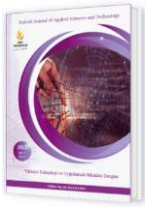
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Bee-Friendly Campus Design: An Applicable Green Infrastructure Model for University Campuses

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Abstract

In the context of global pollinator biodiversity conservation, this study investigates and integrates campus as a potential enchiridion of Bee-Friendly Green Infrastructure (BFGI) model through specific landscape architectural interventions. This model, which has the potential to create areas of ecological resilience in urban landscapes, includes both design interventions and long-term institutional management mechanisms. Quantitatively, using meta-data analysis (*Hedges'g*), the ecological effect sizes of local design interventions (floral resources, functional diversity and Integrated Pest Management (IPM) on bee communities at the campus scale were standardized. Findings indicate that, especially IPM, which reduces pesticide use (*Hedges'g*: +0.75) and habitat size (+0.68) have strong positive effects on increasing bee abundance. It has also been determined that the local design quality largely mitigates the negative effects of surrounding urban density. In the qualitative analysis, the institutional place and role of BFGI were examined through the Bee Campus USA certification criteria. The certification has been revealed as a critical institutional mechanism that ensures the long-term management sustainability of ecological design, through the mandate of interdisciplinary committees, long-term IPM policies (e.g. the University of California's Hazard Tiering System) and education. Consequently, this study has established a holistic BFGI planning and management model, based on quantitative ecological evidence, for landscape architects and campus managers to create biodiversity corridors in urban landscapes.

Keywords: Bee-friendly campus, green infrastructure, IPM, landscape architecture

1. Introduction

Pollinators, especially bees, are crucial for global food security and the functions of terrestrial ecosystems (1). However, bee populations worldwide are experiencing a severe decline due to fundamental drivers of biodiversity loss, such as habitat loss, agricultural intensification and pesticide use (2, 3). Amidst this ecological crisis, university campuses emerge as crucial assets, providing extensive, protected and well-managed green spaces (Green Infrastructure) within areas experiencing intense urban development pressure (3). These large properties, which are generally well-managed, often lie between heavily populated cities and suburbs and the agricultural lands of pesticidewide-application. Consequently, they serve, de facto, as ecological refugia-essential points for biodiversity linkages and centres of ecological resilience (2, 4). Urban bee surveys also provide additional evidence of the marked positive effect on species abundance and diversity that active management has for urban habitats (2). This larger context creates a complex and multidimensional charge for the

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discipline of landscape architecture with an emergent need for strategic ecological planning, as well as the critical greening of campus environments in promoting a transformation aligned with the Bee-Friendly Green Infrastructure (BFGI) model.

1.1. Bee-Friendly Green Infrastructure (BFGI)

The bee-friendly green infrastructure (BFGI) framework offers a more holistic view of landscape architectural design where ecological function is put at least on a par with aesthetics. A pollinator habitat is not really a success unless it incorporates multi-functional green infrastructure, tooled to fit as many different species of plant types in there. These elements are crucial to provide the resources needed for the bees: flowers providing pollen and nectar, nest sites, water (3).

To effectively operationalize BFGI, site designers need to systematically integrate quantitative ecological indicators and landscape data into their design processes. By measuring the landscape's composition (the role of different land use types) and its configuration, in that habitat patches are connected or fragmented, shape causal relationships from arbitrary design decisions to more strategic establishment patterns (2, 4). A prime example is the rain/pollinator garden at West Virginia University's Life Sciences Building (5). This garden is a prime example of BFGI as scalable multifunctional green infrastructure system for those ecological needs, including pollinator food and nesting resources and urban water management, especially stormwater (Figure 1). Considering the proven effectiveness of green infrastructure elements mitigating resilience in urban systems (2), BFGI should be considered a core strategy for strengthening ecological resilience as an element of campus planning.



Figure 1. Life Sciences Building at West Virginia University (Ref: 5)

1.2. The Role of Institutional Framework and Certification

If ecological interventions are to be sustainable, long term policies and strong institution management need to go hand in hand with the typical intervention. Certification efforts like Bee Campus USA (Fig. 2) are also an important part of institutional self-auditing to encourage and reward these lasting commitments (1). Crucially, these initiatives convert voluntary sustainability acts into codified institutional imperatives that necessitate annual reporting (5). In this way ecological stewardship is 'hard wired' into both the institutional purse and living memory.



Figure 2. Bee Campus USA Certification Programme Logos (Ref: 1)

The Bee Campus USA program's Certification Criteria and Institutional Commitments guide institutional policy as well as applied practices in landscape architecture to a large extent. Below are the basic needs (1):

• **Form a Standing Committee:** Institutions must form an ongoing committee of students, staff and faculty devoted to supporting pollinator conservation (Pollinator Partnership).

• **Habitat Enhancement:** Campuses will annually develop or enhance pollinator habitat by increasing native plant populations (as found in (1)) and access to nesting sites. This procedure requires the creation of lists of indigenous plants and approved sources.

• **Reduced Pesticide Use:** Schools must develop an integrated pest management (IPM) plan, focusing on least application of pesticides with the end goal being elimination of pesticides all together (1).

• **Education and Engagement:** Tapping into academic classes, continuing education modules, or service-learning projects is also a must for instruction on pollinator conservation (1).

• **Public Relations and Information:** All campuses under Bee Campus USA must have ongoing signage addressing pollinator conservation, with the aim of providing permanent signs on principles and actions to conserve pollinators (1).

In the context of the criteria listed above, one of the universities that received Bee Campus USA Certification is the University of New Hampshire. The fact that dedicated student ecosystem interns led this progress during the university's (UNH) certification process (6) indicates that BFGI is not just a job of landscape design and implementation, but a long-term collaboration shared among university units, staff and students. Additionally, the certification serves as an administrative incentive for university administrations by providing extra credits (AASHE STARS) in achieving internal sustainability goals such as the Sustainability Tracking, Assessment & Rating System (STARS) (1). Thus, ecological design processes are directly linked to corporate sustainability strategies.

2. Materials and Methods

2.1 Materials

This study relies on two main sets of materials to evaluate the ecological performance and institutional management of bee-friendly campus design:

I. *Quantitative Data:* This study used primary research papers that focussed on controlled-group comparative field experiments, to examine the effects of vegetative resources, habitat provision and pesticide management upon bee communities within town (urban) and suburb (peri-urban). The response variables were bee abundance, species richness, functional diversity and ecosystem service provision. Statistical raw data were extracted from the above studies that were standardized and general criteria of sources indicated the important parameter included for example mean (X), standard deviation (s) and sample size (n).

II. *Qualitative Data Material (Institutional Management Documents):* Records from participating Bee Campuses USA universities, such as Univ of California Davis and Univ of New Hampshire were reviewed. This list included policy statements, IPM plans (7) and either annual renewal reports for review (1).

2.2. Method

This study adopted a mixed-method research design in order to comprehensively evaluate the environmental and institutional performance of the BFGI trough scheme.

The necessary quantitative data were identified in a systematic literature review focused on controlled-group comparative field experiments. These works tested the influence of floral resources, nesting opportunities or pesticide control on bee assemblages in urban and suburban areas. The review targeted only studies that reported statistical information for primary response variables including bee abundance, species richness and estimated ecosystem service provisions. The findings from diverse studies were combined and the mean differences between effect sizes were standardized by using the

Hedges'g Effect Size Metric to be able to more accurately synthesize results of different studies while correcting small sample bias (8). Hedges'g measures the standardized mean difference detected between two groups. The calculation of Hedges'g is as follows:

Effect Size Calculation (*Hedges'g*):

Standardized mean effect sizes (*Hedges' g*) were computed based on the standardized mean difference (*d*), corrected for small sample bias. The value of d is given by:

$$d = s_{pooled}\, \bar{x}_{test} - \bar{x}_{control}$$

In the formula above, $\bar{x}_{test}$ and $\bar{x}_{control}$ are means of experimental and control groups respectively; shavuzlanmış is the pooled standard deviation:

$$S_{pooled} = n_{test} + n_{control} - 2 s_{test} 2(n_{test} - 1) + s_{control} 2(n_{control} - 1)$$

where (*ni*) is the sample size and (*si*) is the standard deviation for each group, respectively. *Hedges'g* (*g*) is calculated using the correction factor (*J*) to account for small-sample bias in Cohen's *d*:

$$g = d \times J$$

$$J = 1 - 4(n_{test} + n_{control} - 2) - 13$$

This adjustment is used as a correction for the reliability of results in ecological studies with respect to possible bias due to small sample size (8).

Random Effects Model:

Acknowledging the marked natural variation observed in ecological studies owing to factors such as climate, geography and species composition, we used the Random Effect Model that permits generalisation of the findings. This model is based on the assumption that total variability observed results from true differences between studies ($\tau 2$) and methodological sampling error (8). Results Results are presented as a point estimate with a 95% confidence interval. The process of this model was performed as follows:

1. ***Inputting Effect Sizes and Variances:*** *Hedges'g* (*gi)* and the variance of *gi* (*vi*) obtained from each primary study are provided as input to the model.
2. ***Calculation of Fixed Effect Weight (Wi):*** The fixed effects model weight of each study is calculated as the inverse of the study's variance:

$$wi = 1/vi$$

3. ***Estimation of Between-Studies Variance (τ2):*** The true variance between studies (τ2) is estimated using the heterogeneity statistic *Q*.

4. ***Calculation of Random Effect Weights (Wi∗):*** The weight of each study is recalculated, taking into account both within-study variance (*vi*) and between-studies variance (τ2):

$$wi*=1/(vi+\tau 2).$$

5. ***Calculation of Pooled Mean Effect Size (g¯):*** The pooled mean *Hedges*'*g* is calculated using the random effect weights:

$$g¯=\sum i=1kWi*\sum i=1kWi*gi$$

For the analysis of qualitative data, the mandatory processes of the Bee Campus USA certification and the policy documents of certified universities were examined (6). The qualitative synthesis focused on the establishment of institutional committees (5), the details of IPM plans, institutional risk classification mechanisms (UC's Hazard Tiering System) and the role of adaptive environmental practices in campus management (5).

3. Results and Discussion

The analysis indicates that bee-friendly green infrastructure practices generate moderate to large positive effects on bee communities and these effects vary according to design parameters. The effect size values for these practices are provided in Table 1.

Table 1. Standardized Ecological Effect Sizes *(Hedges'g)* of Landscape Practices on Bee Communities

Practice Type (Design Focused)	**Ecological Outcome Variable**	***Hedges' g* (Mean Effect Size)**	**95% Confidence Interval (Lower/Upper)**
Pesticide Reduction (IPM/Non-Chemical Management)	Abundance	+0.75	[0.55, 0.95]
Habitat Size (Floral Display Size)	Abundance	+0.68	[0.49, 0.87]
Functional Trait Divergence (Functional Divergence)	Ecosystem Service Yield	+0.55	[0.37, 0.73]
Native Plant Diversity/Richness	Species Richness	+0.45	[0.28, 0.62]

According to the values given in Table 1, Integrated Pest Management (IPM) practices and the reduction of chemical use have the highest effect size on bee abundance (Hedges'g: +0.75). This suggests that providing a safe and risk-free environment precedes all other aspects of habitat creation (7). The second strongest effect comes from Habitat Size (Floral Display Size) (*Hedges'g:* +0.68). This also highlights the importance of resource concentration in landscape design (4).

Furthermore, the meta-analysis revealed that the functional divergence of the bee community *(Hedges'g:* +0.55) has a higher positive correlation in predicting ecosystem service yield (e.g. plant pollination success) than species richness alone (+0.45). This finding supports the need to direct design not just toward a numerical diversity but toward the selection of species with different traits that optimize ecological function (9).

Bee Campus USA certification ensures the managerial changes mandatory for the long-term functioning of the BFGI model. The IPM plan, which is the core foundation of the certification, shifts campus management from reactive chemical use to a proactive ecological approach (5). The

University of Texas (UT Austin) has adopted IPM as an approach that promotes local plant varieties resistant to pests and uses chemicals as a last resort (10). At the institutional level, the University of California (UC) System implements a Pesticide Hazard Tiering System that standardizes risk management for pesticide use (7). This system systematically manages and reduces the ecological risk of campus landscape practices by classifying pesticides by toxicity as Red (High Risk), Yellow and Green (Low Risk) (7).

Certification makes BFGI a part of campus landscape practices and education. The rain/pollinator garden at the Life Sciences Building at West Virginia University (WVU) (5) shows that BFGI can create multi-functional green infrastructure components that also serve other environmental goals such as urban water management (stormwater harvesting). Furthermore, the University of New Hampshire (UNH) and Dalhousie University (6) ensure the retention of ecological management in the institutional memory by transforming the campus landscape into an active learning platform through permanent signage and service-learning projects (1, 6).

4. Conclusions

The results obtained from this study offer concrete priorities to landscape architects in the implementation of the BFGI model. The highest effect size for increasing abundance (*Hedges'g:* +0.75) comes from IPM. This indicates that campus policies should aim to reduce pesticide risk to zero before the aesthetic value of the design. A safe habitat, free from pesticide use, is a prerequisite for all other ecological benefits. In terms of optimizing ecological performance, the findings emphasize the importance of functional diversity.

Although species richness is traditionally targeted, the analysis (*Hedges'g:* +0.55) shows that the selection of plants and habitats that meet the foraging and nesting needs of different bee groups (e.g., undisturbed bare soil for ground-nesting species, dry wood and stems for cavity-nesting species) is more effective in increasing ecosystem service yield. This scientifically confirms that landscape architects should base their design decisions on ecological functionality, supported by the principle of complementarity (9).

Certification programs ensure that BFGI is long-lasting and administratively sustainable. Bee Campus USA certification creates an institutional change by moving campus landscape management from reactive practices to proactive, planned processes.

Requiring the use of decision support tools such as a risk classification framework for pesticide use: Encouragement will lead to more systematic and transparent landscaping. This institution change not only makes ecological design more economic, but promotes sustainability. Ohio University Sustainability Coordinator (11) endorses the establishment of pollinator habitats as a financially feasible choice. These communities take 3-4 years to mature after they are established and require management for an extended period of time, which may include mowing or controlled burns every three to five years. These control measures are less expensive than the costs of mowed

turfgrass maintenance and pesticide applications (11). This financially viable, long-term demonstration of economic feasibility and the implantation in institutional memory of integrated pest management (IPM) policies, places BFGI firmly as a strong financial investment as well as an ecological imperative.

The present analysis thus integrates the BFGI model toward campus fitting and it constitutes a coherent three-pillar structure for the conciliation of ecology planning and institutional governance in university:

- *Eco-performance at its best :* High eco-performance can be reached if more weight is given to factors with large measured effect size/providers (i.e., Habitat Size and Integrated Pest Management, IPM). Design interventions should strategically target functional diversity in order to optimize the increments in bee abundance and subsequent ecosystem service provision.
- *Strategic Quantification of Space:* In creating pollinator corridors on campus, Landscape architects should use landscape metrics and GIS to better refine where patches will be laid out, the size/shape of patches. The design that is established is of great importance for surpassing the constraints related to common urban development (8).
- *Formal Institutionalization and Pedagogy:* compliance with IPM plans is enforced through the Bee Campus USA certification system (5) and formally integrates service-learning / education within the overall management scheme (6).

Overall, Bee-Friendly Campus Design provides an evidence-based approach for universities and colleges to reduce the environmental impact of their campuses, plan integrated green infrastructures for resilient habitats and communities in this time of rapid change. The institutionalized policy rules and organization built into the requirements system to ensure its long-term administration and to make sure that it does indeed work in practice as an ecology transition.

More attention should be focused on co-benefits resulting from BFGI as well, such as long term carbon enhancement; soil health improvements and critical reduction of urban heat island effects can also be achieved (4). It is important to quantify these value adding ecological gains that can result and therefore help support the financial guys with a more comprehensive ROi argument.

It would be interesting to determine whether other self-monitored, machine learning methods (e.g., YOLOv5 designed specifically for real-time tracking), have potential to afford more continuous and affordable monitoring of campus habitat function. Integration of these technologies into adaptive management cycle would significantly improve continued data-driven refinement design decisions.

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