify and qualify the value that BIGSs can provide. These benefits can be aligned with environmental certifications in buildings, enhancing ratings and increasing certification levels. However, the criteria and scoring of different benefits from BIGSs in green building rating systems can influence stakeholders' decisions to implement new green technologies. Insufficient scoring makes BIGS technology less attractive to develop [53]. Additionally, the indirect scoring of benefits from greenery systems does not create direct value for stakeholders and may shift attention to other types of green projects.

For certification entities and assessment tools, BIGSs offer the possibility to incorporate a variety of sustainable construction technologies. Not only can BIGSs provide an aesthetically pleasant environment, but they also offer significant direct ecosystem services such as increased energy efficiency, noise reduction, support for urban agriculture, CO₂ sequestration, etc. Additionally, stakeholders can receive more value from a certificated building as rental fees can increase. Therefore, it is important for certifying entities to consider all these benefits to promote new developments in sustainable construction and the renewal of the urban environment.

This study aims to evaluate the importance of BIGSs in various sustainability rating systems. It seeks to determine if current certification systems adequately recognize BIGSs as crucial for enhancing building and city sustainability, particularly in arid and semi-arid climates. Special attention is given to the impact of BIGSs on the urban environment and efficient water use. By examining weightings, this study assesses the value of accreditation systems for buildings with BIGSs in these climates.

For this purpose, a literature review was conducted on research articles considering vegetation integration systems in building envelopes to improve building sustainability assessments.

Additionally, a thorough review of six certification systems was carried out, and a matrix of percentage values was prepared. This matrix allows for observing whether there is a direct contribution of BIGSs to the overall process of sustainability evaluation. Given the complexity of building sustainability certification process, the matrix also identifies if BIGSs contribute indirectly to sustainability improvements.

The results of these two review processes have made it possible to determine the importance or weight that BIGSs currently hold in building sustainability certification systems and to identify which certification system best reflects the contribution of BIGSs in arid or semi-arid environments.

This article is structured by reviewing the most relevant certification systems for city-level constructions that value the benefits related to BIGSs. With this information, the potential score that can be obtained for each certification system through the presence of BIGSs in both biophilia and sustainable construction aspects was detailed. The main results are presented in a summary table that highlights the direct contributions that BIGSs make to the certification processes. The indirect contributions of BIGSs are also included, whereby the rating systems that value the contributions of BIGSs in arid climate environments more are identified.

2. Materials and Methods

The research process was structured in four main steps, which are graphically summarized in Figure 2.

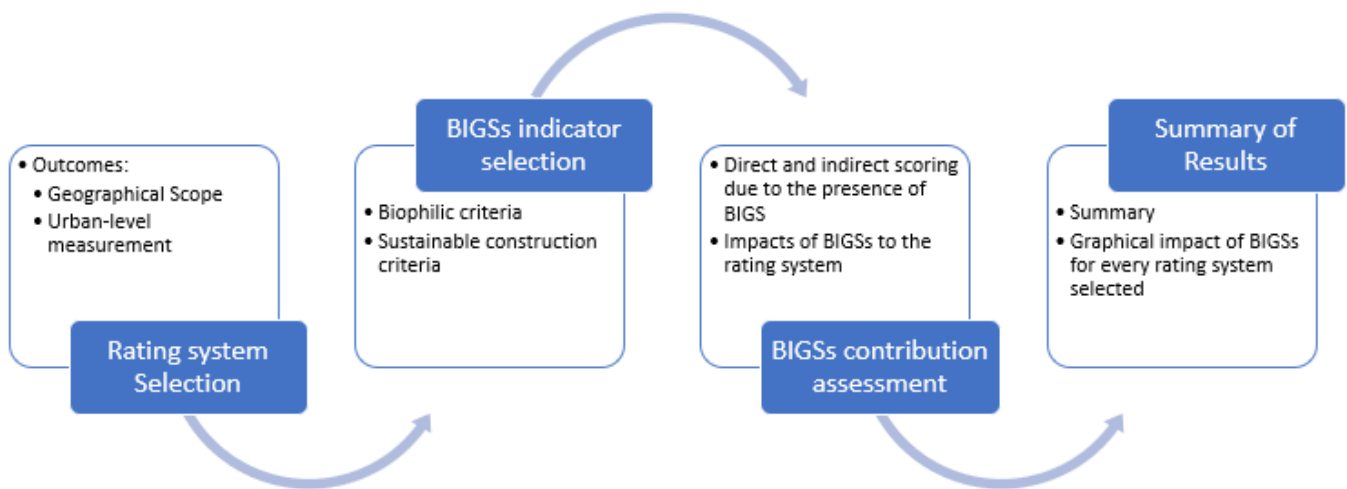


Figure 2. The research process, main stages, and expected outcomes for determining the contribution of BIGSs to certification systems.

Step 1. Rating system selection

The first step was related to the certification selection. Globally, there is a wide range of building certification systems that promote sustainable development, some having a greater or lesser presence, and in some cases, multiple certifications coexist within the same country. These systems have been created to assess various aspects of sustainability in the construction sector. Generally, the certification process involves meeting several requirements during the certification process, followed by a verification process that ultimately generates the certificate representing the building's official certification. An example of this wide variety of rating systems is presented in Table 1.

Table 1. Certification by country (adapted from [54]).

Country	Building Rating System
Australia	Nabers/Green Star/BASIX
Brazil	AQUA/LEED Brasil
Arab Emirates	Estidama
Canada	LEED Canada/Green Globes/Built Green Canada
China	GBAS
Philippines	BERDE/Philippine Green Building Council
Finland	PromisE
France	HQE
Spain	VERDE
Netherlands	BREEAM Netherlands
Hong Kong	HKBEAM
India	Indian Green Building Council (IGBC)/GBCIndia/GRIHA
Indonesia	Green Building Council Indonesia (GBCI)/Greenship

Table 1. *Cont.*

Country	Building Rating System
Japan	CASBEE
Jordan	Jordan Green Building Council
Qatar	QSAS
Korea	Green Building Certification Criteria/ Korea Green Building Council
Malaysia	BBi Malaysia
Mexico	LEED Mexico The Green Business Certification Inc. (GBCI)
Germany	DGNB/CEPHEUS
New Zealand	Green Star NZ
Pakistan	SEED—Specific Green Building Guideline (Pakistan Green Building Council)
Poland	Green house (Polish Green Building Council (PLGBC))
Portugal	Lider A/SBToolPT®
Czech Republic	SBToolCZ
Republic of South Africa	Green Star SA
Romania	Green homes (ROGBC)
Singapore	Green Mark
Switzerland	Minergie
Thailand	TREES
Taiwan	Green Building Label
Turkey	CEDBIK
US	LEED/Living Building Challenge/Green Globes/Build it Green/NAHB NGBS/International Green Construction Code (IGCC)/ENERGY STAR
United Kingdom	BREEAM
Vietnam	LOTUS Rating Tools
Italy	Protocollo Itaca/Green Building Council Italia
European Commission	LEVELS

Certification systems have evolved into different versions over time. Many of them have certification projects in various parts of the world and sometimes use the same principles and rating scales, while in other cases, they have developed variants to address the specific aspects of certain countries or regions. Examples of this presence on different continents include Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), Haute Qualité Environnementale (HQE), World Green Building Council (WGBC), and Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), whose projects span different regions, countries, cultures, and climates.

The LEED certification system is implemented in various parts of the world, with projects present on all continents. Given its origin in the USA, the largest proportion of projects with this certification are found in that region. However, it is possible to find LEED certification projects in practically all regions of the world [55]. For example, in India, the ‘LEED India’ system has been developed, which reflects the specific construction needs of the country and has many similarities with LEED 2009 NC [56]. On the other

hand, academic studies have explored the possibilities of constructions in the Middle East meeting LEED certification [57].

BREEAM is also a global certification with projects on several continents. Much of its expansion is due to the existence of specific variants for some countries and programs adapted to be interpreted according to local needs. In arid climate countries, BREEAM certification has been adopted, as well as in other regions facing extreme climatic conditions. For example, Saudi Arabia and Lebanon have implemented BREEAM [58] to promote sustainable construction practices that address energy efficiency and water management, which are crucial in these environments. Additionally, some parts of Australia [59] have used adapted BREEAM alongside other local certification systems to improve sustainability in their construction projects.

Although the HQE certification was developed in France, it has also developed several schemes to be used globally. The association that controls this certification has three entities responsible for evaluations at the national level (Certivèa, Cerqual, and Cèquami) and one entity (Cerway) for global evaluations [60]. It has a presence on almost all continents, but its presence is smaller compared to LEED or BREEAM. Nonetheless, the countries with HQE-certified projects are very diverse, including Morocco [61], Canada, France, Algeria, Qatar, Russia, Peru, etc. Approximately 26 countries from different regions, cultures, and climates have projects with this certification [62].

The WGBC is a global organization that brings together Green Building Councils from around the world. It has a presence in the Americas, Europe, the Middle East and North Africa (MENA), the Asia-Pacific region, and Africa [63]. For example, in Jordan, there is the Jordan Green Building Council (Jordan GBC) [64], and in Egypt, there is the Egypt GBC [65], which has the mission to promote sustainable practices in the construction sector. In Europe, you can also find associations like the Green Building Council España (GBCe) [66].

The DGNB certification has evolved since 2008 with annual updates, allowing for the certification of buildings both in Germany and internationally. In 2010, an international version of DGNB was launched, and it was adapted to the different uses of buildings and the specific needs of each country. Thanks to its flexibility, several countries have been able to adopt it, such as the Baltic region countries [67], Austria, Switzerland, Bulgaria, Slovenia, and China [68].

Step 2. BIGS indicator selection

Each sustainability certification system is structured differently. In this step, work was carried out to identify in which category of each certification the contribution of BIGSs is considered and to what extent; specifically, the credits assigned to this contribution was investigated.

Step 3. BIGS contribution assessment

The third step was to determine the score as a percentage of the total assessment that can be obtained in the certification process if BIGS infrastructure is present.

In this research, a distinction was made between the direct contribution of BIGSs and the indirect contribution of BIGSs to the sustainability level of a building. Some certification systems directly consider the presence of BIGSs in their scoring tables, while others do not; these additional scores were also identified. Additionally, other scores were analyzed and are presented as an indirect benefit of the certification process, which was carried out because the benefit was not explicitly stated in the selected rating system.

Step 4. Summary of results

The last step involved processing the results obtained and presenting them in a summarized form, i.e., as tables (results matrix) and graphs (radar charts), to collectively observe the contribution of BIGSs to the sustainability of buildings across different sustainability certification systems.

The matrix of results also shows the percentage of additional points that BIGSs can add to specific certification systems when considering the direct benefits for the certification process. This results matrix also presents other benefits that can be considered indirectly in the certification processes as they are sustainable benefits that BIGSs can also contribute to these processes.

Finally, the direct contributions are graphically presented for each certification system, with the aim of visualizing the specific percentage contribution that the BIGSs provide.

3. Results

3.1. Certification Systems Selection (Step 1)

To assess the contribution of BIGSs to building sustainability certification, six different organizations that provide the building certification services were selected: LEED, BREEAM, GBC, DGNB, Green Star, and HQE.

These rating systems were chosen for their long-standing local or regional influence [69] and for their common use of scoring systems to issue certifications. In having a global reach and not being necessarily tied to a specific country or a specific metric (for example, when accounting for carbon emissions avoided), these systems can analyze different climates, societies, and cultures.

The selected certification systems provide criteria to assess the various impacts of a property, allowing for the evaluation of different aspects of sustainability, such as environmental, social, and economic impacts. They can be incorporated from the building planning stage and also during the operational phase of the building. The certifications should not only increase the value of the buildings, but also confirm that the project has utilized solutions for a better living environment, promoting the synergy of environmental, social, and economic value [54].

The six selected brands are represented in Table 2, which also shows their web sites, logos, and countries.

Table 2. Selected building rating systems.

Brand Name	Country of Origin	Logo	Website
BREEAM	UK		https://bregroup.com/products/breeam/ (accessed on 22 July 2024)
LEED	USA		https://www.usgbc.org/leed (accessed on 22 July 2024)
GBCe	Spain		https://gbce.es/ (accessed on 22 July 2024)
DGNB	Germany		https://www.dgnb.de (accessed on 22 July 2024)
GREEN STAR	Australia		https://new.gbca.org.au/ (accessed on 22 July 2024)
HQE	France		https://www.hqegbc.org/ (accessed on 22 July 2024)

Below, the six building sustainability rating systems selected for this study are described. It is very important to consider the particular characteristics of each certification system. This consideration is crucial for interpreting the results regarding the contribution of vegetation integration systems, such as green roofs and facades, to the sustainability evaluation process.

3.1.1. BREEAM [70]

The BREEAM (Building Research Establishment Environmental Assessment Method) was the first and best-known performance assessment system developed in the UK by researchers from BRE (Building Research Establishment) and the private sector. This system assigns a performance certification directed at the marketing of buildings and, indirectly, of designers and entrepreneurs.

Through a checklist, the service of minimum items of performance, design, and operation of buildings are verified, and environmental ratings are attributed. These ratings are then weighted, and a unique number is reached. After meeting a minimum rating, the index enables certification in one of BREEAM's performance classes, and it allows for a relative comparison between buildings certified by the system.

BREEAM is based on document analysis and verification of systems utilized, as well as being one of the only methods that include environmental management aspects in lending to a more transparent and accountability-focused assessment process.

International versions of BREEAM have been adapted to the conditions of Canada and Hong Kong, aiming to prioritize the aspects of regional relevance in the evaluation. Other versions have been, and some still are, developed in Denmark, Norway, Australia, New Zealand, and the United States.

BIGSs, specifically green roofs, can significantly contribute to sustainability rating systems like BREEAM, particularly in areas related to energy efficiency, water use, pollution reduction, land use, and ecology.

BREEAM highly values green roofs for their ability to mitigate the effects of urban development on the natural water cycle and for their thermal performance, which can reduce the energy consumption for heating and cooling buildings. These factors are directly aligned with various BREEAM criteria focused on energy efficiency, water management, the health and well-being of occupants, and reducing environmental impact [71].

Green roofs can contribute to achieving advanced BREEAM accreditation, due to their ability to provide runoff attenuation in areas sensitive to flooding, while maintaining the aesthetics of green roofs. This implies that the implementation of BIGSs can be an effective strategy for enhancing a building's sustainability and meeting BREEAM criteria [72].

3.1.2. LEED [73]

The development of LEED (Leadership in Energy and Environmental Design) began in the United States in 1996 with the goal of facilitating the transfer of environmentally responsible construction concepts to U.S. construction professionals and industry, as well as to provide market recognition for efforts made toward that end.

The environmental performance of a building is assessed globally throughout its life cycle in an attempt to consider the essential precepts of what would constitute a "green building".

Like BREEAM, this system also contains a checklist that allocates a rating for meeting the pre-established criteria. Essentially, these are the design, construction, or management actions that contribute to reduce the environmental impacts of buildings.

BIGSs are a sustainable practice that positively contributes to LEED certification criteria. Green roofs help improve the energy performance of buildings by reducing the thermal load, which is an important component in LEED's sustainability and energy efficiency criteria. Additionally, they contribute to rainwater management and reductions in the urban heat island effect, aspects that are also valued in the LEED scoring system [74].

3.1.3. GBC [63]

The Green Building Council (GBC) is an international consortium formed with the aim of developing a method to assess the environmental performance of buildings through a standardized evaluation protocol that respects technical and regional diversities.

The GBC differentiates itself as a new generation of assessment systems, developed specifically to reflect the different priorities, technologies, construction traditions, and even cultural values of different countries or regions within the same country.

To ensure that the results adhere to local particularities, the GBC establishes reference performances, and the evaluation teams are encouraged to indicate the best weighting between the impact categories for each case.

BIGSs contribute directly to several key categories within the certification system, as described below [75]:

1. Sustainable Sites: Green roofs are valued under credits related to mitigating the urban heat island effect. Specific points are available for properties that implement solutions to minimize this effect, both on surfaces not covered by buildings and on the roofs themselves. Green roofs help to reduce the surface temperature and thus contribute to reductions in the urban heat island effect.
2. Energy Efficiency: Research indicates that green roofs can improve the energy efficiency of buildings by providing additional insulation, which reduces the need for air conditioning and, consequently, energy consumption.
3. Rainwater Management: Green roofs are also important for sustainable rainwater management, helping to absorb and retain rainwater, which can minimize runoff and improve water quality before it leaves the site.

3.1.4. DGNB [76]

The DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) system is based on three main factors: the life cycle, holistic approach assessments, and emphasis on performance. This system focuses mainly on new constructions because it works very well in acting on projects and on the work phase. Created in Stuttgart, Germany, in 2007, by a non-profit organization called the “German Sustainable Building Council”, it now operates not only in Germany, but also on practically every continent.

As a system that takes social and economic aspects fully into account, in addition to considering the sustainable aspects, it is one of the labels preferred among companies and their customers.

It also has the virtue of evaluating the cultural part of a building, taking into account its importance to the community. For these reasons, it is considered one of the most complete systems in the world and the most complete in Europe.

The experience of a green roof located in the city of Kosice in Slovakia shows how its implementation in this building plays an important role in achieving this certification, demonstrating how nature-based solutions can be integrated into the DGNB’s sustainability criteria. The roof design includes insulation layers, a waterproof membrane, and a drainage layer, which is covered by vegetation that not only improves the building’s thermal efficiency, but also contributes to other aspects of environmental sustainability recognized by DGNB [77].

3.1.5. Green Star [78]

With the aim of developing the sustainability industry in Australia, the Green Building Council of Australia (GBCA) was launched in 2002. It is a non-profit institution, and in 2003, GBCA launched its certification plan called “Green Star”.

Initially, GBCA had green legacy tools, and by the end of 2015, all these tools were superseded by a new set of green building rating tools. These tools include four green building rating tools for design: as built, interiors, communities, and performance. They also assess the sustainability of projects at all stages of a life cycle. The Green Star Performance tool assesses green buildings during their operational stage [79].

BIGSs, specifically green roofs, are directly involved in several sustainability criteria that are essential for Green Star certification. These include stormwater management and reductions in the urban heat island effect, both of which are relevant for enhancing the environmental sustainability of buildings [80].

These benefits are in line with the Green Star sustainability criteria, which assess and reward measures that reduce the environmental impact of buildings and improve the quality of life of their occupants.

3.1.6. HQE [81]

The evaluation system of the HQE (Haute Qualité Environnementale) [82] was chosen because France is a country that is in a very advanced situation in relation to sustainable building standards. In 2015, the French government passed a law making it mandatory for companies to build green roofs or use solar panels.

The HQE system is voluntary, and its certification focuses mainly on areas of social quality and respect for the environment, but it does not fail to assess the economy and development. There are two main models, industrial and residential, including both single-family and multi-family residential buildings.

The HQE certification considers the overall performance of buildings in key areas such as energy, environment, health, and comfort. Green roofs directly contribute to these aspects by improving energy efficiency (through thermal regulation of the building), effectively managing rainwater and enhancing air quality and overall well-being in the urban space. Additionally, it focuses on the integration of sustainable technologies in construction and efficient operations throughout the entire life cycle of the building [83].

3.2. BIGS Contribution Indicator Identification and Assessment (Step 2 and Step 3)

For each of the selected rating systems, different indicators were identified to describe the contribution of BIGSs to the sustainability of buildings. Additionally, the direct contribution of each indicator was calculated as a percentage of the total certification process, either referring to the benefits associated with the biophilia effect on the building's users and the built environment (biophilia effect), or to contributing to the improvement of the building's sustainability (sustainable construction).

For each rating system, it was determined whether green vegetative infrastructure points are present or not. Then, for the biophilic criteria, the weight of the indoor environmental quality, biodiversity, light quality, and air quality indicators that grant points due to the presence of BIGSs was determined. For sustainable construction criteria, where BIGSs contribute at the city level, the scoring of the water, pollution, energy, materials, and waste indicators was considered. In some rating systems, the aforementioned last two indicators appear as a single indicator, which will also be reflected in Table 3, where all the criteria and indicators are presented.

This allows us to observe which certifications consider the presence of BIGSs in the building at the time of certification and which do not. Furthermore, it also allows us to observe the contribution of BIGSs to benefits related to the biophilic effect and to a more sustainable construction.

The contribution of BIGSs to sustainability often occurs indirectly. Therefore, a list of indicators describing the indirect contribution of BIGSs to building sustainability has been compiled.

Table 3 provides a summary of the direct and indirect contribution of BIGSs to the six studied certification systems. The following section describes these contributions in detail for each system.

Table 3. Direct and indirect contributions of BIGSs to the six building sustainability certification systems studied. Summary of the scoring values.

			BREEAM (%)	LEED (%)	GBC (%)	DGNB (%)	Green Star (%)	HQE (%)
Green infrastructure (BIGSs)	Green roof and vertical greenery Systems		-	-	-	0.5	-	0.4
	Green roof	Green roof	-	-	-	0.7	-	0.4
Direct BIGS-related benefits	Biophilic criteria	Indoor environmental quality	0	14.5	10.1	8.4	10	22.8
		Biodiversity	6.2	1	0	1.2	6	3.4
		Light quality	0.9	4.5	2.7	-	4	3.1
		Air quality	-	7.3	3.6	5.4	4	4.2
	Sustainable construction criteria	Water	4.9	11	10.9	2.4	5	7.6
		Pollution	5.9	6.4	-	-	3	1.5
		Energy	4.1	34.5	25.5	3	10	7
		Materials and waste	-	7.3	12.7	2.4	24	-
		Materials	2.7	-	-	-	-	10.3
		Waste	-	-	-	-	-	2.6
		Green infrastructure	1.8	-	-	-	-	-
		Noise pollution	1.8	-	-	-	-	-
		Microclimate	1.8	-	-	-	-	-
		Water strategy	2.7	-	-	-	-	-
		Land use	2.1	-	-	-	-	-
		Ecology strategy	3.2	-	-	-	-	-
		Enhancement of ecological value	3.2	-	-	-	-	-
		Rainwater harvesting/management/use	1.1	2.7	1.2	-	-	3
Indirect BIGS-related benefits	Landscape		2.1	-	-	-	-	-
	Optimized energy performance		-	18.2	9	-	1	-
	Site development protecting or restoring habitats		-	1.8	-	-	5	-
	Heat island reduction		-	1.8	1.2	-	-	-
	Site management		-	0.9	-	-	-	-
	Site improvement plan		-	0.9	4.5	1.2	-	-
	Outdoor water-use reduction		-	1.6	-	-	-	-
	Thermal comfort		-	0.9	2.7	4.3	2	7.6
	Efficient irrigation system		-	-	2.7	-	-	-
	Access to open space		-	-	0.9	-	-	-
	Land use		-	-	-	2.4	-	-
	Potable water demand and wastewater volume		-	-	-	2.3	-	-
	Local environmental impact		-	-	-	4.7	-	-
	Creating special health conditions		-	-	-	-	-	2.5
	Quality of outdoor spaces accessible for users		-	-	-	-	-	3.8
	Planning the plot for sustainable urban development		-	-	-	-	-	9.8
	Reducing primary energy consumption		-	-	-	-	-	6.3
	Sound insulation		-	-	-	2.3	-	3.0
	Acoustic comfort		-	-	2.7	2	3	-
	Visual comfort		-	-	-	3.2	-	-

3.2.1. BREEAM

For an in-depth analysis of this system, the BREEAM scoring manual was used to select the topics that fit into each category studied in relation to “biophilic design”. These topics were biodiversity with 6.20% of the total score weight, and quality of light weighing 0.90%. Regarding sustainable construction, the selected indicators were water use and

reuse at 4.90%, groundwater or air pollution at 5.90%, and energy use decrease at 4.10%. The use of natural and sustainable materials weighed 2.70% of the total score, as well as resource efficiency, which is called waste. Table 3 summarizes all the scoring that BREEAM certification gives to biophilic, sustainable construction and BIGS criteria.

BIGSs are mentioned in BREEAM manuals as an example of systems that can be used to achieve sustainable goals and obtain a better qualification. As a case study, BREEAM presents the KLP Eiendom in Oslo, which has a green roof, among other systems, to achieve a BREEAM outstanding certification [84].

Table 3 shows the various ways that the benefits brought by these green infrastructures are considered and their respective percentages in relation to the total score. In the case of BREEAM, the criteria are very well divided, and the percentages are not repeated, which makes it possible to compare the percentages between themselves and in relation to the general score.

3.2.2. LEED

Using the LEED v4 checklist for operation and maintenance [85], the sustainable construction criteria represents more than 50% of the total score available; in detail, energy represents 34.5% of the total score (38 of 110 points), efficient use of water represents about 11% of the score, and materials and waste adds another 7.3%.

Many features of biophilic design are mentioned within the theme “Indoor Environmental Quality”, such as the use of natural light, indoor air quality, thermal comfort, quality of views, etc. Biophilia accounts for approximately 14.5% of the total certificate score. Although green roofs and vertical greening systems are not directly mentioned, the advantages provided by these construction systems are evident. Below is a list of these advantages, with the number of points corresponding to each one shown: (a) site development protecting or restoring habitats—2 points; (b) rainwater management—3 points; (c) heat island reduction—2 points; (d) site management—1 point; (e) site improvement plan—1 point; (f) outdoor water use reduction—2 points; (g) thermal comfort—1 point; and (h) optimized energy performance—20 points. In Table 3, the percentages of each evaluation criteria, as well as the indirect percentages of all criteria that are benefited by the construction of a green roof or a vertical greening system, are shown. It should be observed that some categories are included in more than one criteria, so the percentages should be analyzed separately in relation to the total percentage of points because some of them repeat themselves.

3.2.3. GBC

This system assesses sustainable constructions, with scores ranging from 0 to 110 points. The indicators reviewed are the efficient use of water totaling 12 points (10.9%), energy and atmosphere taking 28 points (25.5%), and materials and resources with 14 points (12.7%). The biophilic aspects approached together are responsible for 18 points, or 16.4% of the overall score.

Green roofs or facades are not directly mentioned in the GBC evaluation manuals; however, their contribution is indirectly explored in the certification process by considering the benefits that BIGSs provide to the environment where they are installed.

3.2.4. DGNB

Considering the DGNB criteria set for new buildings, it is possible to find that this certification process includes special mention of green roofs and facades with additional Agenda 2030 bonuses. Using this criteria set, the contribution of BIGSs to the overall process is related to the topics of biophilic design and sustainability, with the following scoring: thermal comfort with 4.3% of the overall score; internal and external air quality being 5.4% of the total points; acoustic comfort with 2.0% (but only in offices); visual comfort of the place at 3.0%; and 2.1% of the points were attributed to the quality and comfort of the internal environment. The quality of heat transfer, energy efficiency, and the use of natural

resources added up to 3.0%; the use and reuse of drinking water, as well as the extraction of sustainable resources, counted for 2.4%; land use had an importance of 2.3%; and, finally, biodiversity and the use of natural environments were responsible for 1.2% of the total score.

Green roofs are mentioned several times within the certification manuals, and they are effectively considered within the evaluations, with an importance between 0.5% and 0.7%. There are also some compensation methods for the degradation of neighboring environments or the site itself that are considered in the score.

Vertical greening systems are included with factors of 0.5%, and they are primarily explored in the biodiversity categories. The two systems are also considered in the categories of water reuse and local biotype. Table 3 shows the percentages in relation to the overall score of this method of certifications, and these percentages are well defined and do not repeat each other.

3.2.5. Green Star

Considering the indoor scoring tables, it is possible to verify indicators related to biophilic and sustainable construction. The energy criterion accumulated 10% of the score, the water criteria added 5%, materials and waste together have an importance of 24% in the total score, and, finally, pollution represented 3%. The aspects of biophilic design are much explored by this system, which considers quality and use of natural light, air quality, and other ways of improving the internal environment; these items are combined with a category of biodiversity and ecology, which add up to 24% of the overall score. Even though this system also does not directly mention green infrastructure, it brings benefits that are in various categories such as the following:

- (a) Acoustic comfort—3 points;
- (b) Thermal comfort—2 points;
- (c) Sustainable sites—5 points;
- (d) Refrigerant impacts—1 point.

3.2.6. HQE

When analyzing this rating system, indoor environmental quality can be supported due to the implementation of BIGSs, adding 22.83% to the score. In this rating system, the additional score includes other benefits such as thermal and acoustic insulation. In comparison, this rating system places additional emphasis on biophilic criteria, focusing on creating natural conditions within the building and its surrounding area. HQE benefits from the implementation of BIGSs, which enhance scores across all selected biophilic criteria, including indoor environmental quality, biodiversity, and air quality.

BIGSs (green roofs and facades) are explored in a topic called “encourage the greening areas”, adding points if a green roof has a surface planted over 50% of the total roof area, or if a green facade covers at least 10% of the total facade area. This is an indicator that, like DGNB, HQE goes further in greening the environment than the other certification schemes, and it extends the environmental quality to urban development [86].

3.3. Summary of Results (Step 4)

Based on the different certification systems selected, BIGSs can provide additional points to gain a better score in the certification process.

A summary of the direct benefits that BIGS implementation can provide in building sustainability certification is shown in Table 3. Contributions of more than 10% are highlighted in green, those from 1% to 10% are highlighted in yellow, and null contributions are highlighted in red.

In view of the results summarized in Table 3, it can be observed that despite the potential of BIGSs in contributing to benefits to the built environment, the rating systems do not adequately consider them. Only the DGNB and HQE certifications, among the six selected, assign direct credits for the inclusion of a BIGSs in a building envelope. However,

the credits allocated for these are very low, ranging from 0.5–0.7 for DGNB and 0.4 for HQE, relative to the total certification.

When considering the benefits provided by BIGSs in terms of the biophilia effect on building users and sustainable construction, it becomes clear that including BIGSs in buildings has significant potential for improving sustainability.

Direct benefits from BIGSs can be aligned with sustainability goals related to the improvements in use of water, indoor environmental quality, lower use of energy, and reducing the waste from the life cycle. Additionally, BIGSs can provide a wider number of indirect benefits for certifications. These include planning for sustainable urban development, improving health conditions, as well as enhancing visual, thermal, and acoustic control, etc.

Considering the contribution of BIGSs in arid and semi-arid climates, it can be observed that all certification systems contemplate their contribution to energy savings in building and water management, with LEED, GBC, and Green Star standing out. The contribution of BIGSs toward improving urban microclimates and energy savings is scientifically supported [87], and in this regard, building sustainability rating systems take it into account.

Due to the different nature of every certification process, the contribution of BIGSs to the process will also be different. For some certification schemes, BIGSs can contribute to specific biophilic criteria, and for others, the contribution will be associated with specific sustainable construction criteria.

Figure 3 presents a radar diagram showing how BIGSs can impact on the certification process. Considering that the percentage contribution of BIGSs to each certification process is variable, the scale was adjusted to reflect these percentages separately:

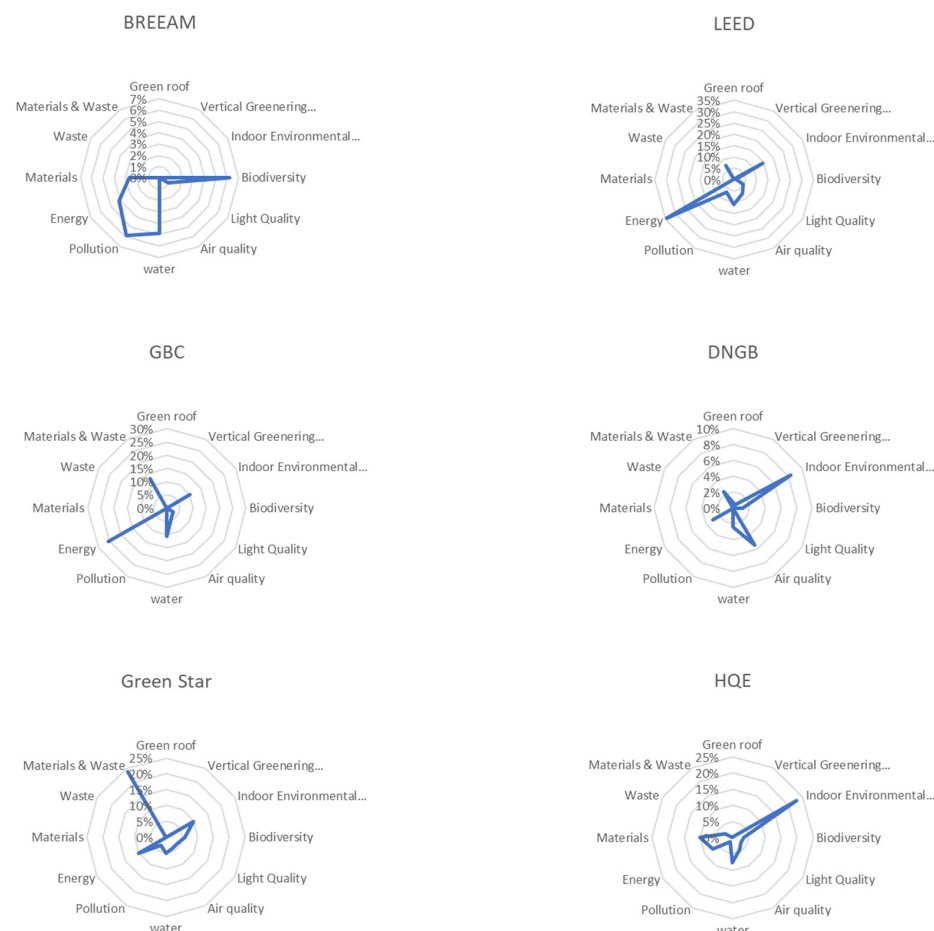


Figure 3. Radar diagrams for the BIGS impact in building sustainability certification systems.

4. Discussion

In Figure 3, the specifics and orientation of each certification can be observed, with highlighted aspects being energy consumption (LEED, GBC) and the indoor environmental quality of the building (DGNB, HQE). BREEAM, while this certification does not directly consider the inclusion of BIGSs in building envelopes, was particularly noted for its high consideration of support for biodiversity.

Regarding the results of previous tables and figures, it is important to note that the benefits from BIGSs have different valuations depending on the certification systems selected. For some systems like DGNB and HQE, the presence of green infrastructure has direct value for the certification process and provides direct scores.

On the other hand, BREEAM, LEED, and Green Star do not consider specific technologies to add more points to the certification process; several sustainable developments like solar panels and green roofs are mentioned as tools that can be implemented to achieve the desired certification goals.

Results also show that Green Star, DGNB, and GBC do not consider some sustainable construction criteria related to pollution and waste. Additionally, BREEAM, DGNB, and GBC do not provide scores for some biophilic criteria like air quality, biodiversity, light quality, and indoor environmental quality.

Differences between certification schemes are related to the focus at the time the certification was created. For this reason, BREEAM, LEED, and Green Star are aligned with environmentally sustainable goals rather than economic or social benefits. This means that BIGSs can contribute indirectly to gaining additional points through the environmental benefits they provide. This gap can be explained since the UN's Sustainable Development Goals were introduced in 2015 [88], and certifications at that time had been on the market for more than 15 years. This also implies that rating systems should be able to transform over time and be open to new technologies to include more fields in the frameworks that recognize new contributions and new areas for sustainable development. New versions of LEED, BREEAM, and Green Star can also be aligned with new frameworks such as Level(s) and can help to fulfil the SDG goals [89].

HQE certification provides the most complete approach to sustainable goals, as it not only provides scoring for environmental benefits, but also considers the presence of BIGSs directly in the framework. Additionally, it indirectly provides indicators to evaluate the impact of a building on the surrounding area during the design and operational phases. This includes planning for sustainable urban development and assessing the quality of spaces for users. This comprehensive approach creates an opportunity to consider the presence of more stakeholders during the certification process [83].

BIGSs bring benefits to indoor conditions. Thermal insulation can provide a better use of air conditioning systems, creating a more pleasant ambience inside buildings [90]. Green building envelopes improve ambient conditions both inside and outside the building [91]. The type of vegetation cover [92] and the reduced use of air conditioning systems due to low heat flux [93] allow for energy savings that can be measured and considered in the rating systems. Table 3 clearly shows the importance of those benefits and their relevance.

BIGSs can provide multiple impacts in urban areas where implemented. From the environmental point of view, they can create and restore habitats, increase biodiversity, reduce the heat island effect, reduce rainstorm runoff, capture CO₂, and reduce energy consumption. From the social perspective, they can create new spaces for human interaction. Depending on the type of green system, they can create conditions for new business, add aesthetic value to urban spaces, and increase property value by renovating spaces and improving conditions for neighborhoods. From the economic perspective, BIGSs can provide new incomes to stakeholders due to the savings in some areas (such as lower energy bills), the possibility to create local economies based on food production, and the increase in rental value of a newly designed or green renovated building. The certification process evaluation can recognize some of these benefits and adapt the process to capture and value the new possibilities that BIGSs bring to cities. This applies both to new buildings

and for retrofitting existing constructions to bring sustainable solutions to urban environments. Stakeholders and the certification process can also take advantage of the multiple cross-benefits that BIGSs provide. For example, it is possible to gain points due to the improvement in the air quality in green buildings, and additional points can be achieved due to the reduction in pollutants [94].

Regarding arid and semi-arid climates, the presence of BIGSs in buildings allows for an improvement in the scoring for LEED certification systems (34.5%), Green Star (10%), and GBC (25.5%) in energy aspects, with LEED certification recognizing this aspect to the greatest extent percentage-wise.

For water management in arid climates, LEED certification grants a higher score and acknowledges the significant contribution that comes with the presence of BIGSs (11%). The contribution of BIGSs to the GBC certification system is also notable (10.9%). The ability to manage rainwater and prevent immediate runoff is crucial for regions with low rainfall, and these certification systems acknowledge and evaluate this contribution with specific scores.

When considering the importance of managing indoor environmental quality in arid climates, HQE certification (22.83%) values this benefit most effectively. Improved indoor environmental conditions reduce the pressure and energy demand of buildings. Additionally, in these climates, the “heat island” effect decreases, providing benefits not only aligned with internal energy management, but also contributing to the surrounding building environment.

There is significant heterogeneity in the rating systems reviewed, making the evaluation process different depending on the type of certification desired. Academic research offers knowledge or specific adaptations of the main rating systems [89]. In the context of arid and semi-arid climates, it is necessary to adjust the measurement scales to better reflect the contribution that nature-based solutions like BIGSs can provide, taking into account the specific needs of these climates. For example, LEED, Green Star, HQE, DGNB, and BREEAM agree on evaluating aspects such as public and private transportation modes [95], but they could decrease these weightings to increase the valuation of aspects such as energy, water management, and indoor environmental quality, which are crucial in arid climates. Specific adaptations of rating systems can also benefit from the presence of BIGS infrastructure. For instance, BREEAM, which does not have a valuation for the presence of open green areas, could include specific scoring by reducing the relative importance of structural stability, which is likely already considered in the construction development plans. Similarly, HQE could decrease its valuations of external local conditions such as perimeter security or visual comfort [96] in favor of valuing green areas capable of improving internal conditions, water management, or energy efficiency. This approach would capture the benefits that BIGS technologies provide while addressing the needs of arid climates.

Indirect BIGS-related benefits, however, are still inadequately considered in building sustainability accreditation systems. For example, acoustic insulation or urban noise reduction are not adequately represented (with 1.8% for noise pollution in BREEAM, and 2.3% for sound insulation in DGNB).

5. Conclusions

Several green building rating systems have been developed to promote building sustainability at the city level [97], bringing opportunities to stakeholders in the sustainable construction field and creating buildings that add value to the environment by the adoption of any of these certifications.

The main scope of this paper was to research the contribution of BIGSs to the certification process. As with any other technology that can be used in the field of sustainable construction, the benefits provided by BIGSs offer an opportunity to stakeholders to certify those benefits in the form of points added to the certification scheme.

Six different green building rating systems were analyzed. From their scoring manuals, specific indicators related to sustainable construction and biophilic criteria common to all

certification schemes were selected. This allows for identifications of the area where BIGSs can provide more points to the process. The research process also identifies the indirect benefits associated with the selected green building rating system by creating opportunities for developing new versions of frameworks that add value through the adoption of new technologies like BIGSs.

Results show that BIGSs can provide several points related to indoor environmental quality, an indicator that is present in all certification schemes. They also provide additional points in sustainable constructions indicators related to energy, water efficiency, and materials and waste management. However, scores related to the light quality in rating systems cannot be well supported by BIGSs as these systems act as an envelope over buildings, thereby affecting the amount of natural light available inside the buildings.

Specifically, the following can be concluded:

- Only the DGNB and HQE certification systems assign direct scoring in the evaluation process when a green infrastructure, such as a green roof or green facade, is implemented in a building. In contrast, BREEAM, LEED, GBC, and Green Star do not assign any direct credits or points to these green infrastructures. Instead, they allow scoring based on the benefits derived from the biophilic or sustainable construction criteria resulting from the implementation of such infrastructures.
- The six reviewed accreditation systems assign points to the benefits derived from the implementation of BIGSs, specifically in the categories of biophilic effects on building users and improvements in sustainability in sustainable construction.
- In the certification systems, the contributions of BIGSs to the following indicators were highlighted: improving indoor air quality, supporting biodiversity, optimizing water use, capturing pollutants, achieving energy savings, and utilizing sustainable materials.
- There is still a lack of alignment between contrasting scientific evidence on the multiple benefits of BIGSs in the built environment and the value assigned to them in the analyzed certification systems; for example, the ability of BIGSs in providing acoustic insulation and reducing urban noise.
- The analyzed rating systems do not align with the needs of arid environments and the contributions that BIGSs can make for these climates. Future studies should review which certifications apply to specific climates and identify the most effective technologies.

In the context of arid and semi-arid climates it is possible to conclude the following:

- BIGSs provide thermal insulation, reducing the need for artificial cooling and thereby lowering energy consumption. This is particularly emphasized in the LEED, GBC, and Green Star certification systems, where energy management is a critical component.
- BIGSs help in capturing and reusing rainwater, which is vital in regions with limited water resources. LEED certification recognizes this contribution significantly, as does the GBC system, which values rainwater management highly.
- Improved indoor environmental conditions due to the presence of BIGSs are particularly valued in arid climates. The HQE certification system places significant emphasis on this benefit, recognizing the role of BIGSs in enhancing indoor air quality and thermal comfort, which reduces the energy demand for cooling.
- BIGSs help improve urban microclimates, which is a significant issue in arid climates. This aspect is acknowledged indirectly in the BREEAM rating system along with other indirect contributions to the certification process such as rainwater management and the development of an ecological strategy.

There are limitations to this study. Firstly, it is restricted to the review of documentation from these certification systems and does not consider measurements or data that allow for the real-time monitoring and quantification of the impacts of BIGSs [98]. Secondly, it is also limited to the review of biophilic and sustainable construction criteria. However, BIGS

technologies have additional impacts on economic and social sustainability levels that have not been considered due to the difficulty of being rated within the current rating systems.

This study also offers an opportunity for future research. For example, to improve urban heat island mitigation, rating systems should measure the effectiveness of BIGSs in reducing temperatures, increasing green coverage and their microclimate impact, and awarding credits for significant reductions. Efficient water management in arid regions should be emphasized through assessing irrigation, gray water use, and water footprint, with higher scores for innovative water-saving techniques. Resilience to extreme weather is crucial, and it is important to account for plant durability, structural integrity, drought resistance, and to award points for high adaptability. Regional adaptations in certification criteria should reflect local conditions, adjusting criteria weights for challenges like extreme temperatures and water scarcity. Additionally, social indicators related to well-being and human-scale development can be added to promote investment in new buildings that create sustainable value for the city.

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